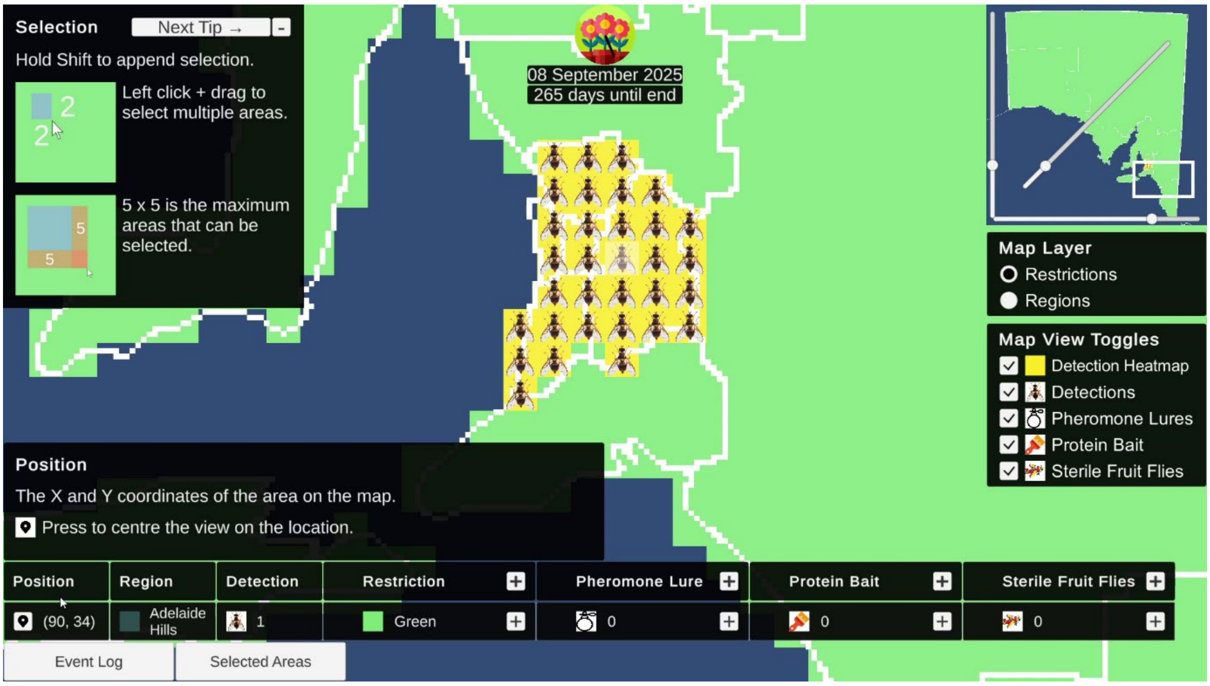
A Serious Game for Simulating Fruit Fly Scenarios

By

Adam Eustis



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Game Downloads: Windows Version | macOS Version | Linux Version

Declaration

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university
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3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

Signature of student............A Eustis..........................

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Date....22/10/2024.............................

Acknowledgements

I would like to express my gratitude to my supervisor, Dr Matthew Stephenson, Lecturer in Computer Science at Flinders University, for his invaluable guidance and support throughout this research. I am also grateful to my industry advisor, Dr Katharina Merkel, Senior Entomologist at PIRSA-SARDI, for her expert insights and mentorship. Additionally, I would like to thank Flinders University for awarding me the Honours Scholarship which provided significant financial support amounting to $1,500.

Abstract

The South Australian horticultural industry is threatened by the Queensland fruit fly. A serious game was decided upon as the core component to address this issue since serious games have proven valuable in their ability to simulate pest management for the purpose of raising awareness and improving understanding. The serious game created for this project was designed to simulate outbreaks and pest management strategies specifically for the Queensland fruit fly in South Australia. The data used for game development and simulations was based on existing South Australian research and as supplied by the industry advisor. A user study was conducted in which participants were surveyed before and after playing the serious game. Participants showed significant increases in familiarity of the Queensland fruit fly and how the fly is managed in South Australia. Participants showed a significant increase in perceived importance of the management of the Queensland fruit fly in South Australia. The majority of participants agreed or strongly agreed that they had fun whilst playing the game and that the game mechanics were intuitive or very intuitive. Analysis of the gameplay log data showed high total engagements with the management strategies across the 15 minutes of gameplay, but there was high variance of player engagement.

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List of Abbreviations

PIRSA	The Department of Primary Industries and Regions South Australia....3
SARDI	The South Australian Research and Development Institute....3

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1. Introduction

1.1 Background

The South Australian horticultural industry is threatened by the bactrocera tryoni, which is commonly known as the Queensland fruit fly (García Adeva, Botha & Reynolds 2012; García Adeva & Reynolds 2012; Popa-Báez et al. 2021). The Queensland fruit fly has been able to survive outside of its native tropical and subtropical habitat due to the increased availability of water sources created for agricultural and horticultural practices (García Adeva, Botha & Reynolds 2012; García Adeva & Reynolds 2012; Popa-Báez et al. 2021). The first fruit fly outbreak in South Australia on record was in 1947, after which 162 outbreaks were recorded over the 50 years that followed (Madge et al. 1997). At the time of writing there are outbreaks in Salisbury North and various suburbs within the Riverland, which is South Australia's primary region for growing citrus (Government of South Australia Department of Primary Industries and Regions 2024). Citrus fruits such as oranges and mandarins are preferred hosts for fruit flies to lay their eggs into, which enabled the flies to spread and damage fruit across the region (Tam et al. 2023). South Australia and Tasmania are the only Australian states that still retain a fruit fly-free classification (Size 2024). To remain fruit fly-free the South Australian government invests 5 million annually (Tam et al. 2023) to protect the horticultural industry which is worth $1.3 billion and employs 37,500 people across 4,000 businesses (Size 2024). The investment funds a grid of traps across the state, disposal bins, quarantine stations, border restrictions, education, public awareness, area restrictions, roadblocks, reactionary efforts, and the release of sterile fruit flies (Tam et al. 2023).

1.2 Overview

The core component of this research is *a serious game for simulating fruit fly scenarios* in South Australia. This serious game simulated fruit fly outbreaks and management strategies to control fruit fly population and spread in South Australia. The primary objective was to educate players about how to overcome the current and historical threat of fruit flies to South Australia. An education focus necessitates accurate presentation of information, images, and behaviour. A qualitative educational experience is dependent on player engagement and comprehension of the mechanics. Real world environments, fruit fly behaviour, and management strategies were simulated in the Unity game engine using C# programmed gameplay algorithms tuned with real world data. A log file was generated for each play session that contained a record of player actions, the values of the game's dynamic parameters over time, and the pre and post gameplay survey responses. The game data was analysed to determine player engagement and usage of the management strategies. The pre and post gameplay surveys included identical questions that were compared to identify any change in player sentiment and understanding of fruit fly management in South Australia.

1.3 Scope

This research aimed to evaluate the effectiveness of a serious simulation game in educating players about how the Queensland fruit fly is managed in South Australia. The game was played by 19 Flinders University students and other members of the South Australian public as part of a user study that was conducted from September to October 2024. Each participant was limited to a pre gameplay survey and a post gameplay survey which consisted of rating scale and dichotomous (Yes/No) questions. The gameplay was limited to 15 minutes and 365 in-game days. The pest management was limited to the Queensland fruit fly in a scaled down simulation of South Australia which was segmented into 10 km^2 areas. Fruit fly management was limited to four strategies, which were fruit movement restrictions, pheromone lures, protein-based bait, and release of sterile fruit flies. Limitations included the small sample size, the potential biases in the self-reported survey responses, and the fact computer games are not accessible to everyone, due to physical, cognitive, or technological barriers.

2. Literature Review

2.1 Serious Games

Serious games are primarily used for education, problem solving, and developing quantifiable results. What sets a serious game apart from other types of games is that entertainment is never the primary purpose of a serious game. (Ávila-Pesántez, Rivera & Alban 2017). Serious games have been used for employee training, raising awareness, competency evaluation, assessing return on investment, education, assessment, promotion, and to establish best practices. Simulation algorithms have been incorporated into serious games to enhance educational value and strategic planning in a structured way that is approachable for participants. Serious game participants can experience simulations safely without real-world time and financial investment (Aldea et al. 2014; Ávila-Pesántez, Rivera & Alban 2017; Corti 2006; Susi, Johannesson & Backlund 2007). Serious games are a novel and engaging way to inform and draw attention to complex problems when research papers are not widely understood or accessible to members of the public (Bradshaw, Holland & Billinghurst 2014).

