# Energy Explorer: A Theory-Informed Design for a Serious Game with the Purpose of Promoting Energy Conservation Behaviours

By

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The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University (UTAS Social Sciences HREC ethics approval number H0015206; CSIRO Social Science HREC ethics approval number 009/16).

Signed: Lindsay F. Wells

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# Abstract

*Games for Change* have been developed to leverage the motivational power of video games in a wide range of areas such as education, training, therapy, and scientific discovery. Whilst positive results have been seen, this work identifies a number of significant limitations to the current approach to Games for Change. Too often there is a reliance on a "one size fits all" solution of points, badges, and leaderboards, and a lack of psychological theory in the design of the games. These limitations stand to curb the effectiveness of such games, as such game elements may have a harmful effect on player motivation. A more robust design informed by theory may be more likely to effectively bring about behaviour change.

Focussing on the application domain of energy conservation, this work contributes a novel method of applying behaviour change theory to the design of a Serious Game. Specifically, this project aims to answer the question:

> *What are the opportunities and challenges in integrating both game design and behaviour change techniques towards the development of a Serious Game for changing residential energy behaviour?*

Though previous Games for Change have addressed energy conservation, they have not capitalised upon contemporary psychological theory to maximise and solidify change. In response, this work is explicitly grounded in the Intervention Research methodology of Thomas & Rothman (1994). Within this wider methodology, a set of Behaviour Change Techniques (BCTs) were identified through a systematic method of designing interventions known as the Behaviour Change Wheel (Michie et al. 2014)—a process which has never before been applied to the area of video games. This study then contributes a novel linking of these BCTs with game elements from literature and popular mobile games.

To understand the nuances and practicalities of implementing this approach, a real-world case-study implementation was developed. Using a Human-Centered Design approach (Holloway & Kurniawan 2010), and the extension of the Behaviour Change Wheel, this work presents a new design of a Serious Game (*Energy Explorer*) which consists of theory-informed game elements. The game responds directly (in terms of game environment and player resources) to the player's actual energy consumption. Further, core game elements such as quests, exploration, and social features all react to energy consumption behaviour. A pilot phase with subject matter experts resulted in an improved version of the game, and the impact of the developed Serious Game was tested using a pre-test/post-test control group design,

including analysis of energy consumption, game metrics, and player feedback surveys. A small but significant difference in change in conservation effect 14 days pre-test and 14 days post-test was observed between the control and intervention groups ($U = 1567$, $n_{control} = 128$, $n_{intervention} = 19$, $M_{control} = 0.234$, $M_{intervention} = -0.043$, $p = 0.043$). On the first day playing the game, a greater conservation effect was observed in females as opposed to males ($U = 18$, $n_{female} = 9$, $n_{male} = 10$, $M_{female} = -0.076$, $M_{male} = 0.114$, $p = 0.030$).

A key result is an empirical assessment of critical factors for the successful design and deployment of a Serious Game that effectively integrates theory-driven BCTs in the energy conservation space. This work presents an in-depth discussion of the challenges involved in the design and implementation phases of the project such that future researchers can utilise the lessons learned herein and avoid the issues that have been identified.

Areas for future work in the body of knowledge around game elements, and behaviour change techniques are presented. Also covered is the issue of the participant group already being energy conscious and familiar with video games. Potential problems with access to smart meter data, the mobile platform, and delivering an appropriate amount of entertainment in the game are discussed, and the need for participatory design in the methodology was identified. Finally, a summary of the challenges and the identified recommendations to mitigate these issues is provided.

This thesis describes the opportunities and challenges of actioning robust behaviour change techniques through theory-informed game elements in a Serious Game and how meaningful change can be delivered in the energy conservation space.

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我非常爱你

# Table of Contents

## List of Figures

## List of Tables

# 1 Introduction

In recent years, many have begun to realise the power of a relatively new form of entertainment to be used effectively in non-entertainment contexts: video games. Recent statistics on video games show their increasing popularity, with 65% of households being home to at least one member who plays video games for more than 3 hours per week in the United States (Entertainment Software Association 2016). It has been argued that we are undergoing or have already undergone a Ludification of Culture (Raessens 2006; Koorevaar 2012), which means that it is not uncommon to see video games or elements from video games in our daily lives, and doing so is no longer a surprising, or jarring experience.

Already, researchers have begun to use video games in a wide range of non-gaming contexts in the form of Gamification (Deterding et al. 2011) and Serious Games (Abt 1970). These areas include (but are not limited to): education (Ke 2012; Emam & Mostafa 2012), training (Nieborg 2004; United States Army 2002; Fitz-Walter et al. 2011; Fitz-Walter et al. 2013), therapy (McGonigal 2012), health (Edgerton 2009), improving web services (Von Ahn & Dabbish 2004), and scientific discovery (Khatib, Cooper, et al. 2011; University of Washington 2008). These games often come under the title of G*ames for Change*.

We will see however, that there are key limitations to these studies, with many Gamification implementations relying upon a "one size fits all" solution of points, badges, and leaderboards (referred to as the *PBL triad* (Werbach & Hunter 2012)), and a lack of psychological theory employed when the purpose of the game is to bring about behaviour change (Mayer et al. 2014; Bryant & Fondren 2009; Thompson 2012; Bogost 2011; Deterding 2011; Robertson 2010).

These issues present an opportunity to improve the design of Serious Games by employing psychological theories in the design process. In order to do this effectively, an application domain needs to be determined in order to move from theory and to concrete insight.

This thesis is situated within the energy sector, where research has gone into improving the design of buildings, renewable energy, and feedback systems for energy conservation. Bringing about energy conservation certainly constitutes a serious purpose, given it is a core component of mitigating C*limate Change*—one of the biggest scientific and social issues of our time. The warming of our planet, rising water levels, and increases in greenhouse gasses are "unprecedented over [the last] decades to millennia" (Pachauri et al. 2014, p.2) and stand to have a dramatic impact on food and water availability, and weather conditions worldwide.

Reducing emissions of greenhouse gasses such as $CO_2$, is an important step in this and reducing our consumption of energy is one way in which this can be achieved.

Providing energy consumption feedback in the residential sector may save up to 100 billion kilowatt-hours of electricity annually in the United States alone by 2030 (Ehrhardt-Martinez et al. 2010). However, estimates of real-time feedback have shown a conservation effect of only 3—5% (McKerracher & Torriti 2013) thus far. Curren energy feedback systems appear to be insufficient for providing meaningful behaviour change, and research has called for improved energy feedback systems (McKerracher & Torriti 2013; Strengers 2008; Houde et al. 2012; Nusca 2011). This thesis will show that video games may be an effective way of providing this feedback.

Research has already begun looking at the use of Serious Games and Gamification in the context of energy conservation; both in terms of energy literacy (Nataraja & Whittinghill 2013), and behaviour change (Brewer et al. 2011). Work in this area has seen some positive short-term results, however a number of limitations exist with these designs. Specifically, the limitations identified in Games for Change in the area of energy conservation mirror the general case: a lack of psychological basis, and a reliance on the PBL triad. There is an opportunity to employ behaviour change techniques in the design of a Serious Game, however given the lack of previous work doing so, it is important to discuss the challenges and pitfalls involved so that future research can benefit. This ultimately leads to the research question:

> *What are the opportunities and challenges in integrating both games design and behaviour change techniques towards the development of a Serious Game for changing residential energy behaviour?*

This work presents a novel methodology to develop a Serious Game intervention for energy conservation which is designed using psychological theory. The overarching methodology follows the Intervention Research (IR) methodology by Rothman & Thomas (1994), which in this case is comprised of a design phase which makes novel use of the Behaviour Change Wheel methodology by Michie et al. (2011), followed by a unique process that leads to a psychologically-based selection of game elements. These elements are situated together in a Serious Game whole developed using the Human-Centered Design approach of Holloway & Kurniawan (2010).

To test the conservation effect of the Serious Game, two experimental trials were run: first, a small pilot trial on a small sample size to obtain feedback and then a larger-scale trial with a Serious Game design improved over the initial iteration. The results of these experiments, and a discussion of the challenges involved in designing and implementing the Serious Game contribute to the research question described above. The remainder of this chapter describes the structure of the thesis.

## 1.1 Thesis Structure

Chapter 2 first provides a literature review of the main focus of this work: *video games*, and the concept of G*ames for Change*. The chapter then explores the limitations evident in Games for Change which provides the motivation for the thesis. After this, the application domain of *energy conservation* is explored, including a literature review of non-gaming strategies, and the problems related to these. Finally, the chapter explores the existing work on combining video games and energy conservation, including a review of the limitations in these games. The limitations of these games, and in Serious Games in general comprise the main motivation for this thesis.

Chapter 3 brings together the reviewed literature to present the research question for the project and the sub-research questions defined to address it. A methodology for answering these questions by defining the data requirements for each question and the sources for that data is then described. The chapter concludes by presenting the research philosophy in terms of the epistemological and ontological positions taken.

The methodology in Chapter 3 describes three phases beyond the literature review: *intervention design*, *game design*, and *experiment*. The chapters following it present the results of these phases.

In describing the *intervention design*, Chapter 4 presents the results of going through the process of the Behaviour Change Wheel (BCW) systematic method for analysing the energy conservation space in behavioural terms to determine promising Behaviour Change Techniques (BCTs). The chapter begins with a full description of the BCW method, followed by each step in the process as it was applied in this project. After the promising BCTs are identified, this chapter continues by presenting the procedure and results of a novel method of mapping game elements from literature to the BCTs. The chapter concludes by listing the game elements considered for inclusion in the Serious Game.

Chapter 5 describes the *game design* by presenting the development process that went into combining the game elements from Chapter 4 into a Serious Game. The chapter begins by describing the prototypes that were developed initially, before explaining the functionality of *Energy Explorer*, the game that was ultimately fully realised. After this, a description of the system architecture to enable the game to react directly to energy usage as recorded by a smart meter.

Chapter 6 describes in detail the *deployment* of the intervention designed and developed in Chapters 4 and 5. The chapter first details the pilot experiment, and the resultant changes to the intervention based upon expert feedback. Then, the experiment process is described in terms of the activities participants undertook: registration, the entry survey, playing the game, and the exit survey. The specific data sources are explored in more detail in this section.

Chapter 7 presents the *results* of the main experiment, specifically exploring energy consumption, game usage, and survey responses.

Chapter 8 contains an in-depth discussion of the challenges involved in the design and implementation of the Serious Game. Recommendations are made, and the chapter concludes by summarising the challenges and the associated recommendations.

Chapter 9 addresses the sub-research questions and synthesises the information to answer the main research question.

Appendix A presents a more detailed description of the internal and external validity of the research design for the main trail phase of this project.

Appendix B presents the results of the optional Theoretical Domains Framework, which is an extended stage of the Behaviour Change Wheel methodology, which has been omitted from the main text for space reasons.

Appendix C lists the game elements that were determined as a result of the brainstorming process described in Section 4.3. Further to this, the considered mobile games and implemented prototypes as part of the Serious Game selection process are described in detail in Appendix D, and Appendix E provides further detail on unimplemented game elements from Chapter 4 in the context of how they would have been implemented in *Energy Explorer.*

Appendix F describes the game elements from *Energy Explorer* for which metrics were recorded, and a summary of the results of how these elements were used is presented in Appendix G.

Appendix H presents the questions used in the exit survey, and observed results of that survey in full.

Appendix I describes the resources that players could collect in *Energy Explorer*, and Appendix J presents three examples of quest dialogue included in the game. The checklist items players were tasked to complete are listed in Appendix K.

The system architecture used to facilitate *Energy Explorer* in terms of the database schema, and extant Web Application Programming Interface commands are listed in Appendix L.

A full comparison of the participant pool compared to those who accepted the invitation to play the game is described in Appendix M. Finally, the recruitment materials used as part of the invitation and registration process are presented in Appendix N

# 2 Literature Review

This chapter introduces the topic of the thesis; video games. More specifically, this project explores the area of *Serious Games*—video games which are designed for non-entertainment purposes. After first introducing the concept of video games in general, this chapter explores how video games (through a *Ludification of Culture*) have given rise to an entire field of study within academia on how video games can be used for serious, non-gaming purposes—most notably in the areas of Serious Games and Gamification.

While there have been many successful examples of Serious Games and Gamification, this chapter will show that these types of studies are still in their infancy, and there are many limitations and criticisms about both—in particular a lack of psychological basis, and the use of a common formula of game elements (predominately points, badges, and leaderboards).

These limitations stand to diminish the potential results of Serious Games, which is significant given the application spaces seen thus far. An opportunity exists, then, to test the use of behaviour change theory to improve the design of Serious Games.

In order to test this, a particular application domain is needed to focus the design by providing a purpose for the Serious Game. Among the many domains that Serious Games have been used in, a prominent one with many examples to draw upon is that of *energy conservation*. Thus, after the introduction to video games, Gamification, and Serious Games, this chapter then continues by providing a review of the literature on residential energy conservation behaviour change. It then marries energy conservation with the concept of video games; reviewing previous work in the area of Serious Games for energy conservation. We will see that the limitations and criticisms of Serious Games and Gamification in general are present also within the specific application domain of energy conservation, showing that there is an opportunity within the space to design and develop a Serious Game improved by behaviour change techniques.

## 2.1 Video Games

In the last few decades, many people have found fascination, inspiration, and escape in video games—which make use of technology to build upon the games we as humans have played for millennia. First coming to popularity in arcades in the 1970s with initial games such as *Pong* (Atari Inc. 1972), *Space Invaders* (Taito Corporation 1978), and *Pac-Man* (Namco 1980), video games soon made their way into the living room with home video game consoles such as the *Magnavox Odyssey* (1972), *Pong* (1975), and *Atari 2600* (1977).

Video games have come a long way since these humble beginnings, but they are still designed using many of the core building blocks that made games like Pac-Man so popular. The video games industry brings in more revenue than of movies, with an estimated $US24.5 billion in revenue from video game software and hardware (i.e. video game consoles such as the Sony PlayStation 3 and 4, and the Microsoft Xbox 360 and One) in the United States alone in 2016 (Entertainment Software Association 2017), and over $AU2.4 billion in Australia in 2015, up 20% from the previous year (IGEA 2016). To put these figures into perspective, the total revenue for movie box office sales in 2015 in the US was $US11.1 billion (Motion Picture Association of America 2015).

The stereotype that video games are only of interest to children is incorrect. The average gamer in Australia is now 33 years of age (up from 24 in 2005), with over 98% of households with children having video game devices (IGEA 2016). Additionally, players interact with games frequently, in Australia averaging 88 minutes over 3 sessions daily (IGEA 2016).

These figures in the commercial games industry are mirrored by a similar increase in interest in the academic community. As this section intends to show, video games are becoming an established part of academia, with Universities offering video game degrees and majors and a number of academic journals and conferences dedicated to video games being run for many years now.

Research on video games has not only looked at how to improve the hardware and software used by commercial video games which traditionally have the purpose of entertainment, but also looked into using the success of video games to deliver value in non-entertainment, non-gaming contexts through means such as Gamification (Deterding et al. 2011), and Serious Games (Abt 1970). As this section will show through examples, these have had an impact in a number of areas, including, but certainly not limited to, education, training, therapy, scientific discovery, and energy conservation. The potential value of video games for delivering non-entertainment benefits is echoed in the wider community. A survey by the IGEA (2016) found 89% of Australian respondents thought video games could help improve thinking, and 61% thought video games could help fight dementia.

The integration of video games into our daily lives not only for entertainment, but also for serious purposes, can be described as a *Ludification of Culture* (Raessens 2006; Koorevaar 2012). Ludification of Culture refers to how play is becoming a fundamental aspect of our lives

(Koorevaar 2012). Essentially it is no longer a jarring experience to see game-like elements in non-gaming contexts, and we are now beginning to see the ways we can leverage the power of video games to enhance these contexts by improving motivation, maximising engagement, and driving behaviour change (Raessens 2006; Koorevaar 2012).

This section examines the elements of this Ludification of Culture in detail, by first reviewing the literature on gaming and video games in general, before narrowing-in on the specifics of Gamification and Serious Games, and an analysis of what this all means in the context of a *ludified* (or Gamified) culture, through the use of examples. We will see however, that many current implementations of Serious Games and Gamification are lacking a psychological basis—particularly when trying to bring about behaviour change. This section will show that there is a need for improved Serious Game design through the use of psychological theory.

### 2.1.1 Games and Play

People have been partaking in games for millennia, with some evidence suggesting the concept of sport (a type of game) to have existed even for cavemen over 17,000 years ago (Aujoulat 2005). An early and often-cited definition of games is by Callois (1958), who stated that games are activities that must satisfy the following criteria:

- the activity is *fun*;
- *separate*: the activity takes place within the bounds of a certain time and place;
- the outcome of the activity is *uncertain*, and unpredictable;
- *non-productive*: the activity does not accomplish anything;
- governed by *rules*; and
- the activity is *fictitious,* and the participants are aware that the game is separate to reality.

Callois' criteria are still used today to describe games. However, the criteria that an activity should be *non-productive* in order to be a game does not hold when one considers *Serious Games* or *games with a purpose*, which are covered later in this chapter. As we will see, games *can* in fact accomplish productive things, such as discovering new proteins (University of Washington 2008), or improving search engines (Von Ahn & Dabbish 2004).

Most definitions of games agree that games are bound by rules and processes, such as the one provided by Juul (2005) which states that games are *"rule-based formal systems* […] *with variable and quantifiable outcomes* […] *where the player exerts effort in order to influence the outcome"* (Juul 2005, pp.6–7), or the definition of Salen & Zimmerman (2006): *"A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome."* It is clear that one of the main requirements for something to be a game is that the activity has clearly defined rules and boundaries. To make an example of one of a classic non-video game, *Tic Tac Toe*, all of Callois' requirements are met.

- the activity is *fun* (although arguably this is not the case as many do not find the game challenging);
- the activity takes place within a distinct set of *boundaries*, with 9 distinct spaces arranged in a 3x3 grid, usually on a piece of paper;
- with a human element, the outcome of the activity is not *certain* (ignoring any dominant strategies related to being the first player);
- the activity is *non-productive* since the outcome of the game does not accomplish anything;
- the activity is governed by a number of *rules* (two players; alternating turns where players place pieces within the boundaries of the game; pieces can only be placed in empty spaces; and a winner is determined if any row, column, or the two diagonals in the play area are filled with pieces from one of the two players); and
- the activity is *fictitious* and has no bearing on anything beyond the boundaries of the activity.

A much simpler definition of a game is given by Maroney (2001):

> *"A game is a form of play with goals and structure"* (para. 2).

The *quantifiable outcomes* described in the Salen & Zimmerman (2006) and Juul (2005) definitions are related to the concept of *goals*, and *structure* can refer to the concept of *rules* and *boundaries*.

While this definition has been criticised for not explicitly stating that a game is an activity (Waern 2012), Maroney (2001) touches on the concept of playing, a term which is very much related to, but distinct from, the concept of gaming. Although play was first defined by Huizinga (1949) in his important work "homo ludens", the difference between the two is perhaps best explained by the continuum of play forms by Caillois (2001):

- *ludus (or "gaming"):* play which is structured by rules; and
- *paidia (or "playing"):* play which is more spontaneous, free-form, and expressive.

According to Caillois' continuum, it is this aforementioned introduction of structure and rules that turns playing (*"a free activity standing quite consciously outside 'ordinary' life* [and is] *'not serious'"* (Huizinga 1949)) into gaming.

The concepts of gaming and playing have been an integral part of the way humans operate for millennia (Caillois 2001). As the prevalence and availability of computers began to rise in the latter half of the 20th century, a new medium through which gaming and play could be achieved was realised: computer games, or the more general term, *video games*. This research focuses on this type of game in particular, although many of the concepts discussed throughout the thesis could be abstracted to a non-technology-aided form of gaming. The following section looks at this form of gaming in detail.

### 2.1.2 Video Games and the Ludification of Culture

In the 1970s, technological advancements in computing allowed a new form of gaming to emerge: games that could be played on arcade machines, and on computers. Building upon the early popularity of games like Pac-Man (Namco 1980) and Space Invaders (Taito Corporation 1978), the video game industry has grown, and in 2016 in the US alone consumers spent over $US24.5 billion on games content, hardware, and accessories (Entertainment Software Association 2017).

In recent years, the industry's growth has been accelerated, with advances in areas such as mobile technology, and social networking (Raessens 2006). Games are able to become pervasive in nature as a result of the recent rise in popularity of mobile games. As of March 2016, games are the largest category on the Apple App Store, making up 22% of all apps (Statista 2016) and according to the Entertainment Software Association (2016), 36% of games in the United States use smartphones for gaming. Interaction between players and their social groups has been enabled via support from huge social networking services (SNSs) such as Facebook and Twitter implementing Open Application Programming Interfaces (Open APIs) that interface with their massive databases of users, as well as the introduction of game-specific SNSs such as Steam (Valve Corporation), Origin (Electronic Arts), and Battle.net (Blizzard Corporation). Game experiences are now tied much more closely to social networking (Wells et al. 2013), as well as the web browsing experience itself.

Entertainment video games are not the only type of game to have been successful. There is also an increasing amount of interest in games for non-entertainment, and non-gaming purposes. This popularity of video games, and their increasing pervasiveness in non-gaming areas, is enabling what some are calling a *Ludification of Culture* (Raessens 2006; Koorevaar 2012) (note the term *ludification* refers to the Latin *ludus* for gaming as described earlier, and is not to be confused with *luddites*). This term refers to the phenomenon whereby games are becoming increasingly pervasive and ubiquitous (Koorevaar 2012). In the last decade or so, this has led to a surge in video game research, so that we may better understand this phenomenon and the games at the centre of it. The next section provides an overview of the state of video game research.

### 2.1.3 Video Game Research

Similar to the increased prominence of the video games industry described previously, research into video games matured, with the topic garnering significant interest from the academic community in the past decade. Although publications on video games had been around for some time, it was not until 2001 that a peer-reviewed academic journal devoted entirely to the research of computer games—appropriately titled *Game Studies*[1]–surfaced (Aarseth 2001). The Editor-in-Chief of the inaugural issue of *Game Studies*, Espen Aarseth, declared 2001 to be *Year One* of video game studies and predicted the importance of the field in the future, noting the cultural and social, communicative and cognitive, and aesthetic significance of computer games compared to other media such as movies and music. 2001 also marked the year of the first international scholarly conference on computer games, *Computer Games & Digital Textualities* (DDCA 2001).

Before 2001, studies on computer gaming only came from prominent publications not dedicated to video games such as *Simulation & Gaming*[2], *Digital Creativity*[3], *Computers and Education*[4], and the *International Journal of Human-Computer Interaction*[5] to name a few.

Aarseth (2001) asked the question of whether a new discipline for video games should be forged, or if researchers should try to *"claim the field for* [their] *old discipline"*. Nearly 13 years on from asking this question, video game studies remain mostly multidisciplinary, with studies being undertaken from psychological, sociological, anthropological, and technological standpoints among many others. Since *Game Studies*, more journals in the area of video games have emerged, such as *Games and Culture*[6], *Eludamos Journal for Computer Game Culture*[7], and *Journal of Gaming and Virtual Worlds*[8]. Similarly, academic conferences either devoted entirely

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[1] http://www.gamestudies.org/

[2] http://www.sagepub.com/journals/Journal200777

[3] http://www.tandfonline.com/loi/ndcr20

[4] http://www.journals.elsevier.com/computers-and-education/

[5] http://www.tandfonline.com/toc/hihc20/current

[6] http://gac.sagepub.com/

[7] http://www.eludamos.org/

[8] http://www.intellectbooks.co.uk/journals/view-journal,id=164/

to computer games, or special topics for computer games have become more frequent, such as *CGames*[9], *Philosophy of Computer Games*[10], and *DIGRA*[11]. The analysis of the content of *Simulation & Gaming* by Hill & Rodrigo (2012) found that 20% of the top 40 cited papers as of 2011 were on the topic of *video games*—the second highest percentage behind the topic of education (35%).

Video game research has helped improve traditional entertainment-based video games both in software and hardware, however a plethora of research has also focussed on video games situated within non-gaming contexts—*Gamification*—and games for non-entertainment purposes—*Serious Games*. While there are differences between the two (which will be explored later in this chapter), they are referred to collectively as *Games for Change* throughout this work.

Games for Change have witnessed an increase in interest recently, with many conferences (such as *Games For Change*[12], *Serious Play*[13], *Serious Games Summit*[14], *GSummit*[15], *Gamification World Congress*[16], *Serious Games Development & Applications*[17], *Gamification 2013*[18]), and journals (*International Journal of Serious Games*[19], *JMIR Serious Games*[20]) dedicated to the subjects, as well as special issues from a number of publications (*Computing and Cultural Heritage*[21], *Information Sciences*[22], *Creativity and Innovation Management*[23], *Computers in Human Behavior*[24], *Information Technology and Management*[25], *Screencity*[26]).

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[9] http://cgamesusa.com/

[10] http://gamephilosophy2013.b.uib.no/

[11] http://dm.lmc.gatech.edu/digra2013/

[12] http://www.gamesforchange.org/

[13] http://www.seriousplayconference.com/

[14] http://www.seriousgamessummit.com/

[15] http://sf14.gsummit.com/

[16] http://www.gamificationworldcongress.com/

[17] http://ddsgsa.net/sgda/

[18] https://uwaterloo.ca/gamification/

[19] http://journal.seriousgamessociety.org/

[20] http://games.jmir.org/

[21] http://jocch.acm.org/?q=seriousgames

[22] http://ispr.info/2012/08/13/call-information-sciences-special-issue-on-serious-games/

[23] http://steffen-roth.ch/2012/12/14/cfp-to-a-special-issue-of-creativity-and-innovation-management/

[24] http://edulearning2.blogspot.com.au/2014/02/computers-in-human-behavior-special.html

[25] http://www.inderscience.com/info/ingeneral/cfp.php?id=1887

[26] http://www.digra.org/cfp-playing-life-gamification-beyond-gaming-special-issue-of-screencity-journal/

There is clearly an interest in this application of video game technology in the form of Games for Change, and there are a wide range of avenues for research in many disciplines. The following sections explore previous examples of studies in these areas.

### 2.1.4 Games for Change

Many studies have attempted to leverage the motivational pull of video games to accomplish things other than pure entertainment or fun. Broadly speaking, these games try to change the behaviour or attitudes of their players, or in some cases attempt to accomplish some other non-gaming outcome through the action of playing the game, hence the categorisation of *Games for Change*. The two main schools of thought for developing Games for Change are Gamification and Serious Games, and these are the focus of this section.

After looking at Gamification and Serious Games specifically, the limitations and criticisms of current work in this area are explored, with a particular focus on the lack of psychological theory used in the design of the games, the limitations of the motivational theories that have been applied in video game research, and some frameworks which have been established to guide researchers and developers in this area.

#### *2.1.4.1 Gamification*

Gamification, in essence, is the use of game elements in non-gaming contexts. Despite being a relatively new term (with first documented use being in a blog post by Bret Terrill (2008)), and being mostly associated with digital platforms, the idea of turning something ordinary or mundane into a game is timeless. A common example that many may relate to is as a child, turning a walk home from school into a game by not stepping on the cracks, pretending certain pieces of pavement are lava, or other numerous variants that young minds can devise.

As the following section will show, there are a number of somewhat conflicting definitions of Gamification, and the purposes and implementations of the Gamification are different depending on which definition you use, and there is quite a strong debate over this. Following a review of definitions, a number of examples are presented.

##### 2.1.4.1.1 Definitions

Even though the term is new, there are surprisingly few definitions offered by scholars on the topic and, when examined, these definitions are found to be conflicting. Huotari & Hamari (2011) define Gamification as:

> *"a form of service packaging where a core service is enhanced by a rules-based service system that provides feedback and interaction mechanisms to the user with an aim to facilitate and support the users' overall value creation"* (p. 5).

While games are *"rule-based formal systems"* (Juul 2005, p.6), the use of the term here is perhaps too broad, allowing the definition to cover a wide range of service "enhancers" and indeed Huotari & Hamari (2011) themselves include loyalty stamp cards as an example, alongside progress bars, and the concept of "mayorship" as seen in the commonly used Gamification example *Foursquare*[27]. In order to clarify what they mean by "game elements" they are careful not to limit their definition by referring to elements or building blocks which are *specific* to games, or ones that are found in *any* game, but to those *characteristic* of games—something which they admit is very much a "heuristic definition with much room for debate over what is 'characteristic' for games" (p. 12).

Zichermann (2011) defines Gamification as the process of

> *"using some elements of game systems in the cause of a business objective".*

However, it can be seen that the most prominent "elements of game systems" referred to here are points, badges, and leaderboards (also known as the *PBL triad* (Werbach & Hunter 2012)). As we will see, these interface-level design elements are not yet proven for positive long-term effects on users. Taken on face-value, and ignoring the specifics of what is meant by *"elements of game systems"*, this definition is still poor due to the addition of the phrase *"business objective"*—which constrains the term to be business-centric, rather than user-centric by aligning goals with that of the business and perhaps highlights a potential bias of Zichermann in wishing to use the term Gamification as a marketing buzzword. Zichermann's definition, and the Gamification implementations stemming from it, has drawn some criticism, as will be seen later in this chapter in Section 2.1.4.3. This definition differs to Huotari & Hamari (2011), which is about enhancing a service's value for the customer, not necessarily for the company.

Where the Huotarai & Hamari and Zichermann definitions fall short is that they limit the possibilities of what Gamification can achieve by assuming too much about the intended outcomes and common implementations, although in this regard, Huotari & Hamari (2011) may be forgiven since their definition is grounded in *service dominant logic*.

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[27] It should be noted that in 2012, *Foursquare* removed its Gamification elements, to focus more on its function as a recommendation system Bea (2012).

Instead, a more concise and not as limiting definition is provided by Deterding et al. (2011), who describes Gamification as:

> *"the use of game design elements in non-game contexts"* (p. 9).

While this definition may seem simple at first, further investigation into how it was formulated shows it to be well thought-out and clearly worded, while simultaneously avoiding restrictions related to business- or user-centred approaches.

Deterding et al. (2011) provide further insight into Gamification as they situate the term amongst similar parallel ideas within the concept of Ludification of Culture such as Serious Games and pervasive games described previously (see Figure 1). Whereas Serious Games are typically fully-fledged games in a non-gaming context, and pervasive games can be considered extensions of games, Gamification instead makes use of game elements, rather than a full "game proper".

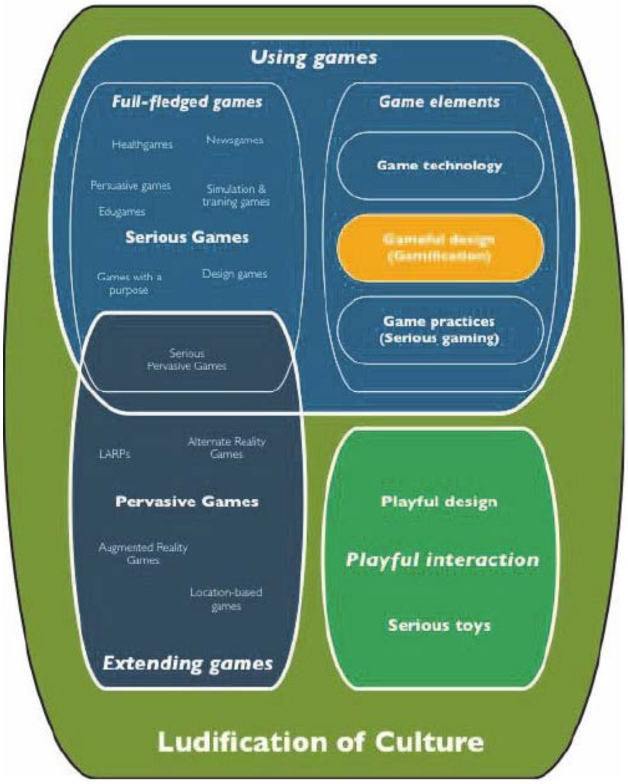



**Figure 1. Placement of Gamification in the field of Ludification of Culture (taken from Deterding et al. (2011, p.13)).**

Perhaps a more prominent distinction in Deterding et al.'s definition than their description of full-game versus game elements is that Gamification relates to *game,* not *play*. This distinction reflects the two ends of the continuum of play forms by Caillois (2001), mentioned earlier.

The following sections explore a number of systems that exemplify Gamification. We will see through these examples that these systems are just that—systems—rather than full games proper. As a result, the examples shown have a clear theme of relying on some standard Gamification "game elements": points, badges, and leaderboards.

#### 2.1.4.1.2 Nike+

Frequently used examples of Gamification include *Nike+* (2006), which records the distance and speed of walking or running activities, and interfaces with the user's mobile phone to provide feedback on walk or run history, as well as providing goals for the user to achieve. The mobile phone application presents a leaderboard to the user, comparing the user to their friends in terms of the number of miles ran, or speed achieved. The application also awards badges for reaching certain milestones. Additionally, players can create challenges for themselves and their friends to reach a certain distance after the challenge is published (Figure 2).