Serious games generally have a low barrier to entry, can incorporate multiple participants, and facilitate discussion (Andreotti et al. 2020; Lairez et al. 2020; Ornetsmüller, Castella & Verburg 2018; Rebaudo et al. 2014; Rouault et al. 2020; Sari et al. 2024). Group sessions can be conducted in which participants play a serious game together with guidance from a researcher. Participants can include stakeholders, such as farmers and agricultural industry representatives. The research can be strengthened if researchers record participant responses to pre and post discussions or surveys (Asplund et al. 2019; Cook et al. 2016; Neset et al. 2019). The content of serious games can be based on existing research, with the caveat that the modelling accuracy is dependent on the scientific knowledge available (Asplund et al. 2019; Rouault et al. 2020). If the scenario is too complex, then a serious games is unlikely to accurately simulate the complexities (Rouault et al. 2020). Simulations that are overly simplified or abstracted are likely to result in simplified solutions. Serious games can open people to new ways of thinking, but lose credibility if they do not represent player's real-world experiences (Asplund et al. 2019).

Serious games come in a variety of physical and digital forms with various advantages and disadvantages for different use cases. Physical or tabletop serious games include board games (Sari et al. 2024), card games (Lairez et al. 2020), or a combination of both (Andreotti et al. 2020; Rebaudo et al. 2014; Rouault et al. 2020), all of which incorporate role-playing elements. These games have a low barrier to entry because most people have prior experience with similar types of games. Research studies involving physical serious game usually require a researcher to be physically present to facilitate, which requires organisation and can limit the reach of the study (Argenton et al. 2015; Helmberger et al. 2022; Ibarra et al. 2020). Digital serious games can be played on range of devices, including computers (Cook et al. 2016), tablets, and phones (Marsh et al. 2016). The software can be web-based (Asplund et al. 2019) or require installation on hardware (Cook et al. 2016). Digital serious games can be shared online and facilitate multiplayer interactivity through the internet (Argenton et al. 2015; Asplund et al. 2019). Development of software is complex, time consuming, expensive, requires customisation for compatibly with PC and mobile devices, requires users training, and software does not always accommodate people with hearing, physical, or other impairments (Corti 2006). A study which produced a tabletop and digital version of a serious game found that the tabletop version was understood quicker, since players did not need to learn mouse and keyboard controls. However, the digital version was more suitable for remote sessions (Helmberger et al. 2022).

2.2 Pest Management in Serious Games

Serious games have been created for pest management (Rebaudo et al. 2014), pesticide application (Rouault et al. 2020), field allocation (Andreotti et al. 2020; Lairez et al. 2020; Ornetsmüller, Castella & Verburg 2018; Sari et al. 2024), and farm investment decisions (Lairez et al. 2020; Ornetsmüller, Castella & Verburg 2018; Sari et al. 2024). Serious games were effective at increasing the pest management knowledge of farmers (Rebaudo et al. 2014; Rouault et al. 2020), especially young farmers who showed some prior knowledge of pest management (Rebaudo et al. 2014). Serious games have been used to simulate climate change scenarios, such as a web-based game (Asplund et al. 2019) and a virtual interactive card game (Neset et al. 2019). These games provided players with choices relating to agricultural-based climate change adaption, whilst managing a budget, and aiming to produce a low maladaptive score. Players faced four different climate change scenarios, which included increased pests and weeds, increased rainfall, increased temperatures, and a prolonged growing season. The games increased player awareness and understanding of climate mitigation whilst prompting reflection on maladaptive outcomes. Some participants found the games thought provoking and influential for their future decision making. Other participants said the games differed from their own experience, as the games were too simplistic, and did not offer enough choices (Asplund et al. 2019; Neset et al. 2019).

Serious games can be focussed, such as Bt Crops which focused on one crop, maize and one pest, the European corn borer (Milne et al. 2015). Other serious games are more broad, covering multiple crops and various pests, such as Pest Quest which incorporated various field crops, insect pests, and pollinators (Helmberger et al. 2022). Since Bt Crops was focused on maize crops, players selected from different types of maize with different pricing and toxicity to the European corn borer. These choices effected pest populations, yield, and profits for multiple player's farms in a simulated region (Milne et al. 2015). Pest Quest simulated three growing seasons for a single farm. Crops were abstracted, pollinators were grouped into a one category, and pests were grouped into three categories; natural enemy, minor pest, and major pest. (Helmberger et al. 2022) Bt Crops demonstrated the value of supressing pests throughout a landscape and highlighting the importance of farmer response networks. A limitation of the study was the exclusion of seed price changes dictated by seed companies (Milne et al. 2015). Pest Quest players reported increased understanding, but the player assessment results did not corroborate an increase (Helmberger et al. 2022).

Research projects have simulated the management of pests in serious games, such as a research project that simulated management strategies for New Zealand pest possum populations in a serious game called Ora – Save the Forest!. Another research project simulated fire blight infection on Apple and pear farms in Victoria Australia in a serious game called A bio-economic 'war game'. Pest management for the spotted wing drosophila fruit fly was simulated in a serious game called Spotted-Stop-It. Pest management of the Queensland fruit fly was simulated in a web-based serious game. Ora – Save the Forest! simulated traps, poison bait, and monitoring in square hectares. The bio-economic 'war game' simulated management options, tree species, economic return, tree density, bee dispersal, quarantine radius, and productivity in patches of 60 x 60 square meters. Spotted-Stop-It simulated fruit fly reproduction and management of fruit growth, harvest, clearing, and wild fruit in a one-hectare farm. The web-based simulation simulated the life-cycle and dispersal range of fruit flies, landscape characteristics, and seasonal weather and temperature variations (Bradshaw, Holland & Billinghurst 2014; Cook et al. 2016; de la Vega et al. 2022; García Adeva, Botha & Reynolds 2012; García Adeva & Reynolds 2012).

The effectiveness of serious games can be measured with surveys, workshop discussions, and by inputting real-world data into the game and comparing the outcome in the game to the real-world outcome. Ora – Save the Forest! was accompanied by surveys that showed that the game supported acquisition of long-term knowledge. The bio-economic 'war game' was accompanied with hands-on workshops. Spotted-Stop-It was accompanied by a questionnaire that showed participants fruit fly identification and understanding of management strategies improved. The accuracy of the web-based simulation was validated against actual fruit fly outbreaks (Bradshaw, Holland & Billinghurst 2014; Cook et al. 2016; de la Vega et al. 2022; García Adeva, Botha & Reynolds 2012; García Adeva & Reynolds 2012).

2.3 Project Application Informed by the Literature

The serious games in the reviewed projects were either generalised or simulated locations outside of South Australia, this project adapted and built upon techniques used elsewhere to produce a simulation that incorporated the characteristics unique to South Australia. The serious games in the reviewed projects did not simulate fruits that are commonly grown in South Australia. This was seen as an opportunity to not only simulate major South Australian produce such as grapes and citrus, but to also expand on previous research by adjusting the densities of fruits for each season. The Queensland fruit fly was only simulated in one of the reviewed serious games, since fruit fly behaviour and characteristics differs among the different types of flies, there was room to expand the research of the Queensland fruit fly, whilst focusing on the fruit fly that poses the largest threat to South Australia. Many of the serious games reviewed divided the simulation space into segments in order to simulate different properties across regions over time and provide simulation data to create prediction models (de la Vega et al. 2022). This concept was incorporated into this project by segmenting the entirety of South Australia using a grid, each cell of the grid representing 10 km^2 and was assigned unique properties to simulate the real-life location. Each 10 km^2 simulated a monitoring trap to provide the player with a way to approximate the number of fruit flies in the area, this was designed to simulate the monitoring traps which are maintained by PIRSA (Merkel 2024; Tam et al. 2023).

One of the ways fruit flies are managed in South Australia is to release sterile fruit flies to disrupt the wild fly breeding cycle, this technique was not incorporated in any of the reviewed projects, but the researchers who created the Spotted-Stop-It serious game suggested that their game could be expanded by adding functionality to release sterile male fruit flies (de la Vega et al. 2022). This project was able to break new ground by simulating the release of sterile fruit flies whilst also representing PIRSA’s real-world usage of sterile flies (Merkel 2024). The reviewed research reported that surveys produced quantifiable results whilst facilitating beneficial engagement with effected communities (Andreotti et al. 2020; Lairez et al. 2020; Ornetsmüller, Castella & Verburg 2018; Rebaudo et al. 2014; Rouault et al. 2020; Sari et al. 2024), so a user study was deemed to be an import component of this research project. The user study for this project incorporated members of the South Australian public for the purpose of playing the serious game to improve participant awareness and understanding, whilst also responding to surveys before and after playing, to generated quantifiable results.