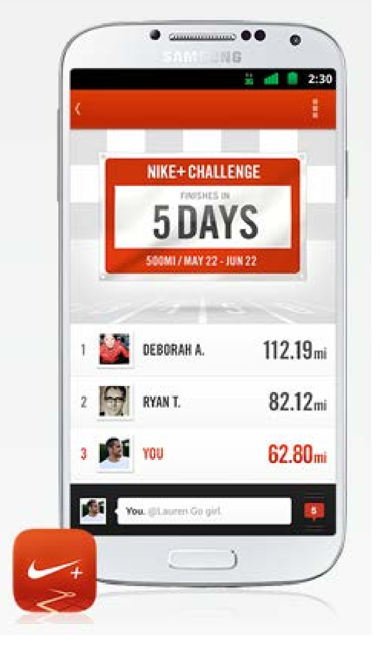


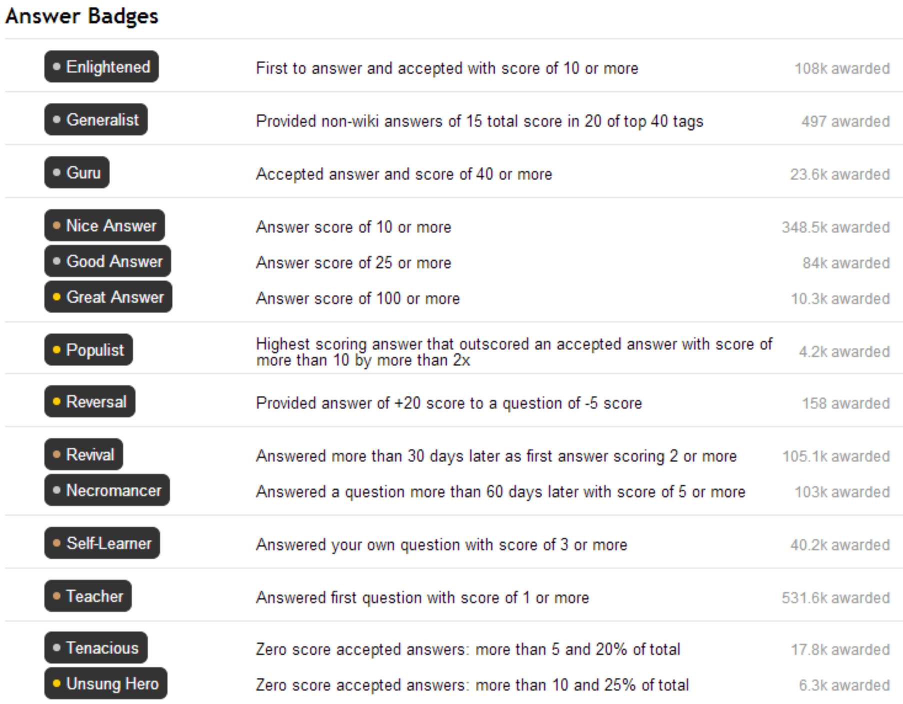

**Figure 2. The Nike+ mobile phone application, showing a challenge leaderboard[28].**

#### 2.1.4.1.3 StackOverflow

Many systems, including websites, have incorporated badges and achievements. A prominent example of this is the programming help website *StackOverflow*. Users are given goals to earn badges of differing values (gold, silver, bronze), for completing tasks that the site owners

[28] https://secure-nikeplus.nike.com/plus/products/gps_app/

would like to see users complete, such as answering questions (see Figure 3), asking questions, participating, and moderating. Whenever a user's name is displayed on the site, their total number of badges of each of golf, silver, and bronze, is listed next to their name, allowing users to display their achievements on the site, and for others to perhaps determine some level of reputation for each user.



**Answer Badges**

| | | |
|---|---|---|
| Enlightened | First to answer and accepted with score of 10 or more | 108k awarded |
| Generalist | Provided non-wiki answers of 15 total score in 20 of top 40 tags | 497 awarded |
| Guru | Accepted answer and score of 40 or more | 23.6k awarded |
| Nice Answer | Answer score of 10 or more | 348.5k awarded |
| Good Answer | Answer score of 25 or more | 84k awarded |
| Great Answer | Answer score of 100 or more | 10.3k awarded |
| Populist | Highest scoring answer that outscored an accepted answer with score of more than 10 by more than 2x | 4.2k awarded |
| Reversal | Provided answer of +20 score to a question of -5 score | 158 awarded |
| Revival | Answered more than 30 days later as first answer scoring 2 or more | 105.1k awarded |
| Necromancer | Answered a question more than 60 days later with score of 5 or more | 103k awarded |
| Self-Learner | Answered your own question with score of 3 or more | 40.2k awarded |
| Teacher | Answered first question with score of 1 or more | 531.6k awarded |
| Tenacious | Zero score accepted answers: more than 5 and 20% of total | 17.8k awarded |
| Unsung Hero | Zero score accepted answers: more than 10 and 25% of total | 6.3k awarded |

**Figure 3. A selection of *StackOverflow* badges[29].**

A preliminary study by Anderson et al. (2013) looked into the behaviour changing effects of adding these badges to the site. The study found an interesting trend in the behaviour of users in the time leading up to, and after, the earning of a badge. They found that users *steered* their behaviour based upon badges they were close to earning. Anderson et al. (2013) measured activity of the users around the time they earned a badge, and plotted the frequency of actions relative to that time. They then averaged these frequencies together and plotted them on a relative time scale. An example of this is shown in Figure 4 for the *Electorate* badge, which was awarded for voting up or down questions posted on the site. It is clear that the number of questions voted for/against raised dramatically in the days leading up to earning the badge, and then dropped off significantly once it was earned. This was repeated for essentially all the other badges where this could be measured easily (i.e. badges for question

[29] http://stackoverflow.com/help/badges

asking/answering/voting), and indicates that the badges have a meaningful, though only short-term, effect in promoting certain behaviours.

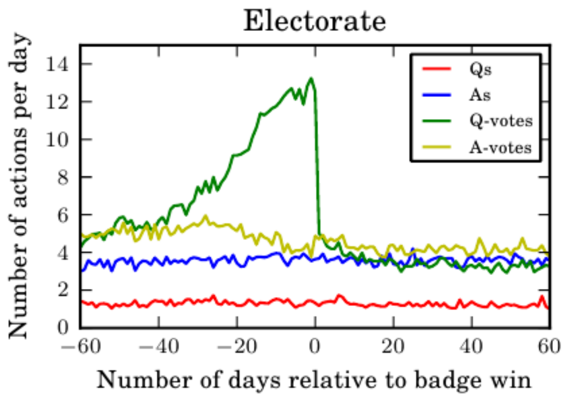



**Figure 4. A graph of the effect of the *Electorate* badge on StackOverflow, showing the average number of relevant actions (questions asked and answered, and questions voted on, answers voted on) per day that a user who earned the badge did. The "electorate" badge centred on voting on questions and it is clear that in the days leading up to the earning of the badge, users focussed or *steered* their behaviour, but this increase was not sustained after winning the badge.**

##### 2.1.4.1.4 FourSquare

Another PBL implementation of Gamification is the addition of badges to the Social Networking Service/check-in service *FourSquare*, however most of these features were removed in 2012 so that the company could focus on its function as a recommendation system (Bea 2012). Badges were earned by reaching milestones such as checking-in a number of times for a particular location or location type (i.e. coffee shop, or park). FourSquare also provided leaderboards to rank users in terms of the frequency of their visits, such that the most frequent visitor is declared "the Mayor" of that location.

##### 2.1.4.1.5 Summary of Gamification Literature

Gamification is the use of game elements in non-gaming contexts. There are competing definitions from a number of authors, based upon differing expected outcomes and applications of Gamification. This section has looked at these definitions and compared them.

A number of Gamification examples have been shown, and a common trend is their heavy reliance on points, badges, and leaderboards—a criticism which is explored later in this chapter. This reliance is perhaps a result of the fact that Gamification systems are not intended to be whole games, but rather systems that make use of game elements. An alternative approach to Gamification is Serious Games which refer to fully-fledged games proper for non-entertainment purposes. The following section examines Serious Games in detail.

#### ***2.1.4.2 Serious Games***

As previously mentioned, the video game industry is primarily entertainment-focussed. However, in the area of video game research, a plethora of work exists on applying games for non-entertainment purposes. These purposes can be situated within essentially any domain. Examples include education (Ke 2012; Emam & Mostafa 2012), training (Nieborg 2004; United States Army 2002; Fitz-Walter et al. 2011; Fitz-Walter et al. 2013; Bindoff et al. 2014), therapy (McGonigal 2012), health (Edgerton 2009), improving web services (Von Ahn & Dabbish 2004), scientific discovery (Khatib, Cooper, et al. 2011; University of Washington 2008), and energy conservation (Brewer et al. 2011; Geelen et al. 2010; Gustafsson et al. 2009). According to Wouters et al. (2009), Serious Games have the potential to improve cognitive skills, acquisition of knowledge, and acquisition of fine-grid motor skills, and to bring about attitudinal change.

There is however, some contention over the exact definition of a Serious Game, and it is important to identify the working definition for the thesis, and how it was determined. Following a review of definitions and origins of the term Serious Games, a number of examples are presented.

##### 2.1.4.2.1 Definition

Many attribute the concept of *Serious Games* to Clark Abt in his book titled *Serious Games* (Abt 1970), where—despite a focus on mostly board and card games—he defined Serious Games as those which:

> *"have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement"* (p. 9).

This definition tends to limit the scope of Serious Games to the educational domain. Whilst many Serious Games are developed for the purposes of education and training, they can also be used for advertising, simulation, health, or even "*for experience or emotion*", and indeed there are a large number of conflicting descriptions in the literature (Marsh 2011). As Sawyer (2007) of the *Serious Games Initiative* points out, "*too often Serious Games is defined only as that which the definer does*", thereby "*ignoring the larger possibility space for Serious Games*" (Sawyer & Smith 2008, p.10).

A similar failing to that in Abt's definition is found in the definition by Zyda (2005), who defines a Serious Game as:

> *"a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives" (Zyda 2005, p.26).*

While this definition lists a number of applications for Serious Games, Zyda's work is predominately in the area of education and training—which is evident in his differentiation between games and Serious Games that "*unlike their entertainment-only counterparts Serious Games use pedagogy to infuse instruction into the gameplay experience*" (Zyda 2005, p.26).

The Zyda (2005) definition also makes use of the term "*entertainment*"—a word seen in the majority of definitions of Serious Games—and indeed it seems that a common theme among definitions is that Serious Games are those games which are used for purposes other than entertainment (Susi et al. 2007). This is reflected in the definition by Michael & Chen (2005), who stated that Serious Games are

> *"games that do not have entertainment, enjoyment, or fun as their primary purpose"* (p. 21)

as well as the definition by Susi et al. (2007):

> *"games that engage the user, and contribute to the achievement of a defined purpose other than pure entertainment (whether or not the user is consciously aware of it)"* (p. 5).

The definition by Susi et al. (2007) adds an element of engagement, but also the important idea that Serious Games can work towards achieving a goal without the user necessarily being aware that it is happening—perhaps as the result of being distracted by the entertainment aspect of the game. This allows users to think of the task at hand in a different way. An example of this is provided below, in the form of *FoldIt* (where players are playing a puzzle game, but protein information is being collected, and new algorithms are being learnt).

As we have seen with the previous definitions, the concept of entertainment has been used in almost all definitions as a point of differentiation between Serious Games and traditional games (entertainment games). Marsh (2011) argues that while some Serious Games may still provide entertainment, it is not a requirement of a Serious Game—it is worth noting that this is in contradiction to the Zyda (2005) definition above which values the entertaining abilities of games, in fact going so far as to say that "the entertainment component comes first" (Zyda 2005, p.26) when designing a Serious Game, rather than entertainment. Instead, Marsh (2011) lists other characteristics that are just as important as entertainment—stating that a game can be "*thought-provoking, informative, awareness-raising or stimulating*" (p. 2). As a result, the focus on terms such as *entertainment*, *fun*, *enjoyment*, and *amusement* in previous definitions—according to Marsh (2011)—makes them inadequate to cover the scope of all Serious Games such as ones which are designed to evoke some kind of *experience* or *emotion* from the player. Marsh (2011) also takes issue with some definitions and their use of the concept of *play*. As Huizinga (1949) states, *play* is voluntary, and Serious Games may in fact violate voluntariness, since in some cases it is a requirement that the users (e.g. students or trainees) play the game in order to complete their training or course (Susi et al. 2007; Marsh 2011). Building upon this idea, Susi et al. (2007) argue that even traditional entertainment games—or *commercial off-the-shelf* (COTS) games—can be considered Serious Games if used for non-entertainment purposes. As an example, the game of chess—which is an entertainment game—can be used for strategic skill training for military personnel (Susi et al. 2007).

Unsatisfied with previous definitions and the limitations on the possible applications of Serious Games including experiential games, Marsh (2011) provides his own definition, complimented by a *Serious Games continuum* which situates games based upon the amount of gaming characteristics they exhibit on a range between *games for a purpose*, through to *experiential and experimental environments with minimal to no gaming characteristics for purpose*. Marsh (2011) defines Serious Games as:

> *"digital games, simulations, virtual environments and mixed reality/media that provide opportunities to engage in activities through responsive narrative/story, gameplay or encounters to inform, influence, for well-being, and/or experience to convey meaning" (Marsh 2011, p.3).*

The Marsh (2011) definition is useful in it provides a number of technologies that Serious Games can take the form of (i.e. simulations, mixed reality, etc.). He goes on to provide a simple way of describing how the success or quality of a Serious Game can be measured—that is "*the degree to which the purpose has been fulfilled*" (p. 3).

The serious *purpose* of Serious Games is what sets them apart from entertainment games. This purpose can vary greatly, despite being dominated by educational and military applications, and indeed the bounds of "seriousness" is often contested. As the abundance of *digital-game natives*[30] increases, so should the range of applications and markets for which Serious Games will be accepted as a viable option.

[30] This term refers to people who have grown up with digital games and are highly familiar with them.

Still, attempts have been made to categorise Serious Games, such as that of Zyda (2005) who list the application domains of *health*, *public policy*, *strategic communication*, *human performance engineering*, *education*, and *game evaluation*. This is similar to the categories described by Michael & Chen (2005) who identify the following markets: *military games; government games; educational games; corporate games; healthcare games;* and *political, religious, and art games*.

Perhaps the most extensive categorisation of Serious Games is that by Sawyer & Smith (2008) who developed a taxonomy identifying seven different purposes, and applied them to seven different markets similar to that of Michael & Chen (2005): g*overnment and NGO*, *defence, healthcare*, *marketing and communications*, *education*, *corporate*, and *industry*. The identified purposes (with some examples in various markets) were:

- *games for health*: such as *exergaming*, and occupational safety training;
- *advergames (games for advertising)*: such as games for promoting political candidates, product placement, and games about products;
- *games for training*: games which train employees, or train people on the use of a product;
- *games for education*: games for learning, and games which can inform the public on various issues;
- *games for science and research*: such as games which collect data, or games for visualisation;
- *production:* games which are used for creation, such as *Machinima*, and policy planning;
- *games as work:* games which enable *command & control* which can translate into actual work being completed.

Applying these purposes across the different markets they identified, the Sawyer & Smith (2008) taxonomy identifies 49 different categories of Serious Game (selected by choosing market and purpose). This can make the taxonomy somewhat cumbersome, despite its completeness.

In order to better explain what constitutes a Serious Game (although some definitions have stated any game at all can be a Serious Game as long as it is being *used* for serious purpose, even if it was not necessarily *designed* that way) the following sections provide some examples from various areas covering training and education, scientific discovery and algorithm improvement, image labelling and meta data collection, and health and exercise.

##### 2.1.4.2.2 America's Army

Serious Games have made a great impact on how people are trained for certain tasks. Through the use of these games, players are able to be trained in ways which would not be practical or possible in the real world since the activity is either too unsafe, costly, or time consuming. A popular example of this is the *America's Army* video game that is funded by and developed by the United States Army (United States Army 2002). Originally released in 2002 utilising the popular video game engine *Unreal Engine* by Epic Games, *America's Army* is a first-person shooter game designed with the purpose of providing to "the public a virtual Soldier experience that was engaging, informative, and entertaining" (McLeroy 2008). It is interesting to note that part of the purpose of the game was to be entertaining, however it does not appear to have been the primary or sole purpose—something that is in line with many of the provided definitions of Serious Games.

*America's Army* has a number of purposes, such as being a strong recruitment tool for new soldiers—to the extent that it has been criticised as being a propaganda device (Nieborg 2004; Delwiche 2007). The game is free to play (which is made possible through financing from the United States government); allowing many prospective new recruits to play it, and is promoted at a large number of events around the country. Further to this goal of recruitment, the game is heavily coupled to the *Go Army* recruitment website.

As the complexity of the game and possibilities provided by the game engine technology increased, the game became suitable as a training device, with the *America's Army* platform being used by other U.S. government departments such as the Secret Service producing training applications. According to Zyda (2005), the training simulation provided by *America's Army* was highly effective, stating, "*soldiers who played the rifle range segment of the game, for example, earned improved scores on the real-life rifle range*" (p. 27).

###### 2.1.4.2.3 Pharmacy Simulator

Another example of a Serious Game for training is *Pharmacy Simulator* (Bindoff et al. 2014), which was designed to teach University-level students pharmacy practice by presenting a wide range of scenarios in a virtual environment. The system was designed to be flexible, allowing educators to easily script new scenarios in a text format without the need for programming knowledge. Students control an in-game avatar in a 3D pharmacy environment (Figure 5), acting as a pharmacist, and are able to interact with objects and characters in the environment. The students engage in dialog with fictional characters, choosing from a range of pre-set questions and statements to which the patient responds. Players need to find medicine and other objects in the environment in order to complete scenarios, as well as navigate social aspects such as nervous or suspicious patients. The game even includes a robbery scenario.


**Figure 5. The *Pharmacy Simulator* game, featuring 3D graphics, and character dialog[31].**

The game excels in the Serious Games domain in that the graphics and gameplay functionality mirror that of a traditional entertainment game, and is indeed developed using the same tools (Unity[32]) used for many entertainment games. As a result, students found fun and enjoyment out of using the simulation, however the authors note that further development of the scenarios was needed in order to obtain significant improvements in knowledge acquisition (Bindoff et al. 2014).