3. Methodology

The primary focus of the project was education, with a secondary focus on the accuracy of the simulation. The project aimed to improve knowledge about Queensland fruit flies, how outbreaks occur, how fruit flies spread, and how to manage and reduce the impact of fruit flies in South Australia. The secondary focus was to accurately simulate Queensland fruit flies in South Australia based on real world data and the entomology expertise of Dr Katharina Merkel, the project’s industry advisor. Education was delivered in the form of a serious game. The game provided a means for players to observe the behaviour of the flies for the purpose of improving player familiarity of the Queensland fruit fly. Players were able to experiment with fly management strategies and observe their effectiveness for the purpose of enabling players to learn about the management strategies.

The more engaged players are, the more likely they are to retain new knowledge. Therefore, player engagement was a critical factor in the success of the project (Aldea et al. 2014; Ávila-Pesántez, Rivera & Alban 2017; Corti 2006; Susi, Johannesson & Backlund 2007). Game data was analysed for player engagement with the management of the fruit flies. Days were simulated during each play session. The data of each day was recorded in a game log. A user study was conducted in which participants played the game. Participants completed a survey before and after playing to measure the effectiveness of knowledge gain. Additionally, the post game play survey measured how effectively the game engaged participants.

3.1 Serious Game

The Unity game engine was used to develop the serious game. Unity was freely available for research purposes. I had prior experience with Unity, which I was able to draw upon to increase productivity. The content and design of the game was based upon my research and Dr Merkel's entomology expertise. I utilised an iterative process, which included regular meetings with Dr Merkel, Dr Matthew Stephenson, and myself. In each meeting I presented the current status and proposed future plans for the project. The game content and plans were continuously adjusted based on the feedback received during the meetings.

Unity was used to create three separate builds of the game, one for each of the following three major PC platforms: Windows, macOS, and Linux. The visuals were projected on screens. The audio was projected through speakers. The game was designed for high-definition resolution (1920 x 1080 px) whilst having the ability to scale to different resolutions as required. The game was controlled using a mouse. An overview of the game's system and subsystems is graphically represented in Figure 1 and described in Table 1. A video demonstration of gameplay can be viewed here: https://youtu.be/rybp6w7Z0J0.

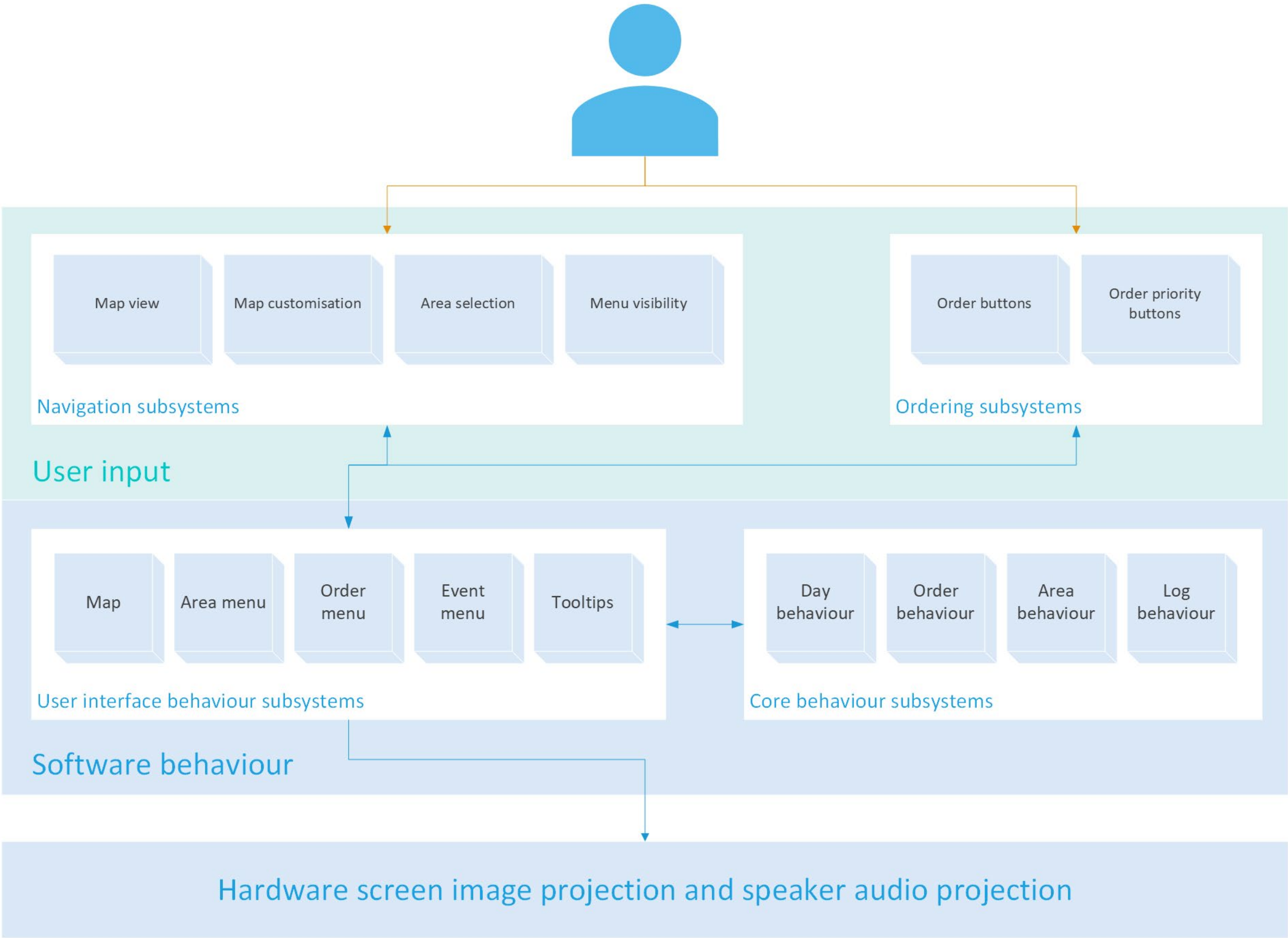

Figure 1 Game system configuration

Table 1 Game system overview

User input *- The player can directly interact with user input subsystems.*
• **Map view** - Adjust map view. The view can be panned vertically and horizontally or zoomed in and out (Figure 2). • **Map customisation** - Set the map layer to restriction or region colours. Show/hide the following on the map; detections, pheromones, protein bait, sterile fruit flies, or detection heatmap. • **Area selection** - The selection/deselection of individual or groups or areas. • **Menu Visibility** - Open/close menus by selecting areas and clicking the tabs at the bottom of the screen. • **Order buttons** - Increase/decrease quantity of management order. • **Order priority buttons** - Increase/decrease priority or cancel management order.
User interface behaviour subsystems *- Control what is shown on screen, based on user input and system state changes received from the core behaviour subsystems.*
• **Map** – Controls the behaviour and presentation of the map. • **Area menu** – Controls the behaviour and presentation of the area menu (Figure 3). • **Order menu** – Controls the behaviour and presentation of the order menu (Figure 10).

- **Event menu** – Controls the behaviour and presentation of the event menu (Figure 11).
- **Tooltips** – Controls the behaviour and presentation of the tooltips.

***Core behaviour systems** – Controls the gameplay loop and functionality using algorithms that incorporate the game's parameters and player input.*

- **Day behaviour** – Controls the duration of each in-game day and the in-game date.
- **Order behaviour** – Stores and processes management orders.
- **Area behaviour** – Controls the behaviour of flies and management strategies in each area (Appendix C).
- **Log behaviour** – Records the data of each in-game day in a JSON format log file.

The time increment for the game was in-game days. Each in-game day was 2.4 seconds in real life, so there was 25 in-game days per real life minute. To ensure consistency, players were not able to adjust the speed or pause the progression of days. Player could shift the view horizontally, vertically, and zoom using a mouse and keyboard or by using the navigational user interface in the top right corner (Figure 2). The map was divided into 10 square kilometre areas to represent capture zones for permanent fruit fly traps which are used to estimate the population of flies in the area. This was designed to simulate the traps which are permanently maintained by PIRSA (Merkel 2024). The areas could be clicked on individually or selected in groups to view their current player visible variables and to implement management options (Figure 3). Changes to areas were also indicated on the map to provide a broader context. Indicators included fruit movement restriction colours, a fruit fly detection heatmap, and images for the location of fruit fly detections, pheromone lures, protein-based bait, and sterile fruit flies. The variables that were used for areas are shown in Table 2. A flow chart that demonstrates the daily algorithm for updating area variables is shown in Appendix C.