#### 2.1.4.2.4 FoldIt

*Games With A Purpose* (GWAP) are a branch of Serious Games which are focussed on human-based computation (Von Ahn 2006). This distinction is somewhat confusing, since otherwise the term GWAP could easily be interpreted to cover any Serious Game that is not just for the purpose of computation. GWAP use the concept of human-based computation where developers and researchers take advantage of the human mind's advanced ability for particular computations like pattern matching, aesthetic evaluation, and problem solving in the context of a game—often with the help of crowd techniques to take advantage of collective human knowledge and ability.

One of the best examples of a GWAP is the game *FoldIt* (University of Washington 2008), a puzzle game distributed online where players manipulate protein-structures to solve

[31] https://www.pharm.utas.edu.au/sim_platform/

[32] http://unity3d.com

complicated protein-structure prediction problems. *FoldIt* takes advantage of our 3D problem solving abilities, and uses the information gained from players to improve current algorithms used by computers for these problems (Khatib, Cooper, et al. 2011). In fact, Khatib et al. (2011), who attempted to formalize and codify strategies used by *FoldIt* players, found that the player strategy outperformed previously published methods. This work in formalizing the player strategy is important as it means that games such as *FoldIt* have the potential to not only solve problems (such as that found by Khatib, DiMaio, et al. (2011) and Eiben et al. (2012)), but to also discover new algorithms for solving problems.

*FoldIt* also used some elements that many consider to be a form of Gamification. These elements included providing a score to players of how "well folded" their protein was, a high score table for score comparisons with other players, and collaborative play opportunities.

##### 2.1.4.2.5 ESP Game and Google Image Labeller

Another commonly cited GWAP is the *ESP Game* by Von Ahn & Dabbish (2004) that has the purpose of labelling images in order to improve image searches and computer vision applications. In the *ESP Game*, players are paired and shown identical images (Figure 6) and asked to guess what the other player is typing (note they are not directly asked to describe the image). Players continue to guess until one types a word the other player had already typed—i.e. they reach an "agreement" (in the Figure 6, this was when player 2 guessed "purse"). Each player is unable to see what the other player has guessed, and both are unable to type any selected *taboo* words or plural variants. These taboo words are generated for each image where previous players had agreed on that image, and is done in order to get a wide range of labels for images and increase the challenge of the game.

The game saw excellent uptake from users, generating nearly 1.3 million labels from 13,630 players in the first four months after release (Von Ahn & Dabbish 2004) with promising results in terms of label accuracy and labelling frequency.


**Figure 6. The ESP Game, showing an example of guesses by two players on a picture of a handbag, where the tag "purse" is agreed upon as that is the first repeated word guessed (Von Ahn & Dabbish 2004).**

Google also obtained the rights to produce their own version of the game, distributed via *Google Labs*, with the purpose of improving their *Image Search* product.

##### 2.1.4.2.6 Darfur is Dying

An example of serious games used for the humanitarian purposes is *Darfur is Dying* (Figure 7; Peng et al. 2010), which aimed to provide awareness of and prompt players to take action to help Darfurnian refugees. The game accomplished this by presenting various stories (depending on the player's gender) to illustrate the real-world issues taking place. Drawing upon the data of over 800,000 players in 2006, Peng et al. (2010) measured participants willingness to help the Dafurian people (be it through donation, signing a petition, forwarding the game to other players, or participating in further discussions), and found that when compared to a piece of static content with comparable information, people who played the game were significantly more likely to take these positive actions to help.


**Figure 7. The *Darfur is Dying* serious game (Peng et al. 2010), showing an example of the messaging and gameplay[33].**

Peng et al. (2010) further compared the effect of playing the game vs simply watching it, and again found that people playing were more likely to be willing to help than those who simply watched another player. This is a particularly interesting finding (although it would be interesting to replicate this study in more recent times) given the rising popularity of consuming game media via online streams or pre-recorded gameplay videos.

It is clear that *Darfur is Dying* represents a Serious Game whole, rather than a Gamification implementation, as the entire experience itself is a game, with the serious content embedded *within* the game.

#### 2.1.4.2.7 Exergaming and Health

A popular purpose of Serious Games is that of improving the health and wellbeing of users. One way in which Serious Games can do this is by presenting exercise in the form of a video game—commonly referred to as *exergaming*. Exergaming systems have existed since the late 1980s but became popular as a result of the success of Konami's rhythm game *Dance Dance Revolution* (Konami 1998; Konami 2005) which was originally an arcade game featuring 4

[33] Image sourced from a review of the game at https://www.commonsense.org/education/game/darfur-is-dying

pressure-sensitive plates designed to be pressed by the player's feet in time with on-screen directions matching the beat of popular dance tracks, but was later ported to home consoles with a portable peripheral for the dance mat.

The concept of exergaming received further attention with the release of Nintendo's *Wii Remote* and *Wii Balance Board* peripherals accompanied by the exercise game *Wii Fit*. The Nintendo *Wii* console sold over 100 million units as of 2013 (Nintendo 2013), reaching a large range of people who had never played video games before. Microsoft and Sony produced their own contenders to the *Wii*'s exergaming peripherals, releasing the *Microsoft Kinect* and *Playstation Move* respectively.

Exergaming is not the only type of Serious Game within the health domain. While most health-related "games" are Gamification examples similar to *Nike+*, health Serious Games have begun looking at the area of smoking cessation. Building upon Gamification implementations of smoking cessation apps, *Quittr* (Bindoff et al. 2016) is a Serious Game whole with a city builder game at the core of the experience. Consecutive days not smoking, and viewing education and support resources within the app provide the player with "QuitCoins" which can be used in the city builder game to purchase or upgrade buildings.

##### 2.1.4.2.8 Summary of Serious Games Literature

Serious Games are video games with a main purpose other than entertainment. They differ from Gamification methods in that they are entire games, rather than just elements, and they are played as games proper, rather than game elements being included in the interface of a traditional website or app.

The potential of Serious Games such as the ones described previously is clear. Since the areas of Serious Games and Gamification are still quite young relative to other areas of academia, and so there are still a number of limitations to the studies in the area. This section concludes by exploring these limitations and the current criticisms of Serious Games and Gamification.

#### *2.1.4.3 Criticisms of Games for Change*

Despite several successful instances of Games for Change, there are a number of criticisms of the approaches of Gamification and Serious Games, and these are addressed in this section. The criticisms evident in the literature and presented in this section primarily focus on the design and game elements used in Games for Change: a lack of a strong psychological basis underpinning these elements, and a reliance on the same subset of commonly re-used theories. A recent editorial by Nacke & Deterding (2017) notes that Gamification research needs to mature (and is, to some degree) by focussing on more theory-driven studies, improved design methods, and broader application areas. While the criticisms presented here primarily refer to Gamification, similar issues can be seen in Serious Games, particularly when Serious Game implementations are perhaps erroneously named so, as their feature-sets are closer to Gamification.

##### 2.1.4.3.1 Design and Game Elements

Deterding et al. (2011) note that many critiques of Gamification from both industry and academic sources identify Gamified applications as being almost exclusively aligned with the *ludus/gaming* end of Caillois' (2001) continuum of play forms, as opposed to the exploratory *paidia* end.

The recent popularity of Gamification as a solution has led to the term being considered by many as a marketing "buzzword" (Boulet 2012; Edmonds 2011; Vendler 2013). The need for a term with "less baggage" (Deterding et al. 2011, p.14) for use in an academic setting is, according to Deterding et al., based upon the *"industry origins, charged connotations, and debates about the practice and design of Gamification"*.

These criticisms often stem from the most frequently used "game elements" used in Gamification. Unlike the Serious Game examples presented such as *Pharmacy Simulator* and *Quittr* which feature rich, three-dimensional environments with player avatars and complex simulation mechanics, Gamification implementations have primarily used points, badges, and leaderboards. While Deterding et al. offer five different levels of game design elements in increasing stages of abstraction (interface design patterns, design patterns and mechanics, design principles and heuristics, game models, design methods), in practice the majority of industry and academic implementations of Gamification have only focused heavily on the concrete level of interface design patterns (Deterding 2015). Examples of this level of game design element are the PBL interface elements described earlier with the Zichermann (2011) definition. While empirical research has shown in many cases that PBL may indeed increase engagement and motivation in the short term, there is little to suggest that such increases are repeated over a longer period of time (Lockwood & Kunda 1997). The demotivating effects of traditional "superstar" leaderboards has been well documented (Preist et al. 2014; Lockwood & Kunda 1997; Haaranen et al. 2014; Harper et al. 2007; Deterding 2011; Nicholson 2014; Kumar 2013; Kraut et al. 2012).

Direct parallels can be seen between the commonly used Gamification game element the *badge*, and the merit badges awarded to boy scouts for completing various tasks (of America 1912). Additionally, many (naïve) Gamification implementations where users are awarded *points* have similarities to traditional loyalty marketing schemes (e.g. "on your 10th visit to our store get 10% off your purchase" etc.)—note the *points* referred to here are the cumulative points systems found in Gamified applications, which are different to the traditional points obtained in computer games (i.e. ones which reset every time you play the game, like a *Pac-Man* score). Gamified points are generally cumulative instead—the difference being that these points better reflect *time spent* or *actions performed*, rather than *skill level* (traditional points represent a single instance of a player playing the game, instead of all of the instances). Due to these similarities between things like Boy Scout badges and loyalty marketing schemes, one might question the novelty of Gamification.

Despite this, the use of PBL is widespread. A meta-analysis of 24 empirical studies on Gamified systems by Hamari (2014) found that PBL were the most commonly found game elements, making up 66% of the reviewed papers. From an industry perspective, the implementation seems similar to that of academia with Gamification "vendors" such as *Bunchball* and *Badgeville* providing PBL solutions to organisations offering increased engagement and higher return on investment (Bunchball 2017).

The doubts surrounding the capacity of PBL to increase engagement and participation among users has stigmatised Gamification in both industry and academic circles. For instance, industry consultant Margaret Robertson (2010) has called Gamification an "*inadvertent con*", taking issue with the PBL elements, claiming that current Gamification should be instead called "*pointsification*" since:

> *"Points and badges have no closer a relationship to games than they do to websites and fitness apps and loyalty cards"* (Robertson 2010, para. 4).

Robertson's criticisms of PBL highlight the fact that while both games and obtaining points can be hard or difficult, games differ in that they are *interestingly* hard. She also states that Gamified systems lack any kind of *meaningful* choice—Gamification's PBL provide "*choices of quantity*", whereas many video games provide choices that can make significant impacts within the game. This lack of choice is then exacerbated, according to Roberston, by a similar lack of loss or failure, which produces only upward escalation in accumulation of points that ultimately have very little meaning.

This opposition to points is echoed by academic Ian Bogost (2011) in a position statement titled *Gamification is Bullshit*. Bogost takes issue with the rhetorical power of the term afforded by the *-ification* suffix stating:

> *"-ification involves simple, repeatable, proven techniques or devices: you can purify, beautify, falsify, terrify, and so forth. -ification is always easy and repeatable, and it's usually bullshit. Just add points"* (Bogost 2011, para. 10).

He claims that a term such as "*exploitationware*" would be a more accurate representation of Gamification implementations at the time, stating that Gamifiers are merely taking advantage of the mystery and complexity of games, and the hype built up around the term, only to provide questionable results that "*last only long enough to pad their bank accounts before the next bullshit trend comes along*"(Bogost 2011).

But Bogost does end his statement with a brief caveat that there are people out there who consider games to be more than just "*an affirmation of existing corporate practices*", referring to these people as "*leaders*". One such leader in this regard is Sebastian Deterding, from whom the most well -regarded definition of Gamification was born. Whilst Deterding is well known for his definition, he is also known for his open discrediting of a book written on the topic titled *Gamification by Design* (2011) and the debate which followed with the author Gabe Zichermann.

In a lengthy argument, Deterding (2011) argues that Zichermann has misinterpreted where the motivational power of games comes from by equating PBL to games. The following section explores the psychological theories commonly referenced in studies on Games for Change.

##### 2.1.4.3.2 Common Psychological Theories

The most commonly referenced theory in Games for Change literature (according to Deterding (2015)) is Self Determination Theory (Ryan & Deci 2000), which suggests that intrinsically motivated tasks may satisfy "innate psychological needs" of *competence*, *autonomy*, and *relatedness*. Ryan et al. (2006) applied SDT to video games by including in-game factors of competence, autonomy, and relatedness, as well as adding factors of presence (to do with how immersed the player was in the game environment), and intuitive controls.

SDT describes activities as being *intrinsic* (of inherent interest to the person), and *extrinsic* (done to avoid punishment or for some kind of extrinsic reward such as money). Many Gamification rewards as we have seen in the previous examples can be considered extrinsic in nature, however research has shown this can be problematic as extrinsic rewards can undermine intrinsic motivation to do a task, particularly when the reward is removed (Deci et al. 2001). Instead research has suggested that designs should focus on fostering intrinsic motivation instead, by focussing on the person, and how to make the activity interesting for them (Deci et al. 2001).

This is not the only potential misapplication of theory in Gamification. For example, in *Gamification by Design* (2011), Zichermann consistently mixes theories such as *Flow* (Csikszentmihalyi 1990)[34] with operant conditioning techniques along the lines of Skinner Boxes. In addition, he makes inappropriate use of Bartle's (1996) *Multi-User Dungeon* (MUDs—a text-only precursor to modern games like World of Warcraft) player types, extending these player types that were originally only designed to describe players in MUDs to describe "*social status*" as a highly effective motivator. Social status makes up one part of Zichermann's *SAPS* model of *status*, *access*, *power*, and *stuff*—a model that Deterding (2011) warns is merely a "*pet theory*" with "*no research behind it. No data to back it up".*

The use of Bartle's player types in Gamification is concerning (Deterding 2015), and Bartle himself has cited Gamification as an area that has "completely misunderstood" the theory (Bartle 2012). Nonetheless, according to Google Scholar at time of writing, Bartle's player types have been referenced with the term "Gamification" included in their content over 500 times[35].

A more robust alternative to Bartle's player types are the ten motivating factors for playing video games as described by Yee (2006). Yee used principle components analysis on questions answered by more than 3,000 Massively-Multiplayer Online Role-Playing Game players, resulting in motivational factors categorized by *achievement*, *socializing*, and *immersion*. A more recent alternative to Bartle's player types is *BrainHex* (Nacke et al. 2011), which classifies players based upon neurobiologically-derived archetypes of *seeker*, *survivor*, *daredevil*, *mastermind*, *conqueror*, *socialiser*, and *achiever*. The authors of BrainHex have gone on to attempt to link their player types to Myers-Briggs personality types (Myers 1962) using data from over 50,000 online participants, although from an academic standpoint, at time of writing, anything beyond these preliminary results remains unpublished.

Aside from the work by Yee, Nacke et al., and the application of Self Determination Theory to games, the academic literature on the psychology of video games is sparse. The literature has shown us that Games for Change have relied on PBL, which has an extrinsic motivational focus, and is seldom underpinned by research and literature from the psychology and social

[34] A complex phenomenon whereby a person is in a state of neither being too challenged (frustrated) nor too bored (the activity is too easy); i.e. an optimal experience.

[35] This advanced search may be reproduced using the following link: https://tinyurl.com/ydbh23yx

science spaces. Where there has been work here, it is seldom focussed on applying theories from psychology that are built to deliver meaningful behaviour change.

##### 2.1.4.3.3 Summary of Game for Change Criticisms

Gamification is met with criticism when the game elements used in the implementation are merely the PBL triad, and when the motivation behind using Gamification is to provide an easy solution that will provide motivation and engagement in a boring task without due consideration of the target audience. The PBL triad facilitate extrinsic motivation, which we have seen can be detrimental to long-term intrinsic motivation and behaviour change (Deci et al. 2001). In describing Serious Games, this chapter has presented examples of Serious Games that go beyond Gamification implementations, however as we will see in Section 2.3, the distinction between Gamification and Serious Games within the energy domain is much less clear. As a result, many of the criticisms of Gamification apply to Serious Games, even if the games are not labelled as Gamification.

#### *2.1.4.4 Design Frameworks in Games for Change*

While there have been criticisms of some Games for Change implemention, it is important to note that previous work exists which attempts to guide designers in how to develop their games and how to conceptualize them.

As part of their work developing the *Orientation Passport* for students beginning their degrees at the Queensland University of Technology, Fitz-Walter et al. 2011 developed a framework for conceptualizing the broad components that went into their Gamification implementation. This consisted of three layers, namely:

- the *game* layer: which comprises the game elements of the intervention;
- the *context* layer: which conceptualises the user interactions with the intervention; and
- the *utility* layer: which incorporates functions key to the underlying goals of the intervention.

This framework highlights the methodology used in Gamification, whereby game elements (in this case badges) are layered “on-top” of existing serious systems (in this case an orientation guide).

While it is important from an academic standpoint to be able to distinguish the game elements from the rest of the intervention, this thesis argues that researchers should strive for a closer, more meaningful link between game elements and the serious content, and to do so based upon appropriate theory.