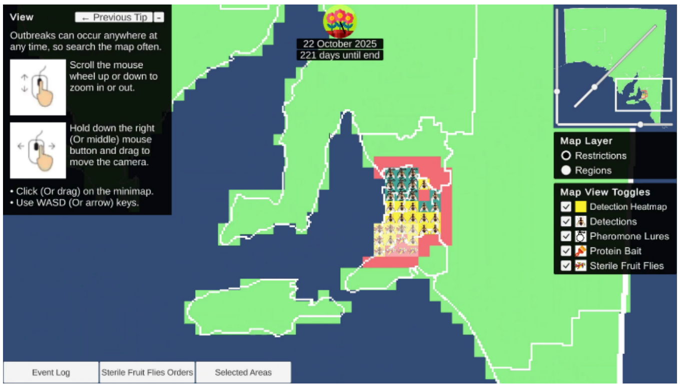

Figure 2 Map view

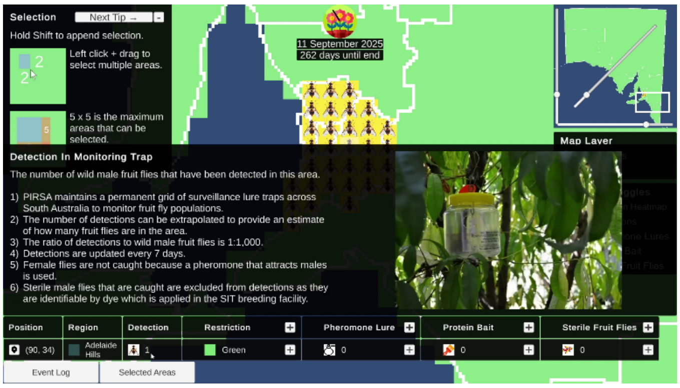

Figure 3 Detection tooltip

Table 2 Area variables

Name	Data Type	Visible To Player
Position	Vector3Int	Yes
Region	Region	Yes
Detection Count	ulong	Yes
Juvenile Wild Male	List<FruitFlyGroup>	No
Juvenile Wild Female	List<FruitFlyGroup>	No
Unmated Adult Wild Female	List<FruitFlyGroup>	No
Adult Wild Male	List<FruitFlyGroup>	No

Fertile Adult Wild Female	List<FruitFlyGroup>	No
Infertile Adult Wild Female	List<FruitFlyGroup>	No
Sterile Male	List<FruitFlyGroup>	No
Active Restriction	Management	Yes
Active Pheromones	List< Management >	Yes
Active Proteins	List< Management >	Yes
Active Sterile Fruit Flies	List< Management >	Yes
Ordered Restriction	Management	Yes
Ordered Pheromones	uint	Yes
Ordered Proteins	uint	Yes
Ordered Sterile Fruit Flies	uint	Yes

The density of fruit in the regions of South Australia was set for each season to simulate the times of the year when plants are fruiting (Table 3; Figure 4; Figure 5). The Murray and Mallee was assigned a high density of fruit in winter and spring as this is when most of the citrus trees produce fruit. The Barossa Light and Lower North was assigned a high density of fruit in summer as this is when grapes mature on the vines.

Table 3 Region fruit density

Region	Spring	Summer	Autumn	Winter
Adelaide Hills	Medium	High	Low	Low
Barossa Light and Lower North	Medium	High	Low	Low
Eastern Adelaide	Low	Medium	Low	Low
Eyre and Western	Low	Medium	Low	Low
Far North	None	None	None	None
Fleurieu and Kangaroo Island	Medium	High	Low	Low
Limestone Coast	Medium	High	Low	Low
Murray and Mallee	High	Medium	Medium	High
Northern Adelaide	Low	Medium	Low	Low
Southern Adelaide	Low	Medium	Low	Low
Western Adelaide	Low	Medium	Low	Low
Yorke and Mid North	Medium	High	Low	Low

Figure 4 Generic regions tooltip

Figure 5 Adelaide hills region tooltip

Parameters were set to control the behaviour of fruit flies (Table 4; Table 5). Fruit flies hibernate during the lower temperatures of winter, so the game began on the first day of winter to provide players time to familiarise themselves with the interface. Parameters were set for each season to simulate temperate and seasonal effects on fruit fly behaviours, including egg laying, maturation, lifespan, and mobility. Parameters were set for each fruit density to simulate the change in fruit fly behaviour based on the quantity and availability of fruit. The density of fruit in an area determined the maximum number of eggs that could be laid in the area per day to simulate how fruit flies can reach higher populations in areas where more fruit is available to host offspring (Table 3). The density of fruit in an area determined the daily percentage chance for each fruit fly to relocate to simulate how fruit flies are more likely to travel in search of fruit in areas where less fruit is available and more likely to remain in place where fruit is abundant.

Table 4 Season dependent parameters

		Values Based on Season				
Name	**Data Type**	**Winter**	**Spring**	**Summer**	**Autumn**	**Visible To Player**
Female Eggs Laid Per Day	Byte	0	13	13	13	No
Male Eggs Laid Per Day	Byte	0	13	13	13	No
Juvenile Fruit Fly Days To Mature	byte	Perish	21	19	23	No
Adult Fruit Fly Lifespan	byte	Paused	30	30	30	No
Daily Percentage Chance Of Transport By People	Float	0	0.0001	0.0001	0.0001	No
Daily Max Eggs Laid Per Area Per Gender	uint	0	Table 5	Table 5	Table 5	No
Daily Percentage Chance For Fly To Relocate Self	Float	0	Table 5	Table 5	Table 5	No

Table 5 Fruit density dependent parameters

		Values Based on Fruit Density				
Name	**Data Type**	**None**	**Low**	**Medium**	**High**	**Visible To Player**
Daily Max Eggs Laid Per Area Per Gender	uint	0	1,000	10,000	100,000	No
Daily Percentage Chance For Fly To Relocate Self	Float	1	0.00005	0.00002	0.00001	No

The restriction colour categories determined the movement of fruit by people. A matrix demonstrating the rules for each restriction colour is shown in Figure 6. The daily percentage chance per adult fly to be transported by a person is included in Table 4. Management strategies can be ordered for selected areas using the + buttons in the area menu (Figure 7; Figure 8; Figure 9). Orders were processed at the end of each in-game day. There was no limit to the number of fruit movement restrictions processed per day, but the other restrictions had limits which are shown in Table 6. Restrictions remained indefinitely, unless changed, whilst the other management strategies had a set number of days before expiring. Orders were queued before being processed; the order in which orders were processing was adjustable in the orders menu (Figure 10). Processed orders and fruit fly detections were recorded in the event log (Figure 11).