In this vein, three other frameworks for Games for Change development have been identified in the literature, specifical the Game Object Model V2 by Amory (2006), the MAPLET framework by Gosper and McNeill (2012), and the model-driven Serious Games framework by Tang & Hanneghan 2010). While these frameworks are primarily focussed on the domain of education, there are learnings to be drawn from these in terms of Serious Games as a whole and thus are well-worth describing here.

The Game Object Model V2 (Amory 2006) is a model of education game development which provides recommendations for elements and design principles which games in that area should use. The authors suggest education-specific components such as interventions needing to be gender-inclusive, allowing for reflection, and being non-confrontational in nature, but also suggest the use of challenges, puzzles, and quests.

Similarly, the MAPLET framework by Gosper & McNeill (2012) is a form of learner-centred design (a sub-set of user-centered design), which provides a serious of principles for integrating technology interventions into an existing curriculum. Specifically, it suggests that the intervention and curriculum should have matching *aims*, *processes*, *learner expertise*, and *technologies*. The MAPLET framework takes these high-level principles and applies these to the domain of games-based learning, and specifically focusses on associating and aligning gaming activities with assessment strategies.

Finally, Tang & Hanneghan (2013) provide a framework for logically structuring and separating game intervention components from the platform and technology used to deliver the intervention. While the framework has more sub-layers than what is presented here, the core models in the framework are:

- the *Game Content Model*: which encompasses the serious game intervention design itself and is platform and technology agnostic, focussing primarily on the behaviours and intervention goals itself;
- the *Game Technology Model*: which translates the content model into a platform-specific model at the level of console/phone/desktop etc; and
- the *Game Software Model*: which translates the technology model to a specific software methodology and code template appropriate for that technology (e.g. iOS/Android/Cordova/etc. for a mobile technology).

While on the surface this separation may seem similar to that of the one described by Fitz-Walter et al. (2011), the separation doesn't truly consider the underling utility as a separate concept, as this framework is designed to facilitate Serious Games which embed the serious purpose within the framework of a game.

These frameworks primarily focus on Serious Games from an education perspective, and while education can be considered a form of behaviour change, at time of writing there are no frameworks Serious Games for behaviour change as a whole in the extant literature. Instead, we must look to other frameworks for designing behaviour change interventions, and indeed this work primarily uses the Behaviour Change Wheel framework by Michie et al. (2011), which is discussed at length later in Chapter 4.

#### *2.1.4.5 Summary of Games for Change Literature*

The two main schools of thought for developing Games for Change are Gamification and Serious Games. This section has introduced and contrasted both, with Gamification representing the use of game elements in non-gaming contexts, whereas Serious Games represent whole games proper with a purpose other than pure entertainment. Despite these differences, through the examples presented in this section, it is clear that the main motivation of these Games for Change are to attempt to bring about behaviour change or attitudinal change, or to solve some kind of non-gaming problem through the act of playing the game.

Issues with Games for Change were identified, specifically a reliance upon Self Determination Theory, and overuse of points, badges, and leaderboards. Finally, existing frameworks for designing Gamification and Serious Games were highlighted, however these primarily focussed on the education domain.

### 2.1.5 Summary of Video Games Literature

This section has introduced the concept of a game: a form of play with a structure and rules. Advances in technology in the late 20$^{th}$ century saw games make their way to arcades and personal computers in the form of video games. Video games are currently thriving, as shown by remarkable revenue statistics for the commercial sector, and an increase in interest from the academic community. This section examined how this has led to a Ludification of Culture.

Research into Serious Games and Gamification have shown there is huge potential in the use of video games in non-entertainment and non-gaming contexts in the form of Games for Change. This section has shown a number of examples of the use of these techniques, and we can see that there have been many projects with positive results. Gamification implementations, despite wide criticism, have the potential to bring about increases in motivation and engagement. Serious Games have been used in a plethora of domains, with many authors reporting positive results toward their aims for educating and informing users, harnessing the power of the crowd, and bringing about behaviour change in their users.

We have seen that there are several limitations to Games for Change however, specifically a reliance upon a set of un-proven game elements such as points, badges, and leaderboards, and a lack of psychological theory guiding the work. This problem provides the main motivation for this work.

The possible effects of Games for Change stand to be improved by additional design informed by psychological theories, thus there is an opportunity to further the body of work on Games for Change by exploring the ways in which this can be done.

Given the lack of pre-existing work and that the scope of Games for Change is essentially unbounded, the development of a general framework for the integration of a broader set of behavioural theories into the design of Games for Change is likely premature. It is important to scope this work within a particular application domain, so as to allow more focussed research on a target problem, whilst keeping the process of implanting psychological theories broad such that it can be applied in other domains in future work. To this end, selection of a particular application domain must be undertaken. Energy conservation is one area of Games for Change in which there is a significant amount of previous work to both draw upon and compare to.

## 2.2 Energy Conservation

As this section will show, there have been many attempts to get people to decrease their energy usage both using Games for Change, and using more traditional, non-gaming methods. Energy conservation was chosen as the domain for the Serious Game given the plethora of previous work in the literature, and the important nature of the issue, as will be described in this section. This allows us to build upon these examples and draw comparisons to them.

Before exploring these examples, it is first important to understand the motivation behind the need to conserve energy, and this section will particularly focus on its relationship to *Climate Change*. To this end, this section first begins with a description of the dire consequences of *not* mitigating Climate Change, before identifying different strategies for conserving energy. We will see that a key opportunity for reducing energy use lies in the residential space, and this section will provide a review of the tools which are helping in this effort, namely smart meters, in-home displays, and web portals. This section will explore in detail traditional, non-gaming methods for bringing about residential energy conservation. We will see however, that there exist limitations to the effectiveness of these non-gaming methods and this will provide context for the next section, which marries the two concepts of Games for Change and energy conservation.

### 2.2.1 Climate Change

Climate Change, as the name suggests, can refer to any change in the properties of the environment (such as temperature or water levels), over a long period of time (NSIDC 2014). In the current context, Climate Change refers to the overall warming of the Earth (*global warming*), the rising of sea levels, and increases in greenhouse gasses such as $CO_2$ in the atmosphere. Climate Change is a prominent topic of discussion and debate amongst governments on an international scale, the scientific community, and society as a whole.

Established in 1988 by the United Nations Environment Programme (UNEP), the Intergovernmental Panel on Climate Change (IPCC) is the foremost authority on providing scientific information on Climate Change to the world (IPCC 2016). To this end, the primary function of the IPCC is to produce assessment reports, bringing together the work of leading Climate Change scientists, in the general areas of physical sciences, impact and adaption, and mitigation. At time of writing the most recent report was completed in 2014, and brings together the work of hundreds of authors from around the world.

The Fifth Assessment Report states some frightening observations:

> *"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." (Pachauri et al. 2014, p.2)*

These observations have dire consequences according to the report, which predicts Climate Change will have a negative impact in a number of areas including: health and livelihood; infrastructure and critical services; food and water; and ecosystems and biodiversity (Pachauri et al. 2014, p.65). In Australia in particular, Climate Change has had a significant impact on the biodiversity of many important locations such as the Great Barrier Reef (Ainsworth et al. 2016), as well as a decline in production from the agriculture and forestry industries as a result of drought and fire (Climate Council 2013). It is also expected that the frequency of coastal flooding and storms will increase. Worldwide, the effects of Climate Change are expected to cause food and water shortages as well as an increase in disease.

Climate Change is clearly a topic of great importance, and so a large amount of research has gone into identifying the causes of it. The Fifth Report from the IPCC makes some claims over the attribution of Climate Change:

> *"Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century." (Pachauri et al. 2014, p.4)*

According to this report, Climate Change is not a myth and it is humans who are causing it. This is supported by a recent review of nearly 12,000 abstracts since 1990 on the topic of Climate Change which found that over 97% agreed with existence of human-caused global warming (Cook et al. 2013).

If humans are indeed the dominant cause of Climate Change, it follows that the dominant force in mitigating Climate Change in order to avoid potentially devastating effects should also be humans. A major component of humans' influence on Climate Change is that of greenhouse gas (such as $CO_2$) emissions. The Fifth Report identifies a number of sectors where Climate Change mitigation technologies can be employed, such as energy, transport, buildings, industry, and agriculture (Pachauri et al. 2014, p.47).

Energy conservation is extremely important to reducing $CO_2$ emissions both in the residential and industrial sectors (IPCC 2015, p.569). There is a chance to dramatically reduce energy consumption in the residential area (Ehrhardt-Martinez et al. 2010). A report by the American Council for an Energy-Efficient Economy (ACEEE) suggests that there is the potential to save up to 100 billion kilowatt-hours of electricity annually in the United States by 2030, if we develop efficient energy feedback solutions (Ehrhardt-Martinez et al. 2010)—to put this in context, this is equivalent to taking 14.7 million cars off the road or sequestering carbon from 1.8 billion seedlings grown for 10 years (Environmental Protection Agency 2014).

This research project looks to contribute to the mitigation effort in the energy domain, and this is considered in more detail in the following section.

### 2.2.2 Energy Conservation Strategies

The IPCC report lists a number of mitigation technologies for the energy sector (IPCC 2015, p.569):

- energy efficiency improvements;
- reduction of fugitive non-$CO_2$ GHG emissions;
- switching from (unabated) fossil fuels with high specific GHG emissions (e.g., coal) to those with lower ones (e.g., natural gas);
- use of renewable energy;
- use of nuclear energy;
- and carbon dioxide capture and storage (CCS).

In addition to these strategies that can be employed at the distribution and supply levels of the energy chain, reduction in $CO_2$ emissions can be achieved at the consumer level in a number of ways including but certainly not limited to:

- reducing the use of personal transport (Wegener 1996);
- the design of smaller and more energy efficient households (Joelsson 2008);
- public-private-people partnerships (4P) when creating new developments or legislation (Kuronen et al. 2010);
- energy conservation behaviours such as learning to live with less air-conditioning, using less hot water, replacing high energy usage devices, and more; and
- providing effective energy consumption feedback beyond just simple energy bills (Mankoff et al. 2007; Ehrhardt-Martinez et al. 2010).

This research focuses on the final point regarding feedback, as we will see the most relevant examples in Games for Change are in this area. Human behaviour in terms of energy consumption can indeed vary based upon environmental and weather conditions, as well as location and socio-economic status (Parker et al. 2008), however studies have shown in cases where the environment is similar, major variation can still occur. For example, a study by Parker et al. (1996) on 10 different homes with identical appliances and equipment all within the same area found the standard deviation of average total electricity consumption was nearly half the mean value of 43 kWh/Day. This study shows human behaviour is a core part of energy consumption, not just the choice of appliances. If we can change behaviour, then there is the potential to have a massive impact on energy consumption.

There is a chance to dramatically reduce energy consumption in the residential area by up to 100 billion kilowatt-hours annually in the United States by 2030 by developing energy usage feedback solutions (Ehrhardt-Martinez et al. 2010).

According to Ehrhardt-Martinez et al. (2010), who performed a meta-analysis of 36 different studies that provided energy feedback to consumers, the level of feedback (*direct* or *indirect*) is a contributing factor to the amount of electricity savings reported (Figure 8). They found that 4–12% savings could be achieved using feedback, a result mirrored by another meta-analysis performed by Darby (2001) of 38 studies which found an average of 10% savings.

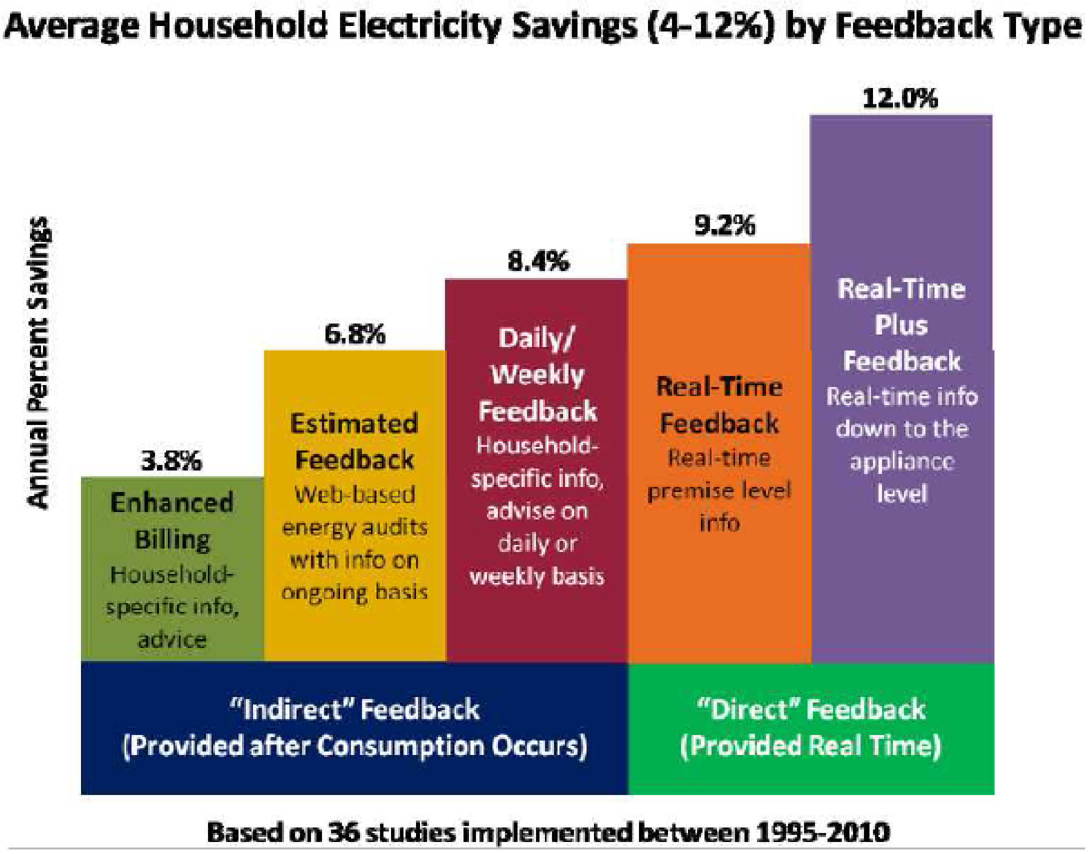



**Figure 8. Average amount of electricity savings in residences based upon feedback type (Ehrhardt-Martinez et al. 2010).**

Ehrhardt-Martinez et al. (2010) refers to two kinds of feedback: indirect and direct and this is further expanded upon by Darby (2001) who identifies a number of examples categorised by two variables: the *immediacy* of the information (immediate/frequent/real-time versus single-event/infrequent), and the *control* the user has over finding and using the information (whether the feedback initiated by the user, or from another source such as the energy provider). This is summarised in Figure 9.

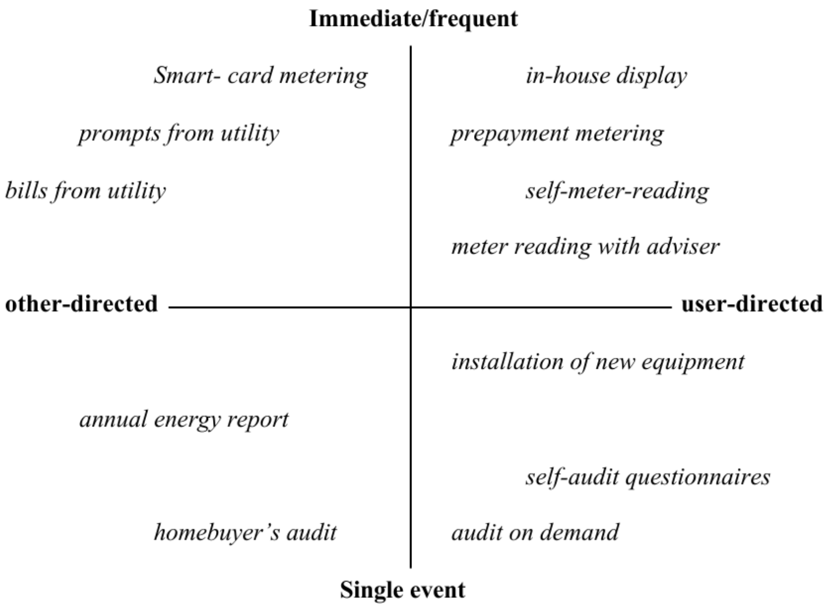



**Figure 9. Different forms of energy-related feedback varying between immediacy and control of information as identified by Darby (2001).**

Ehrhardt-Martinez et al. (2010) however point out some issues with their findings from the meta-analysis. They note that many studies they examined suffered from small sample sizes and short durations. Additionally, they note the potential of some of the lower-ranked *enhanced billing methods* as being quite a cost-effective solution for the savings yielded compared to the real-time feedback that may require expensive equipment such as smart meters or in-home displays. The Darby (2001) study also highlights the variation in sample sizes (3–2,000), and other factors such as the duration of studies, and location.

The Ehrhardt-Martinez et al. (2010) study notes that it is not just the type of feedback provided that has impact on the amount of energy savings. They identify that tailored feedback, multiple sources of information, meaningful feedback, and motivational techniques such as goal setting, social norms, commitments, and social comparison are things that must be considered in the design of an effective feedback system in the energy domain. Also, it is interesting to note that studies which focussed on peak-usage or other cases where a specific time period was targeted only averaged a 3% decrease in consumption, compared to 10% for those that did not. Ehrhardt-Martinez et al. (2010) suggests that this is due to these methods prompting participants to move their energy usage to another time, rather than reducing it in general. This has its own merit since peak load is an area of interest to energy suppliers and retailers.

This section examines ways in which feedback can be provided in a residential setting. First, examples which do not rely on technology are presented, before moving on to examples which have been enabled by technology in the form of smart meters.

#### *2.2.2.1 Non-Technology-Based Strategies*

The main school of thought in trying to bring about energy conservation (at least before the introduction of smart meters) has been through the use of social norms, a concept covered by *Social Normative Theory* (Perkins & Berkowitz 1986).

Social Normative Theory suggests that our behaviour is governed at least in part by social norms (Perkins & Berkowitz 1986). The Cialdini & Trost (1998, p.152) definition of social norms states that they "are rules and standards that are understood by members of a group, and that guide and/or constrain social behaviour without the force of laws". They go on to describe four main kinds of social norms:

- *injunctive norms*: societal expectations of behaviour;
- *descriptive norms*: expectations of our behaviour based upon our observations of others behaviour;
- *subjective norms*: expectations of valued others for our behaviour; and
- *personal norms*: expectations of ourselves for our behaviour.

Put more simply, Cialdini et al. (1991) state that descriptive norms refer to that of what *is* (the typicality of a specific behaviour) whereas injunctive norms refer to what *ought* to be (whether significant others approve of a specific behaviour).

Social norms provide the basis for a common way of trying to bring about energy conservation behaviours, providing *normative feedback*.

Normative feedback allows an individual to monitor their behaviour in reference to what is the *norm*. The concept has been used in a variety of areas including: driver safety (Feng & Donmez 2013), recycling (Schultz 1999), alcohol consumption (Collins et al. 2002; Lewis & Neighbors 2007), drug use (Donaldson et al. 1994), gambling (Larimer & Neighbors 2003), littering (Cialdini et al. 1990), and—as mentioned previously—energy conservation (Schultz et al. 2007; Foster et al. 2010; Laskey & Kavazovic 2010).

As Torriti (2012) points out, normative feedback (in the form of "consumption data sharing") has been used in the area of energy conservation in a number of cases. One example of this is a study conducted by Schultz et al. (2007) who provided normative feedback to participants on their energy usage behaviours. They compared two kinds of feedback. The first kind of feedback showed the participants their energy consumption for previous weeks, alongside a *descriptive norm* that showed participants the average energy consumption of other people in their area (i.e. they were shown what the norm for energy consumption by similar others was).

For this kind of feedback, the Schultz et al. (2007) study provided the expected kind of results for descriptive normative feedback—as the authors put it, the feedback was both *constructive* and *destructive* depending on who was receiving it. That is, participants who initially used an above-average amount of energy reduced their energy consumption by an average of 1.22kWh—showing the *constructive* power of social norms—whereas participants who initially used a below-average amount of energy *increased* their energy consumption by an average of 0.89kWh. This phenomenon is referred to as the *boomerang* effect, where the average figure shown in the descriptive norm tends to act as a magnet—positively affecting those doing poorly to improve their behaviour and negatively affecting those already doing well. Torriti (2012) refers to the boomerang effect in the energy conservation space as the *zero conservation effect*, and according to Fischer (2008) is the main contributor to poor performance by normative feedback methods. A similar effect was also found by Elliott (2012).

The second kind of feedback Schultz et al. (2007) tried was the same descriptive norm plus an additional *injunctive norm* in the form of a simple hand drawn smiley face (☺) or sad face (☹) depending on whether or not the household had consumed less or more than the average consumption for their area—indicating the approval or disapproval of the household’s energy consumption. Schultz et al. hypothesised that the inclusion of this injunctive norm would remove the boomerang effect based upon Focus Theory (Cialdini et al. 1991), which suggests that if only a descriptive norm or an injunctive norm are present in an individual’s consciousness (and not both) then that norm will have the strongest influence on the individual’s behaviour. Their predictions were correct and found that with this second kind of feedback; the boomerang effect was not present.

This kind of normative feedback has been put into practice by electricity company *OPOWER* who place a smiley face (injunctive norm) and comparison feedback (descriptive norm) on customer bills. OPOWER have reported a 2—5% aggregate increase in energy savings using this method (Laskey & Kavazovic 2010; Allcott & Rogers 2014; Allcott 2011), which is considerable given the large sample size of their customer base. According to Fischer (2008), electricity companies in Denmark are legally required to provide normative feedback on electricity bills.

An important aspect of providing normative feedback is the reference group used as the source of the norm. Abrahamse et al. (2005) state that *"by giving comparative feedback, a feeling of competition, social comparison, or social pressure may be evoked, which may be especially effective when important or relevant others are used as a reference group"* (p. 279). Loock et al. (2012) found evidence for this effect, finding that reference groups that are more local were more effective than groups that were more distant, and Lewis & Neighbors (2007) found that gender could also play a role.

A strong example of the effect of locality of the reference group is shown in a study by Goldstein et al. (2008) on towel reuse in a hotel. They tested normative messages to hotel guests with various level of reference group locality by leaving a message saying messages along the lines of "*N% of people in X reuse their towel*" where *X* referred to one of: people (in general); people who stayed at the hotel; and people who stayed in that room number. They found that those with the most local reference group (given a normative message about those who stayed in the same room) were more likely to reuse towels. This is an interesting example of the effectiveness of reference group closeness since the closeness of people staying in the same hotel room seems rather unimportant.

Normative feedback has been selfdom integrated in to technology-based solutions in this space, a notable exception being—the *Wattsup* application (Foster et al. 2010) which provided social comparison of energy usage powered by Facebook. They found a significant reduction in energy consumption for participants given the social comparison condition compared to a control group who were not given it.

Despite some positive results, some academics have identified a number of limitations to the use of normative feedback in the energy conservation domain, and these limitations are explored in the following section.

##### 2.2.2.1.1 Limitations

Some studies have suggested that the preferences of individuals may affect the efficacy of normative feedback (Abrahamse et al. 2005; Costa & Kahn 2013; Allcott 2011). Costa & Kahn (2013) found different responses in energy conservation to the same normative feedback between those with pro-environmental/liberal preferences and those with republican preferences.

Fischer (2008) states that feedback (in their case, on energy consumption comparisons) is useless without the precondition that the individual is motivated to conserve in the first place. Fischer's comments are based upon a meta-review of a number of studies using just comparative, descriptive norm-based feedback, and *not* those that have employed an injunctive norm-based form of feedback such as shown by Schultz et al. (2007). It is arguable that the injunctive norm itself provides motivation by triggering the individual's urge to avoid social sanctions since the injunctive norm indicates that their behaviour of failing to conserve energy is not socially approved.

Cialdini (2003) notes that some normative feedback information—such as ones presented through television or news—are too far removed from the opportunities to perform the change in behaviour that the feedback promotes. In the case of the stealing of wood example provided by Cialdini, the opportunity to perform the socially acceptable behaviour of *not* stealing wood was provided immediately after the feedback (signage placed at the park where wood is stolen). Whereas if that same information were provided through a means such as a television public service announcement (PSA), then the opportunity to not steal wood would not arise until the next time the person visited the park.

##### 2.2.2.1.2 Summary of Non-Technology-Based Strategies

Non-technology-based strategies in energy conservation primarily use Social Normative Theory as a basis. From Caildini & Trost's definition, we can see that social norms impact our behaviour, and we have already seen a number of examples where their application through normative feedback has brought about behaviour change. Surprisingly, the designs of the technology-based solutions in the following section do not make use of this particular theory, and later in this chapter we will see that this is also true in terms of the design of Games for Change in this area.

With an understanding of the methods used for non-technology-based strategies for energy conservation, the following section explores how the introduction of technologies such as smart meters and in-home displays have brought about new strategies for bringing about energy conservation.

#### *2.2.2.2 Technology-Based Strategies*

Recently, a number of solutions that aim to provide better feedback to users have been developed that make use of improved technology in the energy sector. In order to understand the ways in which improved feedback can be provided to consumers, it is important to first examine the technology that enables such information to be collected (*smart meters)* and displayed (*in-home displays* and *web portals*)—the foci of the following sections.

##### 2.2.2.2.1 Smart Meters and Advanced Metering Infrastructure (AMI)

In the 1970s, electricity meters were developed which were able to remotely send energy usage to utilities using technology called Automated Meter Reading (AMR). These early devices exhibited characteristics now common in smart meters we see today, and provided benefits to utility companies such as reducing the labour required to make meter readings (employees no longer need to directly visit each meter), and improving reading accuracy.

AMR technology improved to provide further benefits, such as energy profiling and demand prediction, and ultimately evolved into the beginnings of Advanced Metering Infrastructure (AMI, Ehrhardt-Martinez et al. (2010)). AMI, and subsequently smart meters, came about in response to electricity deregulation and the introduction of market-driven pricing whereby energy production companies were free to sell on their energy with fewer restrictions. Utilities were faced with a need to match the amount of energy they bought from producers with the amount of energy consumed by their customers. Smart meters help combat these problems and provide a range of benefits to all stakeholders in the electricity market, including producers, utilities, and consumers.

Smart meters are generally installed in residences, replacing existing electricity meters, and interfacing with other meters such as gas or water, and they communicate this information with utilities using a communication technology such as an ADSL internet connection, wireless network (such as GSM or GPRS), or Power Line Carrier (PLC) (van Gerwen et al. 2006). It is this communication that makes the meter *smart*, and enables their key features of remote meter reading, remote service usage limitation and cancellation by the utility, and smart grid functionality where homes can feed electricity back in to the grid using their renewable energy sources such as solar panels. Additionally, the collection of data over time, and the ability to query this data over various intervals (such as yearly, quarterly, daily, hourly, or sub-hourly) differentiate smart meters from traditional meters. An overview of the main components of a smart meter system is provided in Figure 10.

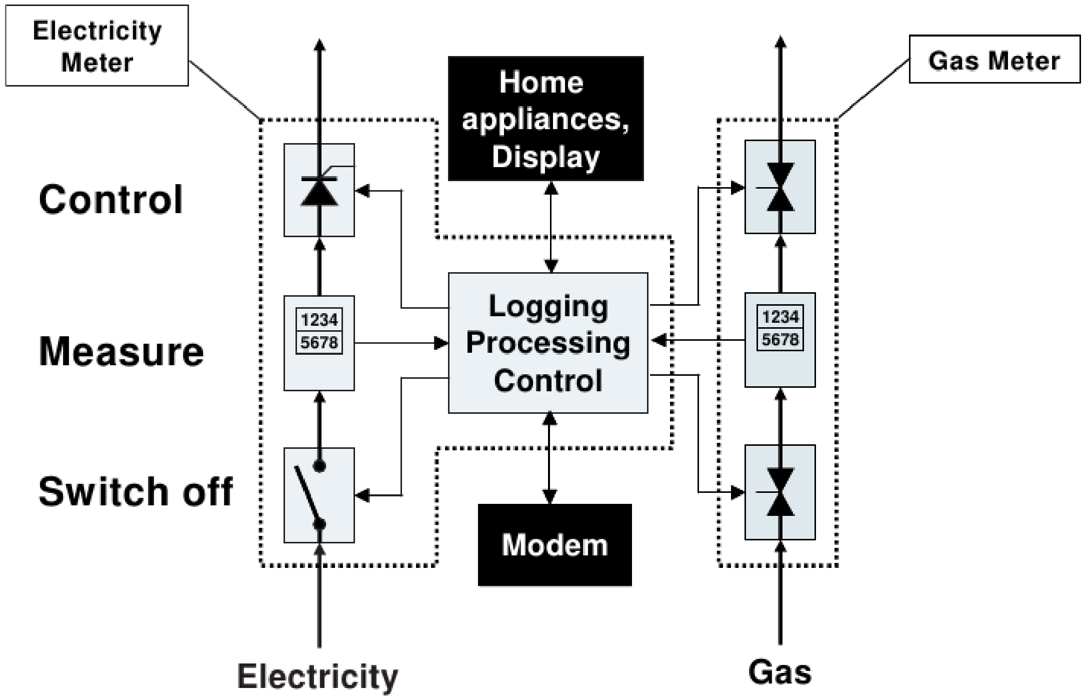



**Figure 10. Schematic overview of a typical smart meter configuration, taken from van Gerwen et al. (2006). Key features are the communication with different meters, in-home displays, and the outside world using a modem.**

Smart meters can provide the consumer, retailer, and distributor feedback at a per-household level at various levels of granularity without any major change in infrastructure other than the installation of the meter itself.

Smart meters are being identified internationally as a powerful way of not only implementing Smart Grid technologies, but also as a way of providing important (in some cases real-time) feedback to energy users. Navigant Research (2013) estimates that up to 130 million new smart meters will be installed internationally each year until 2022, and that by the end of 2022 80% of residential premises in Europe will use a smart meter (EYGM 2013).

While the potential for conservation through improved and more immediate feedback is great (see the next section on in-home displays), there are some ethical concerns in the community about smart meters. McKenna et al. (2012) review these concerns, the greatest of which is the potential to infer private activities in a dwelling from the smart meter data. This has the potential to aid in burglaries, through establishing any *routines* of absence, or as low or no consumption can indicate the vacancy of a household (Lisovich et al. 2010; McKenna et al. 2012). Similarly, stalking could be aided by the knowledge that a person *is* present in the household. Other concerns include use of information by advertising companies for targeted advertising (Lisovich et al. 2010), law enforcement to detect illegal activity (Quinn 2009), and household members "spying" on other household members (Hargreaves et al. 2010). These concerns are having an impact on smart meter rollouts globally, with many rollouts now being voluntary rather than mandatory (McKenna et al. 2012).

In the Australian state of Victoria, smart meters are now the standard type of meter in homes and businesses, and according to the State Government Victoria (2016), the rollout there is complete, with over 2.75 million meters installed. Benefits are already being seen in the state, with smart meters enabling metering (and rewarding) of solar panels feeding electricity back into the grid, electricity retailers actively using remote connect/disconnect to transfer services, and in-home displays being installed.

The Victorian rollout has been engineering-based and therefore mandatory, and as such has received considerable criticism given the concerns over privacy of smart meter data mentioned previously. Other Australian states such as New South Wales (State Government New South Wales 2014) and Tasmania (State Government Tasmania 2015) have learnt from this and are performing consumer-based rollouts which allow for competitive pricing, and consumer choice (including the choice to not install a smart meter).

In New Zealand, over 1.2 million smart meters are estimated to have been installed (Block 2015), up from 971,109 in 2013 (Beatty 2013). This is more than 50% of all residences. According to the latest statistics provided by the Department of Energy, Climate Change United Kingdom (2016) over 2.32 million smart meters have been deployed in residential properties in Great Britain by the end of 2015, and nearly double that in non-residential locations. The UK claims there will be a sharp increase in installations in the near future and aims to bring smart meters to 30 million domestic properties by 2020 (Smart Energy GB 2016).

As of 2014, the United States has a rollout of over 58 million smart meters, 88% of which are on residential premises (Institute for Electric Innovation 2014). This represents a coverage of over 43% of homes (Institute for Electric Innovation 2014), and is part of a steady increase in installation of the smart meters, as shown in Figure 11.

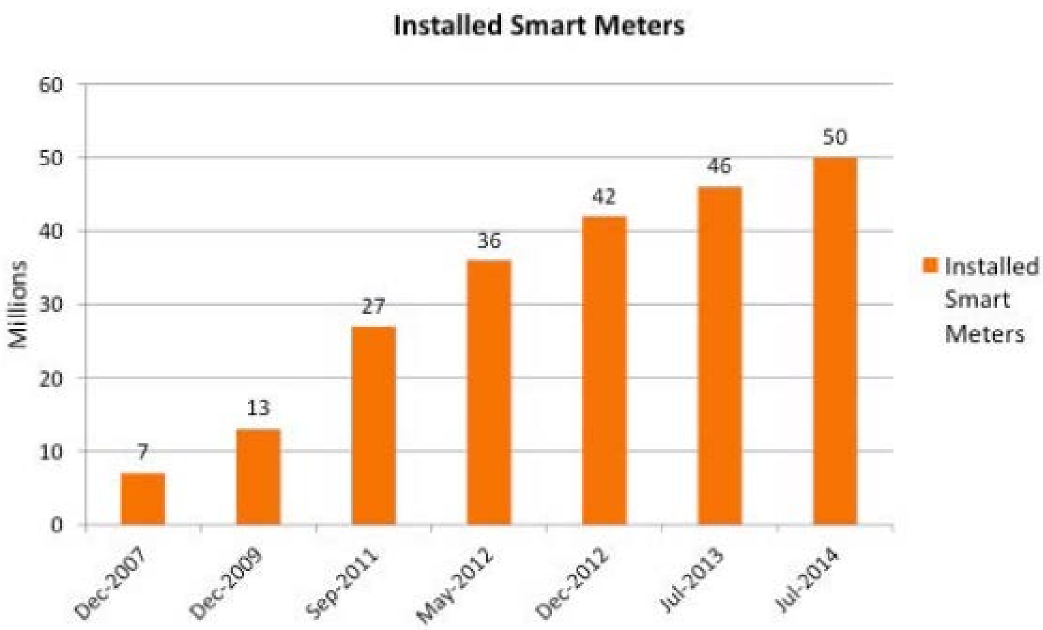



**Figure 11. Smart meter rollout figures by year in the United States (Institute for Electric Innovation 2014).**

The extent of rollouts has varied, but has been fuelled by the potential benefits from smart meters including automated meter reading and the ability to provide feedback to consumers. The most common forms of feedback from smart meters have been in the form of in-home displays and web portals, and this is discussed in the following section.