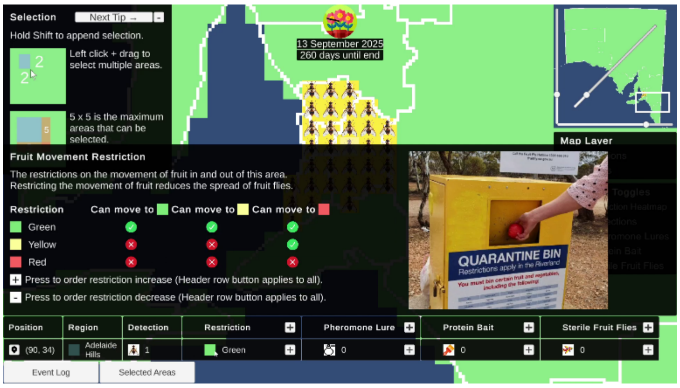

Figure 6 Fruit movement restriction tooltip

Figure 7 Pheromone lures tooltip

Figure 8 Protein-based bait tooltip

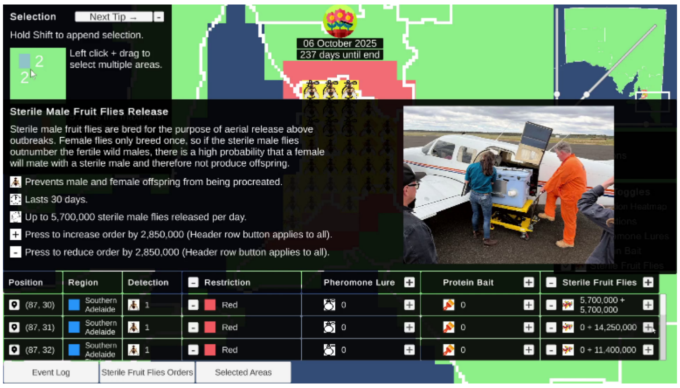

Figure 9 Sterile fruit fly tooltip

Figure 10 Orders menu

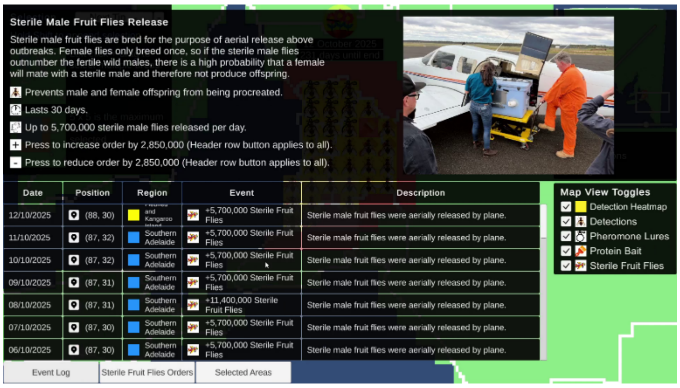

Figure 11 Event log

Table 6 Management Parameters

Name	Data Type	Value	Visible To Player
Number Of Detection Traps Per Area	Byte	1	Yes
Pheromone Lifespan	Byte	90	Yes
Protein-Based Bait Lifespan	Byte	14	Yes
Max Pheromone Placements Per Day	Uint	1,000	Yes
Max Protein-Based Bait Placements Per Day	Uint	20,000	Yes
Max Sterile Fruit Flies Placements Per Day	uint	5,700,000	Yes
Daily Percentage Chance Of Permanent Trap	Float	0.001	No
Daily Percentage Chance Of Pheromone Kill	Float	0.001	No
Daily Percentage Chance Of Protein-Based Bait Kill	Float	0.00005	No

The percentage chance for an unmated female fruit fly to mate with a sterile male or a wild male was determined by the number of sterile males and wild males in the area (Equation 1). Every game play session used the same random seed to initialise a pseudorandom number generator to ensure every session produced the same probability distribution.

Equation 1 Percentage chance for female to mate with sterile male in zone

$$Chance\ of\ female\ to\ mate\ with\ sterile\ male = \frac{no.of\ sterile\ male}{no.of\ sterile\ male + no.of\ wild\ male} \times 100$$

Each play session started with outbreaks in the Adelaide regions. Throughout game play additional outbreaks could occur anywhere within South Australia at any time, except for during winter (Table 7). On average, outbreaks occurred 2.76 times per play session (Equation 2).

Table 7 Outbreak parameters

Name	Data Type	Value	Visible To Player
Outbreak From Interstate Female Quantity	Byte	1	No
Outbreak From Interstate Male Quantity	Byte	30	No
Daily Percentage Chance Of Outbreak From Interstate	float	0.01	No

Equation 2 Average number of outbreaks per play session

$$Average\ no.of\ outbreaks = Daily\ Chance \times No.Of\ Non\ Winter\ Days = 0.01 \times 276 = 2.76$$

3.2 Data Collection and Analysis

After the serious game was developed, surveys were created, followed by ethics approval, then data collection. Each game play session generated a log file which contained a record of the data for that session. Session data was divided into days. Each day contained a record of the total fly populations, management counts, fly deaths, eggs laid, flies matured, flies mated, orders fulfilled, outbreaks, flies transported by people, and self-relocated flies. The log file data was in JSON file format that was later processed using RStudio and Excel.

The user study was conducted with 19 Flinders University students and other members of the South Australian public ($n = 19$). Participants filled in a survey directly before (Appendix A) and directly after playing the game (Appendix B). The post gameplay survey repeated all the pre gameplay survey questions, so that the results could be compared. The post survey included additional questions designed to measure the game's effectiveness, player experience, and player engagement.

The data analysis hardware consisted of an Intel(R) Core(TM) i5-6600K CPU @ 3.50GHz 3.50 GHz processor, NVIDIA GeForce GTX 1060 6 GB graphics card, 16 GB RAM, and a 250 GB SSD. The data analysis software consisted of Windows 11, RStudio, and Excel. The gameplay log data was analysed to assess participant engagement. Participant usage of fruit fly management strategies was included in the log data to determine which management strategies were engaged with the most.

Rating scales were used for the surveys to enable participants to express themselves whilst simultaneously producing quantitative measurable data, unlike open-ended questions that produce qualitative data (Appendix A; Appendix B). The rating scales were consistently formatted for each question, to reduce the chance of participants misinterpreting questions and answering incorrectly. The top response options were the most positive, with each subsequent response less positive than the former. The format was as follows: Very Positive, Positive, Negative, Very Negative. The final four questions were dichotomous (Yes/No). These questions were included at the end of the post-survey to reduce confused caused when the formatting of questions changed. These questions used a different format as their goal was to determine which management strategies the participants recalled engaging with.

The pre and post survey data was compared to determine if there was any change in responses. Participant familiarity with the Queensland fruit fly and management was analysed to determine how effective the game was at educating. The participant ratings of the importance of the management of the Queensland fruit fly in South Australia was analysed to determine how effective the game was at raising awareness. The participant ratings of the effectiveness of the management of the Queensland fruit fly in South Australia was analysed to determine participant sentiment with existing management options. The additional post survey responses were analysed to determine the effectiveness of the game as a learning tool, how enjoyable the game was, how intuitive the game was, and how engaging the game was.

4. Results

This research study included 19 participants. Each participant was presented with an identical game scenario. To ensure the duration of each gameplay session was 15 minutes, it was not possible to pause the game. Each gameplay session consisted of 365 in-game days. The same random seed was used for all participants to ensure all random calculations were consistent. However, differences in player actions altered the usage of the random seed. This meant the quantity and position of outbreaks differed between play sessions.

4.1 Survey Results

The pre gameplay survey consisted of four questions (Appendix A). These four questions were repeated in the post gameplay survey (Appendix B). Appendix D summarises the survey questions and participant responses, with diverging stacked bar charts included to visualise the rating scale responses. The post survey responses are included below the corresponding pre survey responses to assist visual comparison of the two. Table 8 provides a summary of the first four repeated questions and Table 9 provides a summary of the remaining questions which were only included in the post gameplay survey. The percentages of participant selections for each response are included. The means for each question were calculated by assigning values to each response which are included in the table headers e.g. Very Unfamiliar had a value of 0, Unfamiliar had a value of 1, Familiar had a value of 2, and Very Familiar has a value of 3. The t-values and p-values were calculated using a two-tailed t-Test using the Excel Data Analysis ToolPak for each of the corresponding pre and post gameplay survey responses with the hypothesized mean difference set to 0 and the significance level (alpha) set to 0.05.

Table 8 Pre gameplay and post gameplay survey responses summary and comparison

How familiar are you with the following?	Survey | Q	Very Unfamiliar (0)	Unfamiliar (1)	Familiar (2)	Very Familiar (3)	Mean	t-value	Two-tail p-value
The Queensland fruit fly.	Pre | 01	42.11%	26.32%	31.58%	0%	0.89	-3	0.008050
	Post | 01	10.53%	36.84%	47.37%	5.26%	1.47		
How the Queensland fruit fly is managed in South Australia.	Pre | 02	31.58%	47.37%	21.05%	0%	0.89	-7	0.000002
	Post | 02	0%	26.32%	47.37%	26.32%	2		
How important do you consider the following?	**Survey | Q**	**Very Unimportant (0)**	**Unimportant (1)**	**Important (2)**	**Very Important (3)**	**Mean**	**t-value**	**Two-tail p-value**
Management of the Queensland fruit fly in South Australia.	Pre | 03	0%	15.79%	47.37%	36.84%	2.21	-2.381	0.029258
	Post | 03	0%	5.26%	36.84%	57.89%	2.53		
How effective do you consider the following at managing fruit flies?	**Survey | Q**	**Very Ineffective (0)**	**Ineffective (1)**	**Effective (2)**	**Very Effective (3)**	**Mean**	**t-value**	**Two-tail p-value**
Management of the Queensland fruit fly in South Australia.	Pre | 04	0%	15.79%	63.16%	21.05%	2.05	-0.437	0.667577
	Post | 04	0%	21.05%	47.37%	31.58%	2.11		