#### 2.2.2.2.2 In-Home Displays and Web Portals

In order for smart meters to provide feedback to users, the data they collect needs to be sent through to some kind of feedback service. Most commonly these are *in-home displays* (IHDs) and *web-portals*. The meta analyses mentioned previously by Ehrhardt-Martinez et al. (2010) and Darby (2001) included feedback mechanisms of this type, and considered them to be *real-time*. This section examines a number of examples of IHDs and web portals, as well as looking at meta-analyses specific to IHDs.

In Australia, a number of web portals exist based upon energy provider, and smart meter technology (Economic Development & Resources 2016):

- *Australian Power & Gas*[36];
- *AGL*[37];
- *EnergyAustralia*[38];
- *Lumo Energy*[39];
- *Origin Energy*[40];
- *Powershop*[41];
- *Jemena*[42];
- *SP AusNet*[43]; and
- *UnitedEnergy*[44];

*The Energy Detective* (TED) IHD (Figure 12) is able to measure energy demand at a resolution of 10W every second reported to an LCD display (Parker et al. 2008), allowing for real-time monitoring of devices of varying size (i.e. it is possible to detect the difference made by a small and large appliances/devices alike).

[36] https://onlineservices.australianpowerandgas.com.au/

[37] http://www.agl.com.au/residential

[38] http://www.energyaustralia.com.au/ewise

[39] http://www.lumoenergy.com.au

[40] http://www.originsmart.com.au

[41] http://www.powershop.com.au

[42] http://www.electricityoutlook.jemena.com.au/

[43] http://www.myhomeenergy.com.au/

[44] https://energyeasy.ue.com.au/


**Figure 12.** ***The Energy Detective*** **(TED) in-home display (Parker et al. 2008).**

A study by Parker et al. (2008) on the use of the TED found an average reduction of 7% in energy use after installing the display. The study however is not statistically significant since it was performed on a self-selected group of 20 homes in Florida. Additionally, they found high variation in energy savings that ranged from a best of a 27.9% decrease to a 9.5% *increase* in consumption.

The *PowerCost Monitor* (pictured in Figure 13 with more detailed specifications) is manufactured by Blue Line Innovations Inc. and is able to provide feedback at a resolution of 100W every 30 seconds (Parker et al. 2008)). Note that this is a much lower resolution and slower update time than TED, which may impact a user's ability to track the energy use of small appliances, as well as their ability to track immediate changes.


**Figure 13. The *PowerCost Monitor* and features as provided by the maker's website[45].**

Unlike the studies on TED and other IHDs that had low numbers of participants, a study by Mountain (2006) using the PowerCost Monitor examined the effect of real-time feedback from an IHD on over 400 participants. The sample covered a number of locations throughout Canada and represented a diverse population with varying configurations of heating, cooling, appliances, income, education levels, and weather impacts. The study covered a 2.5-year period and reported a 6.5% conservation effort.

#### *2.2.2.3 Limitations of Energy Conservation Strategies*

The increased sample size and lower reported savings of the Mountain (2006) study are part of a trend in real-time feedback studies according to McKerracher & Torriti (2013). In a meta-analysis of 33 different studies (both peer-reviewed and not), they found a notable downwards trend over time in the reported energy savings percentages from studies, as well as a positive trend for the sample size of studies over time (Figure 14), and correlation was found between these two variables ($R^2$ = 0.239). They claim the increase in sample size is based

[45] http://www.bluelineinnovations.com/powercost-monitor-2

upon the move into the smart grid era, with a mean sample size in the pre-smart grid era of 116 compared to a mean sample size of 1868 in the smart grid era.

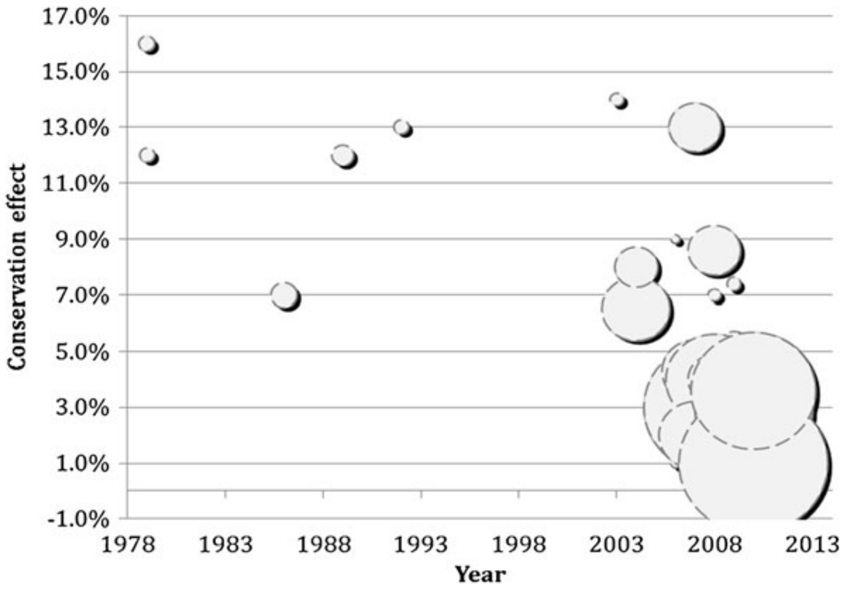



**Figure 14. Conservation effect by year and sample size, showing a decrease in conservation effect as sample size increases McKerracher & Torriti (2013).**

McKerracher & Torriti (2013) suggest that the conservation effect of IHD feedback is closer to the 3–5% range rather than 6–10% as suggested by earlier studies such as Ehrhardt-Martinez et al. (2010) and Faruqui et al. (2010). McKerracher & Torriti conclude that real-time feedback through IHDs may not be the most cost-effective option for reducing carbon emissions since the cost of using real-time feedback is still significantly higher than the cost for companies in the energy sector to pay for carbon taxes.

According to Strengers (2008), current feedback systems do little to alter everyday behaviours such as bathing, laundering, heating, and cooling. They suggest that for feedback systems to be more likely to change behaviours, they need to be redesigned to consider social norms by showing users comparisons to relevant social groups about what is the *norm*.

Research by Houde et al. (2012) has suggested that IHDs such as the ones described above have short-term effects on reducing energy consumption, but suffer from a lack of long-term engagement. This can be seen in Google's effort at providing a simple interface for tracking consumption with their product *Google PowerMeter*, which was discontinued just two years after its release, due to lack of uptake and use (Nusca 2011). This inability to engage users and bring about long-term changes in energy usage behaviour is a problem which is yet to be fully addressed, and is of significance if smart meters are to help combat the effects of Climate Change.

In addition to limitations related to engagement, IHDs tend to simply show information in the form of numbers and graphs, such as in Figure 15, and this make monitoring energy consumption feedback a mundane or demotivating task equivalent to examining an electricity bill (Vaijayanthi & Marur 2012; Reeves et al. 2012). As the following chapter will describe, there is an opportunity within this space to use a technology that excels at providing intuitive feedback to users: *video games.*

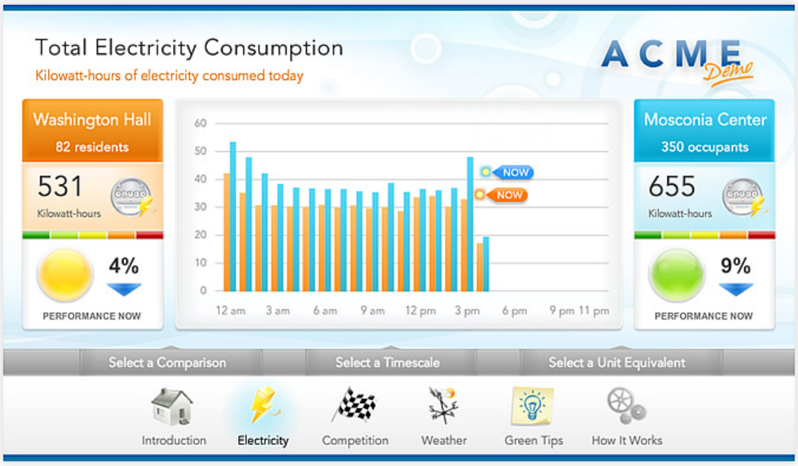



**Figure 15. An example of traditional energy consumption feedback, showing the use of numbers and graphs[46].**

#### *2.2.2.4 Summary of Energy Conservation Strategies*

Smart meters, in-home displays, and web portals allow us to provide more improved energy usage feedback over traditional billing methods. Smart meters are being rolled out on an international scale, with most of Europe and America likely to be using them within the next decade.

The information provided on in-home displays and web portals however generally consists of merely numbers and graphs, which may be confusing or uninteresting to some. In many cases the data is not sent in real-time, which we have seen previously is a factor in the effectiveness of the feedback. There is a need for more engaging feedback mechanisms, and to make use of psychological theories such as Social Normative Theory when designing these feedback interfaces (Nolan et al. 2008; Schultz et al. 2007).

[46] http://www.luciddesigngroup.com/images/starter/starter_screenshot1.jpg

#### 2.2.3 Summary of Energy Conservation Literature

We have seen that Climate Change is an extremely prevalent subject of discussion and debate of international importance. This section has reviewed evidence suggesting the impact of warming of the planet and ways we may be able to mitigate these changes.

Reducing home energy consumption is one way that society as a whole may contribute to the mitigation effort, and this can be aided by technological advances in systems such as smart meters, and providing effective feedback to energy users.

While early analysis suggested that the conservation effect of real-time feedback may be in the 6–10% range, the studies examined have suffered from small sample sizes and other limitations. According to McKerracher & Torriti (2013), the range 3–5% is more representative if one factors in more recent studies with higher sample sizes. In large-scale rollouts with larger sample sizes, the conservation effect has shown to be much smaller.

McKerracher & Torriti (2013) suggest that social comparison is key in reducing energy consumption. In addition, as the immediacy of the feedback increases, so does the conservation effect. Most feedback displays—either on in-home displays or web portals—merely provide the information in the form of numbers and graphs, and despite research suggesting immediacy of information, often the data is delayed. There is an opportunity in the energy conservation space to improve these forms of feedback with the aim of providing higher levels of motivation and more sustained behaviour change.

In the previous section, a review was provided of the considerable work that has gone into developing Games for Change which intend to bring about behaviour change in a number of application domains. One way of approaching the problems described above is to introduce Games for Change in the energy conservation space, and indeed this idea is not new: in the next section we will see a number of examples in the energy conservation domain where video games have been used to try and bring about behaviour change.

## 2.3 Games for Change and Energy Conservation

This chapter has so far shown that much research has gone into the use of video games for non-entertainment, serious purposes in the form of Games for Change. However, there is a problem; the design of these systems is lacking psychological basis. There is an opportunity, then, to explore ways in which a Serious Game can be informed by psychological theory. To this end, the application domain of energy conservation was chosen, and previous work in non-gaming forms to bring about behaviour change in this area have been explored.

The idea of using Games for Change in the area of energy conservation is not new, and this section aims to present examples in the extant literature on bringing these two concepts together. The examples provided are not intended to be exhaustive, but rather illustrative of the examples of games developed in the past. Johnson et al. (2017) provide a comprehensive systematic review of both Serious Games and Gamification examples for domestic energy conservation. It should be noted that Johnson et al. (2017) refer to Serious Games and Gamification collectively as "applied games", in the same way that this work refers to the two collectively as Games for Change. From 2,831 initial papers, Johnson et al. (2017) examined 24 relevant interventions (half of which were deemed to resemble Gamification, the other half Serious Games), including 10 studies aiming to bring about real-world behaviour change. Of these 10, only five were assessed to be of high quality, and none of these focused specifically on what is referred to by Nicholson (2015) as "meaningful Gamification" (e.g. play, exposition, choice, information, engagement, and reflection).

Following the presented examples, a discussion of a number of limitations to these studies; limitations which are similar to the ones presented in Section 2.1.4.3 is provided. These limitations represent the necessity for this thesis, as well as the contribution it stands to provide to the area of energy conservation, and Games for Change more broadly.

### 2.3.1 Gamification Energy Conservation Examples

A recent trend in the energy sector is to provide feedback to users in the form of comparison. This is almost exclusively done in the form of *super-star leaderboards* (Lockwood & Kunda 1997), or comparison to broad groups, such as the top 20% of households nationwide. As we will see later in this section, this form of leaderboard does not use relevant or meaningful reference groups, which may limit their effectiveness.

Initiatives such as the *Green Button*[47] project, which allow users to download their energy consumption data in a standardized XML format, and then upload this data to a third-party, allow developers the chance to write applications to visualize and handle home energy consumption data. Issues with the Green Button system include the fact that users have to upload data themselves and the data is not real-time. Due to these constraints, so far none of the Green Button designed apps are game-like beyond PBL implementations. As this section will show through examples, this reliance on PBL is echoed across the sector.

The following sections examine Gamified energy conservation attempts.

[47] http://energy.gov/data/green-button

#### *2.3.1.1 JouleBug*

The *JouleBug* smart phone application is an example of Gamification in the energy conservation space. The application relies heavily upon the concept of PBL in that it awards users badges (called *pins*, illustrated in Figure 16) for completing various energy conservation tasks (Elliott 2012). These tasks may be as simple as wearing warmer clothing to allow the thermostat to be lower or shutting curtains to retain heat, or more complex such as buying a more energy efficient dishwasher, or fixing faulty equipment in the home. JouleBug works on an honesty system, such that users input into the application when they participate in energy conserving behaviour and are awarded points for doing so. Using an estimation process outlined by Elliott (2012), the phone is able to provide feedback to the user about how their actions contribute to the energy conservation effort. The implementation of JouleBug is mainly limited to PBL, other than a *Newsfeed*-style social component where users can share and brag about their energy conserving behaviours.


**Figure 16. The JouleBug mobile application, listing a number of badges that for different energy conservation behaviours[48].**

The JouleBug study relied upon self-reporting from participants to determine if a change in energy consumption occurred, which introduces the possibility for the effect of Social Desirability Bias (Fisher 1993) to result in a greater reported reduction in usage than actually occurred.

#### *2.3.1.2 OPower*

The OPower social application[49] provides leaderboards of energy consumption, as well as a comparison to significant groups such as the top 20% of residences in the United States (Figure 17). In keeping with the PBL implementations of many Gamified systems, the OPower application also awards badges to users for completing various milestones.

[48] http://blog.joulebug.com/wp-content/uploads/2014/04/Discover.png

[49] https://social.opower.com/

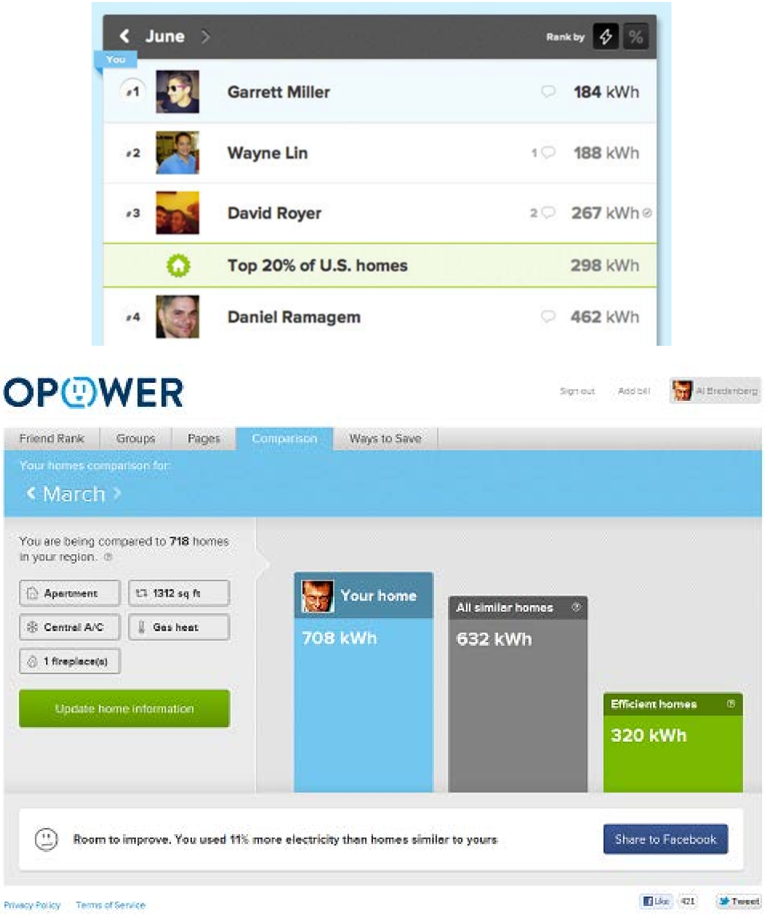



**Figure 17. The OPower social application[50].**

#### *2.3.1.3 Eco-Avatars*

*Eco-Avatars* is a proposed feedback design by Gouveia et al. (2012) that is inspired by the game element of the player avatar. Players customise their own avatar that appears on a feedback screen in the form of a forest which transitions from healthy to desolate and deforested as shown in Figure 18. The avatars appear in a different part of the environment based upon their owner's energy consumption behaviour, and exhibit different facial expressions, and conversations also based upon this. This feedback screen is coupled with a more traditional feedback screen in the form of a graph. The work is still in the design stage, and thus has not yet been deployed or tested. The authors plan on furthering their work to foster long-term engagement, although at time of writing this has not yet been published.