Table 9 Post gameplay (only) survey responses

How effective do you consider the following at managing fruit flies?	Q	Very Ineffective (0)	Ineffective (1)	Effective (2)	Very Effective (3)	Mean
Fruit movement restrictions.	05	0%	15.79%	73.68%	10.53%	1.95
Pheromone lures with insecticide.	06	0%	31.58%	47.37%	21.05%	1.89
Protein-based bait with insecticide spray.	07	0%	15.79%	52.63%	31.58%	2.16
Sterile fruit flies.	08	0%	21.05%	47.37%	31.58%	2.11
How effective do you consider the following?	**Q**	**Very Ineffective (0)**	**Ineffective (1)**	**Effective (2)**	**Very Effective (3)**	**Mean**
The game as a tool for learning.	09	0%	26.32%	52.63%	21.05%	1.95
Do you agree with the following?	**Q**	**Strongly Disagree (0)**	**Disagree (1)**	**Agree (2)**	**Strongly Agree (3)**	**Mean**

I had fun whilst playing the game.	10	0%	10.53%	73.68%	15.79%	2.05
How intuitive do you consider the following?	**Q**	**Very Unintuitive (0)**	**Unintuitive (1)**	**Intuitive (2)**	**Very Intuitive (3)**	**Mean**
The game mechanics.	11	5.26%	31.58%	47.37%	15.79%	1.74
Which management techniques did you experiment with?	**Q**	**No (0)**		**Yes (1)**		**Mean**
Fruit movement restrictions.	12	15.79%		84.21%		0.84
Pheromone lures with insecticide.	13	5.26%		94.74%		0.95
Protein-based bait with insecticide.	14	0%		100%		1
Sterile fruit flies.	15	10.53%		89.47%		0.89

4.2 Gameplay Log Data Results

Table 10 provides a summary of the total number of times participants used the management strategies. This data was obtained from the gameplay log data. The box and whisker plots shown in Figure 12 and Figure 13 provide graphical representations of the management strategy usage.

Table 10 Summary of participant usage of management strategies

Participant	Restrictions	Pheromone	Protein	Sterile	Total
1	128	261	188	117	694
2	90	268	1390	487	2235
3	100	86	187	90	463
4	49	933	473	420	1875
5	1	1064	2041	910	4016
6	203	104	103	9	419
7	40	115	133	115	403
8	72	209	252	321	854
9	44	2379	1009	2758	6190
10	0	1867	1593	1252	4712
11	117	128	68	150	463
12	22	215	76	106	419
13	426	313	378	531	1648
14	78	164	341	184	767
15	58	84	321	176	639
16	492	276	327	127	1222
17	47	12	145	111	315
18	21	338	628	393	1380
19	134	626	329	110	1199
	Restrictions	**Pheromone**	**Protein**	**Sterile**	**Total**
Sum	2122	9442	9982	8367	29913
Mean	111.68	496.95	525.37	440.37	1574.4
Min	0	12	68	9	315
Q1 (LQ)	42	121.5	166	113	463
Q2 (Median)	72	261	327	176	854
Q3 (UQ)	122.5	482	550.5	453.5	1761.5
Max	492	2379	2041	2758	6190
Standard Deviation	132.83	643.25	567.56	643.12	1647.6

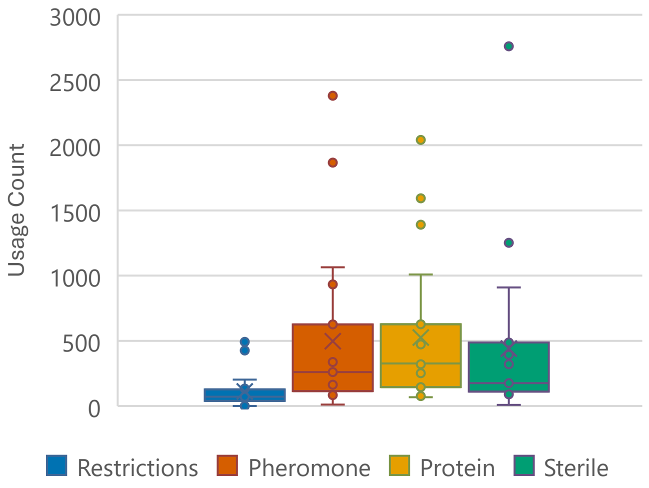

Figure 12 Management strategy usage counts

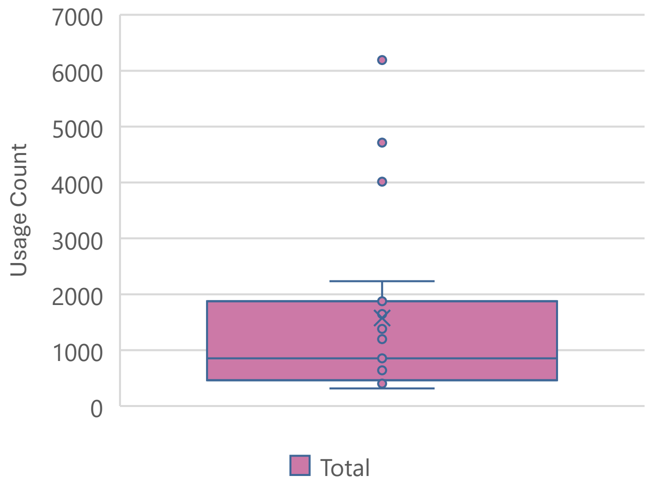

Figure 13 Total management strategy usage counts

Table 11 provides a summary of the combined total management strategy usage count for all participants for each minute of the game. This data was obtained from the gameplay log data. The graphs shown in Figure 14 and Figure 15 provide graphical representations of the management strategy usage over time. Please note that there were 25 in-game days per minute except for the 15th minute which was 15 in-game days and therefore lasted 36 seconds.

Table 11 Summary of participant usage of management strategies per minute

Minute	Restrictions	Pheromone	Protein	Sterile	Total
1	113	224	126	7	470
2	80	1151	914	565	2710
3	158	1284	806	1058	3306
4	87	412	722	957	2178
5	71	445	629	1118	2263
6	137	496	689	547	1869
7	88	458	484	367	1397
8	109	468	544	368	1489
9	66	793	731	544	2134
10	264	829	798	517	2408
11	278	699	806	471	2254
12	108	499	606	434	1647
13	145	546	679	541	1911
14	277	713	872	555	2417
15	141	425	576	318	1460
	Restrictions	**Pheromone**	**Protein**	**Sterile**	**Total**
Sum	2122	9442	9982	8367	29913
Mean	141.47	629.47	665.47	557.8	1994.2
Min	66	224	126	7	470
Q1 (LQ)	87.5	451.5	591	401	1568
Q2 (Median)	113	499	689	541	2134
Q3 (UQ)	151.5	753	802	560	2335.5
Max	278	1284	914	1118	3306
Standard Deviation	73.47	288.29	192.96	290.55	662.24

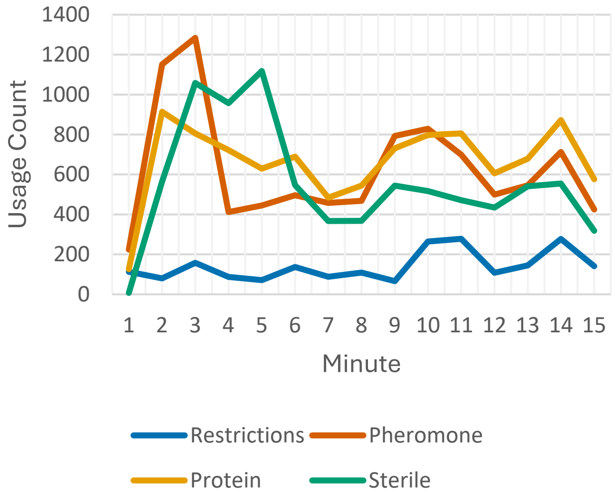

Figure 14 Management strategy usage counts per minute

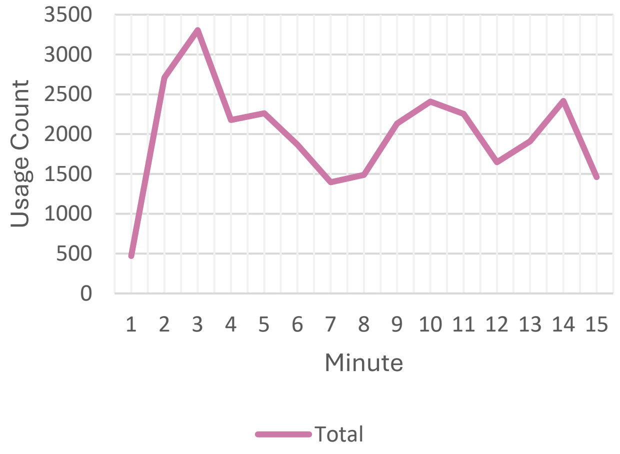

Figure 15 Total management strategy usage counts per minute

5. Discussion

5.1 Education

For the question: "How familiar are you with the following? The Queensland fruit fly" the paired T-Test indicated a significant increase in familiarity in the post gameplay survey, $t(18) = -3$, $p = 0.008$ (Table 8). This result suggests a statistically significant improvement in participants' knowledge about the Queensland fruit fly after playing the game. For the question: "How familiar are you with the following? How the Queensland fruit fly is managed in South Australia." the paired T-Test indicated a significant increase in familiarity in the post gameplay survey, $t(18) = -7$, $p = 0.000002$ (Table 8). This result suggests a statistically significant improvement in participants' knowledge about how the Queensland fruit fly is managed in South Australia after playing the game. For the question: "How effective do you consider the following? The game as a tool for learning." the majority of participants (73.68%) perceived the game as a very effective or effective tool for learning (Table 9). This highlighted the game's potential for educational use, but there was a segment of the participants who did not consider the game effective for learning, this segment of participants might be more inclined to other educational tools, such as traditional teaching methods.

5.2 Sentiment

For the question: "How important do you consider the following? Management of the Queensland fruit fly in South Australia." the paired T-Test indicated a significant increase in perceived importance in the post gameplay survey, $t(18) = -2.381$, $p = 0.029258$ (Table 8). This result suggests a statistically significant improvement in participants' valuation of the management of the Queensland fruit fly in South Australia after playing the game. For the question: "How effective do you consider the following at managing fruit flies? Management of the Queensland fruit fly in South Australia." the paired T-Test did not indicate a significant change in perceived effectiveness in the post gameplay survey, $t(18) = -0.437$, $p = 0.667577$ (Table 8). This result suggests that there was no statistically significant improvement in participants' valuation of the management of the Queensland fruit fly in South Australia after playing the game. Participants may have had a disassociation between the game and the real-world, or simply the game aligned with players preconceived opinions.

For the question: "How effective do you consider the following at managing fruit flies?” the majority of participants perceived all of the management techniques to be effective or very effective. “Protein-based bait with insecticide spray” was considered the most effective by participants with the majority of participants (84.21%) considering it either effective or very effective with the highest mean value (2.16) (Table 9). “Fruit movement restrictions” also resulted in 84.21%, but with a lower portion of very effective and the third highest mean value (1.95). “Sterile fruit flies” was third (78.95%), with the second highest mean value (2.11). “Pheromone lures with insecticide” was considered the least effective by participants, however, it was still considered effective or very effective by the majority of participants (68.42%), whilst receiving the lowest means score (1.89). It is interesting that participants considered protein-based bait the most effective and pheromone lures the least effective as these were the two management strategies that were the most similar. This could be a result of some parameters being valued by participants more than others. For example, the tooltips informed players that protein-based bait allowed up to 20,000 applications per day and killed both male and female flies whilst pheromone lures allowed up to 1,000 applications per day and only killed male flies (Table 6; Figure 8; Figure 7). The lifespan parameters were likely less valued by participants since protein-based bait had a shorter lifespan (14 days) than pheromone lures (90 days).

5.3 Quality

For the question: “Do you agree with the following? I had fun whilst playing the game.” the majority of participants (89.47%) agreed or strongly agreed that they had fun (Table 9). This is promising since a positive correlation has been shown between fun serious game elements and learning effectiveness (Fokides et al. 2021; Iten & Petko 2016; Ravyse et al. 2017; Sailer & Homner 2020; Wouters et al. 2013). Additionally, it has been shown that fun can increase player engagement, resulting in improved learning outcomes (Larson 2020; Schrader 2022; Tondorf & da Silva Hounsell 2022). For the question: “How intuitive do you consider the following? The game mechanics.” the majority of participants (63.16%) responded that the game mechanics were intuitive or very intuitive (Table 9). This is important because participants had limited time to play the game, so the quicker they were able to understand the mechanics, the more time they had to engage with the game as intended. If the mechanics were unintuitive there is also a chance that players could misinterpret educational elements or miss elements entirely. The segment of the participants who did not consider the game mechanics intuitive, may be unfamiliar with this type of game or games in general, either way, the accessibility and onboarding of the game could be improved to accommodate these players.

5.4 Engagement

The mean number of times participants used the management strategies was 1574.4, indicating high engagement levels with educational aspects of the game, however the significant standard deviation (1647.6) suggests variability among participants (Table 10). Disparity in participant familiarity with games or computers in general could factor in the variability along with the three recorded upper outliers which more than doubled the majority of participants. On average, protein-based bait was engaged with the most with a mean value of 525.37, followed by pheromone lures with a mean value of 496.95, then sterile fruit flies with a mean value of 440.37, and then restrictions with a mean value of 111.68. These results align with the survey responses for the question: "Which management techniques did you experiment with?" where participants provided the most yes responses for protein-based bait (100%), followed by pheromone lures (94.74%), then sterile fruit flies (89.47%), and restrictions (84.21%). The order of most used to least used did not align with the order of most effective to least effective rated management strategies, so other factors should be considered, such as the duration of the management strategy effects. Management strategies with shorter durations required more frequent applications. Protein-based bait which was used the most had the shortest duration (14 in-game days), pheromone lures were used the second most and had the second longest duration (90 in-game days), sterile fruit flies was used the third most and had the second shortest duration (30 in-game days), and restrictions were used the least and had an infinite duration of in-game days (Table 6). Furthermore, the four management strategies received significant standard deviations, suggesting variability among participant usage of the strategies.

Participants engaged with the management strategies the least during the first minute (total 470) of the game and the most in the second (total 2710) and third (total 3306) minutes of the game (Table 11), after which engagement ebbed and flowed within the range of 1397 to 2417. It is likely that during the first minute of the game players were more focussed on reading the tooltips and learning how to play the game. The higher engagement during the second and third minutes may be related to the fact that the game begins with outbreaks across Adelaide regions, so players feel a sense of urgency. Player attention may decrease after the first three minutes or players may take time to observe and assess the effectiveness of the management strategies they have implemented. Positioning in the user interface may factor into which management strategies were used first. Pheromone lures were the most used during the first minute (224) and were positioned second in the user interface, protein-based baits were the second most used during the first minute (126) and was in the third position in the user interface, restrictions were the third most used in the first minute (113) and were the first position in the user interface, and sterile fruit flies were used the least in the first minute (7) and were positioned last in the user interface. Restrictions were listed first in the user interface, but unlike the other management strategies, restrictions were indefinite and therefore could not be pressed multiple times to que multiple usages.

6. Conclusions and Future Works

The primary goal of the research was to educate participants about the management of Queensland fruit flies in South Australia using a serious simulation game. After playing the game participants showed significant increases in the familiarity of the Queensland fruit fly and how it is managed in South Australia. The majority of participants considered the game as an effective or very effective tool for learning. However, exclusively using games to educate is not recommended, since the participants who considered the game ineffective as tool for learning will likely find other teaching methods more effective. After playing the game participants showed a significant increase in perceived importance of the management of the Queensland fruit fly in South Australia. This suggests that the game can increase community support, it worth considering making the game available to stakeholders such as fruit farmers, community leaders, and people living in outbreak areas. After playing the game participants did not indicate a significant change in perceived effectiveness of the management of the Queensland fruit fly in South Australia, so it is not recommended to pursue the use of games to increase player perception of the effectivity of pest management.

The majority of participants agreed or strongly agreed that they had fun whilst playing the game and that the game mechanics were intuitive or very intuitive. These two factors highlight the quality of the educational experience, but it is important to note there were participants who did not have fun or find the game intuitive, so there are still improvements that can be made to improve the learning experience for a wider audience. Another key component is the level of engagement with the educational experience. The total engagements with the management techniques across the 15 minutes of gameplay (mean 1574.4) suggests a high level of engagement. However, the was high variance of player engagement (standard deviation 1647.6). Participants engaged the least in the first minute and the most in the second and third minutes. Overall engagement was promising, but the high variance suggests that there is still room for improvement to keep all types of players engaged.

The game was designed to accommodate future research projects. The simulation parameters are easily modifiable to accommodate new data. There is potential for AI to play the game using deep reinforcement learning algorithms to determine optimal strategies to manage fruit flies in South Australia for theoretical or real-world scenarios (Dobrovsky, Borghoff & Hofmann 2016, 2017). Dr Stephenson and Dr Merkel have suggested that the project could be expanded upon in future to PHD level, with the possibility of incorporating additional researchers and industry involvement and collaboration.

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Appendix

Appendix A - Pre-gameplay survey

How familiar are you with the following? Select the option that best represents your familiarity.	
The Queensland fruit fly.	◯ Very Familiar ◯ Familiar ◯ Unfamiliar ◯ Very Unfamiliar
How the Queensland fruit fly is managed in South Australia.	◯ Very Familiar ◯ Familiar ◯ Unfamiliar ◯ Very Unfamiliar

How important do you consider the following? Select the option that best represents the importance.	
Management of the Queensland fruit fly in South Australia.	◯ Very Important ◯ Important ◯ Unimportant ◯ Very Unimportant

How effective do you consider the following? Select the option that best represents the effectiveness.	
Management of the Queensland fruit fly in South Australia.	◯ Very Effective ◯ Effective ◯ Ineffective ◯ Very Ineffective

Appendix B - Post-game play survey

How familiar are you with the following? Select the option that best represents your familiarity.	
The Queensland fruit fly.	◯ Very Familiar ◯ Familiar ◯ Unfamiliar ◯ Very Unfamiliar
How the Queensland fruit fly is managed in South Australia.	◯ Very Familiar ◯ Familiar ◯ Unfamiliar ◯ Very Unfamiliar

How important do you consider the following? Select the option that best represents the importance.	
Management of the Queensland fruit fly in South Australia.	◯ Very Important ◯ Important ◯ Unimportant ◯ Very Unimportant

How effective do you consider the following? Select the option that best represents the effectiveness.	
Management of the Queensland fruit fly in South Australia.	◯ Very Effective ◯ Effective ◯ Ineffective ◯ Very Ineffective

How effective do you consider the following at managing fruit flies? Select the option that best represents the effectiveness.	
Fruit movement restrictions.	◯ Very Effective ◯ Effective ◯ Ineffective ◯ Very Ineffective
Toxic pheromones.	◯ Very Effective

	◯ Effective ◯ Ineffective ◯ Very Ineffective
Toxic fruit paste.	◯ Very Effective ◯ Effective ◯ Ineffective ◯ Very Ineffective
Sterile fruit flies.	◯ Very Effective ◯ Effective ◯ Ineffective ◯ Very Ineffective

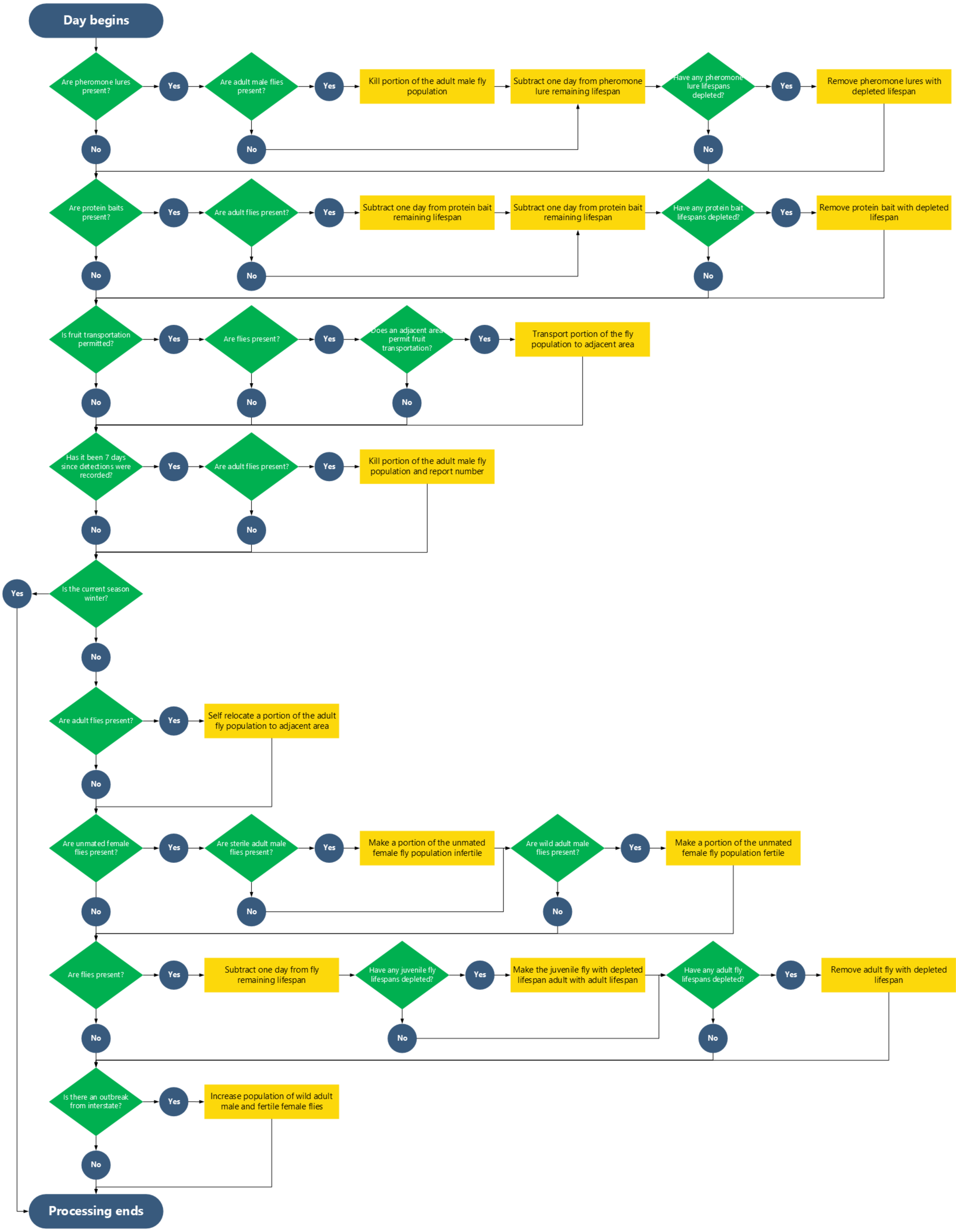
How effective do you consider the following? Select the option that best represents the effectiveness.	
The game as a tool for learning.	◯ Very Effective ◯ Effective ◯ Ineffective ◯ Very Ineffective

Do you agree with the following? Select the option that best represents your agreeance.	
I had fun whilst playing the game.	◯ Strongly Agree ◯ Agree ◯ Disagree ◯ Strongly Disagree

How intuitive do you consider the following? Select the option that best represents the intuitiveness.	
The game mechanics.	◯ Very Intuitive ◯ Intuitive ◯ Unintuitive ◯ Very Unintuitive

<table>
<tr><td colspan="2">Which management techniques did you experiment with?
Tick all that apply. If none apply, leave all unticked.</td></tr>
<tr><td>The fruit fly management techniques I experimented with in the game.</td><td>☐ Fruit movement restrictions
☐ Toxic pheromones
☐ Toxic fruit paste
☐ Sterile fruit flies</td></tr>
</table>

Appendix C – Area flow chart



Appendix D – Survey responses summary

Question	Component	Options	Survey | Q
How familiar are you with the following?	The Queensland fruit fly.	Very Unfamiliar, Unfamiliar, Familiar, Very Familiar	Pre | 01
			Post | 01
	How the Queensland fruit fly is managed in South Australia.		Pre | 02
			Post | 02
How important do you consider the following?	Management of the Queensland fruit fly in South Australia.	Very Unimportant, Unimportant, Important, Very Important	Pre | 03
			Post | 03
How effective do you consider the following?	Management of the Queensland fruit fly in South Australia.	Very Ineffective, Ineffective, Effective, Very Effective	Pre | 04
			Post | 04
How effective do you consider the following at managing fruit flies?	Fruit movement restrictions.		Post | 05
	Pheromone lures with insecticide.		Post | 06
	Protein-based bait with insecticide spray.		Post | 07
	Sterile fruit flies.		Post | 08
How effective do you consider the following?	The game as a tool for learning.		Post | 09
Do you agree with the following?	I had fun whilst playing the game.	Strongly Disagree, Disagree, Agree, Strongly Agree	Post | 10
How intuitive do you consider the following?	The game mechanics.	Very Unintuitive, Unintuitive, Intuitive, Very Intuitive	Post | 11
Which management techniques did you experiment with?	Fruit movement restrictions.	No, Yes	Post | 12
	Pheromone lures with insecticide.		Post | 13
	Protein-based bait with insecticide.		Post | 14
	Sterile fruit flies.		Post | 15