[50] http://news.thomasnet.com/IMT/2012/04/10/update-on-green-gamification-could-the-green-button-be-the-killer-app-for-consumer-energy/

**Figure 18. The Eco-Avatars feedback screen, showing avatars played in an environment based upon their owner's energy consumption behaviours (Gouveia et al. 2012).**

### 2.3.2 Serious Game Energy Conservation Examples

The Gamification examples in the previous section all exhibit the issues with Gamification identified earlier in this chapter. The implementations featured points, badges, and leaderboards which have been covered throughout this chapter, however the leaderboard present in OPower does use a social normative approach. The examples were also representative of *systems*, rather than *games*, as it common for Gamification. This section presents a number of Serious Game examples, which, by definition, should differ in that they represent full game wholes, rather than systems implementing game elements. We will see however, that some of the examples presented are less like games, and more like the Gamification examples seen earlier.

#### *2.3.2.1 Kukui Cup*

The most substantial Serious Game for energy conservation in the literature was developed in Hawaii and is called the *Kukui Cup* (Brewer et al. 2011). The Kukui Cup was a program presented to University students in student accommodation, where players could earn points by completing various tasks such as watching educational videos or enrolling in a University unit on energy usage. These points would go toward the total score for their area (generally their floor in their building), allowing for cooperation within teams, but also competition across teams. In addition, teams were challenged to meet energy usage goals, which were calculated using a baseline and previous time period's energy consumption. The Kukui Cup also used an interesting way of providing rewards to players. Prizes were not given directly to those with the most points. Instead, points acted as raffle tickets that players could assign to different prizes based upon their interest in each prize. Those with more points had a much higher chance of winning a prize, and also the ability to assign their raffle tickets effectively over whichever prizes they liked. However, you were still in with a chance even if you only had one point—this somewhat alleviated any potential de-motivational effect arising from seeing players with a much greater number of points than yourself.

The game elements of the Kukui Cup were presented in the form of a website, as shown in Figure 19.


**Figure 19. The Kukui Cup (Brewer 2013)web interface[51].**

Overall the results of the Kukui Cup suggested some short-term reduction of energy usage (as high as 16% for one team), however the there was no evidence of sustained energy conservation (Brewer 2013).

The Kukui Cup is not a fully-fledged video game like some of the examples described later in this section. As Section 2.1.4.3.2 outlined, extrinsic rewards such as the prizes, points, badges, and leaderboards implemented in the Kukui Cup, may have a detrimental impact on intrinsic motivation, and result in a lack of long-term behaviour change. Brewer (2013) describes Social Normative Theory (Perkins & Berkowitz 1986). as well as Self Determination Theory (Ryan & Deci 2000) to discuss intrinsic and extrinsic motivation, however when considering the game design itself, it is not clear that to what extent, if any, the design was informed by these theories. This lack of a clear link between theory and game design is prevalent in energy conservation Games for Change.

[51] http://i1.ytimg.com/vi/LZJwMPd3T0k/maxresdefault.jpg

#### 2.3.2.2 Energy Battle

*Energy Battle* (Geelen et al. 2012) is a Serious Game that is similar to the Kukui Cup in design. The game focussed on competition and cooperation with teams in a largely equivalent way to that of the Kukui Cup, and provided players with tips on how to better conserve energy. The main game component of Energy Battle was a simple block building game. Prizes were awarded for building attractive structures in the block building game. Energy feedback however, was only provided in the form of graphs and numbers, and the only aspect of the system that was dissimilar to traditional energy feedback techniques was that saving electricity would provide the player with more resources with which to use in the game.

The authors reported that during the competition, electricity savings averaged 24% (with some teams reaching 45%), and that "*follow-up interviews indicated that some of the behaviours developed in the game had transformed into habits*" (Geelen et al. 2012, p.1). However, the long-term effects were minimal, with most participants slowly returning to the baseline levels of usage they exhibited prior to the competition.

The design of *Energy Battle* references the Motivation-Ability-Opportunity-Behaviour [52] (MOA) model (Ölander & Thøgersen 1995), and the similar Fogg Behaviour Model[53] (Fogg 2009). Again, it was not clear how these models informed the design of the game. As with the Kukui Cup, the game design relies largely on Gamification elements and is an incomplete game whole.

#### 2.3.2.3 Power Agent

Gustafsson et al. (2009) examined the use of a pervasive game (*Power Agent*) that aimed to encourage teenagers and their families to reduce energy consumption. This game focussed on competition between families (homes), while educating households about effective ways to reduce electricity use. *Power Agent* connected to the electricity meter in the participant's homes, which sent the usage data to the game servers. Players would interact with the game on their mobile phones, where they would be given missions to use less energy (these missions were presented to the player at some time in the peak usage period of 17:00 and 22:00). The missions educated players by assisting them in reducing energy consumption in different

[52] The MOA model states that performance can be influenced by affording improved motivation, opportunities, and abilities to individuals (Ölander & Thøgersen 1995). This model is traditionally applied to the workplace.

[53] The Fogg model states that the higher motivation and ability are, the more likely it is that a person performs the target behaviour (Fogg 2009)

aspects of the house such as *lighting*, *kitchen*, *entertainment equipment*, *heating*, *washing equipment*, and *bathroom*.

A limitation of the application, however, was that the data provided to the game from the electricity meter was not in real-time, and in fact was only exchanged at 24-hour intervals. The authors noted that this issue may have affected the usefulness of the application, and its ability to provide feedback to the players. Future iterations of the game are expected to include more up-to-date information[54].

Another limitation is that the application has not been evaluated on a large group of people. The evaluation of the application by Gustafsson et al. (2009), only consisted of 6 families in two competing teams. Results were promising, with a median percentage reduction in electricity consumption of 24%. The authors noted the issue of *displacement* of energy usage. The game missions occurred during the peak time period, and it was found that consumption during the peak period did as consumption was moved to times outside of the peak time in order to comply with the mission, but then higher usage was displaced to a different time that day.

Gustafsson et al. (2009) noted that it did not appear that the *Power Agent* game had any long-term effects on energy consumption habits. For the participants that they were able to collect data from, they found that after the game evaluation period had ended and they no longer had the game, power consumption habits returned to normal.

#### *2.3.2.4 Wattever*

Vaijayanthi & Marur (2012) proposed the design of a serious, persuasive game aimed at digital natives called *Wattever*. The game aims to represent in a virtual world the energy consumption of a user by manipulating the environment within that world. The virtual world described by the authors consists of a garden plot which changes based upon the energy consumption habits of the user (the more energy the player users, the more the garden will deteriorate, see Figure 20). The Wattever app is designed to prompt users with notifications to give them the opportunity to participate in energy conservation behaviours, as well as educate them on how to accomplish such behaviours. Points awarded in the game are able to be spent on in-game content to enhance the game experience (this is an enhancement of the use of points in PBL implementations, where points merely exist as a form of status or progress).

[54] It should be noted that at time of writing, no such future publication was found.

Much of the design revolves around the concept of presenting the energy consumption information in a novel and meaningful way by using game elements.


**Figure 20. The proposed *Wattever* Serious Game interface, showing a virtual world consisting of a garden plot that is affected by user energy consumption (Vaijayanthi & Marur 2012).**

The Wattever app proposed design, whilst not yet implemented represents an experience much closer to that of a traditional entertainment *casual* game. This was intentional, as the authors aimed to design a game that targets digital natives who are familiar with casual social games such as *Farmville* and *Angry Birds*. In doing so, the Wattever game, and also the Eco-avatars concept described in the Gamification section, combat a number of limitations of the games presented later in this chapter.

#### *2.3.2.5 Power House*

*Power House* was initially proposed by Reeves et al. (2012). Power House featured multiple online mini-games, which reacted to real world energy consumption of players. In the minigame described by Reeves et al. (2012) and pictured in Figure 21, players help a fictional family complete daily tasks (e.g. laundry, exercise, watching television) by turning on appropriate appliances and lights. Players attempt to optimize the energy output of the family. Energy literacy is offered throughout the game, however the social aspect of the game was limited to the accumulation of points and leaderboards.


**Figure 21. The *Power House* prototype minigame screen (Reeves et al. 2012).**

The game was tested in the field and a significant but small (~2%) decrease in energy consumption was found between the 30 days before playing the game and 30 days after playing (Reeves et al. 2015).

#### *2.3.2.6 MAEGUS*

The previous examples of Serious Games in the energy conservation space have used smart meter data to occasion behaviour change. Another way behaviour change can be brought about is through education, and *Measuring Alternative Energy Generation via Unity Simulation* (MAEGUS; Figure 22) by Nataraja & Whittinghill (2013) aims to do that. Like a number of the examples provided here, MAEGUS is a prototype Serious Game. The purpose of the game is to improve energy literacy about renewable energy in the form of a realistic three-dimensional simulation developed using the *Unity* game engine. The game features graphics of real-world locations using Google satellite imagery, and challenges players to use renewable energy sources such as solar and wind to provide a requisite amount of energy to the location. The game is still a prototype, and there has been no published work on its results as of yet.

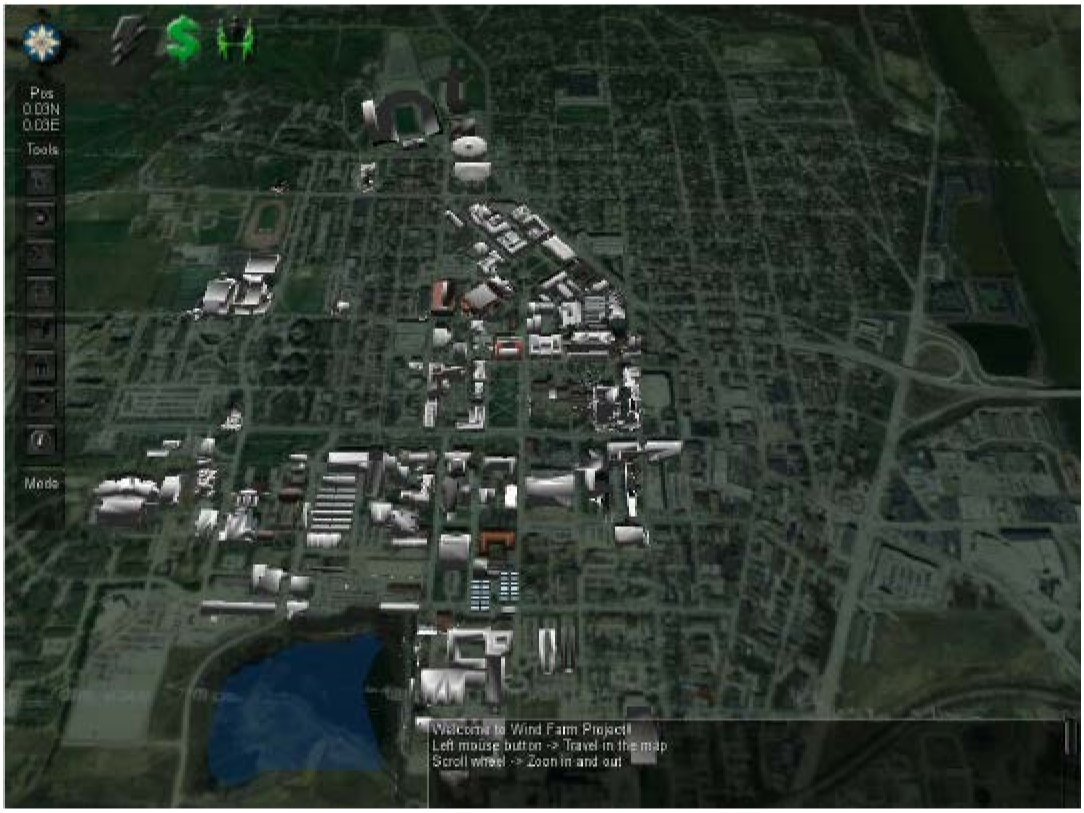



**Figure 22. The MAEGUS Serious Game prototype for energy literacy (Nataraja & Whittinghill 2013).**

#### *2.3.2.7 Reduce Your Juice*

The *Reduce Your Juice* mobile Serious Game by Yam et al. (2017) represents an example of a Games for Change implementation within the energy conservation space with high production values. Reduce Your Juice is made up of three minigames, each based around a different energy literacy concept: optimal temperature management, washing machine temperature, and switching off lights and appliances in unoccupied rooms.


**Figure 23. Marketing materials for the Reduce Your Juice (Yam et al. 2017) Serious Game[55], showing the main menu screen and one of the mini-games.**

The game was evaluated with 17 participants across six households, however energy consumption was not recorded. Instead, the study evaluated reported qualitative measures through a self-report. The behaviours of switching off lights, and washing machine temperature were reported to be the most influenced by the game. Similar to the Gustafsson et al. (2009) study, it was found that participants found themselves competing within the household to perform energy conservation behaviour.

The theory behind the Reduce Your Juice study ultimately relies upon game-oriented version of Self Determination Theory (Ryan et al. 2006), and no details on the design of the game itself beyond what mini-games were available was offered[56].

### 2.3.3 Criticisms of Energy Conservation Games for Change

While the Serious Game examples in this section have seen positive results, there are a number of limitations with some of the elements used within the games from a motivational point of view Johnson et al. (2017) that may be limiting just how effective they can be. These limitations mostly stem from the fact that these implementations make almost exclusive use of the PBL Triad (as previously discussed in Section 2.1.4.3.1). Extrinsic rewards such as the prizes, points, badges, and leaderboards implemented in the Kukui Cup, may have a detrimental impact on intrinsic motivation, and result in a lack of long-term behaviour change. There is a

[55] http://reduceyourjuice.com.au/about/

[56] It should be noted that the Reduce Your Juice study by Yam et al. (2017) is very recent, and describing the game and its elements in detail was not the focus of the publication. It is hoped future studies on the game detail the elements, and provide justification for their use.

lack of a clear link between theories selected (if any was selected) and game design. Additionally, many studies such as JouleBug (Elliott 2012) and the Reduce Your Juice game by Yam et al. (2017) relied upon self-reporting, and so *actual* change in energy consumption brought about these studies is not immediately clear.

#### 2.3.4 Summary of Games for Change and Energy Conservation Literature

This section has reviewed the extant literature on the use of Games for Change within the application domain of energy conservation. We have seen that there have been a large number of previous examples in this area. The amount of previous work in this area combined with the number of limitations to the studies presented makes it an ideal candidate for further study into improving the design of Serious Games.

## 2.4 Problem and Purpose Statements

We have seen a range of examples of Games for Change both in academia and from industry, in application domains of learning, training, scientific discovery, and many others. Problems with these implementations have been identified, however, particularly we have seen a lack of psychological theory being used in their design, as well as a reliance on game elements known as the PBL triad which have not shown to have meaningful long-term effect, and may indeed be de-motivating in the long term.

These limitations stand to reduce the potential of Games for Change. Through identifying a lack of psychological theory in Games for Change, it can be seen that an opportunity exists to address this problem, and this study aims to contribute to that.

There have been many studies into the use of technology to bring about energy conservation through smart meters, in-home displays, and web portals, however recent work has shown that as sample sizes have increased, the overall conservation effect of in-home displays and smart meters is reduced. We have seen that as the immediacy of feedback increases, so does the conservation effect garnered.

To summarise the key issues identified in energy conservation Games for Change, previous studies:

- suffer from small sample sizes, from very specific populations;
- found no long-term behaviour change;
- combatted peak load only in terms of shifting the peak to a different time;
- consisted of implementations providing little more than simply points, badges, and leaderboards; and

- lacked clear guidance from psychological or behavioural theories.

The issues above were from the author's reading of the literature, however the recent review by Johnson et al. (2017) mirrors many of these findings:

> *"shortcomings* [were] *identified in the methodologies of the reviewed studies, including small sample sizes, poorly described methodologies, limited use of validated measures to quantify outcomes, absence of controls, presentation of descriptive statistics only, and narrow data collection timeframes"* (p. 261).

Seeing these problems prevalent across all examples within a particular application domain strengthens the case that there is a need for improved design in Games for Change by employing psychological theory. By focussing on the domain of energy conservation it is possible to directly contrast and compare with many specific and relevant examples, and present a way of designing better games within an important area of work attempting to mitigate Climate Change—a serious issue which has serious implications for mankind and our planet. Scoping to a particular domain for Serious Game design also allows for the development and testing of a technological solution.

The identified issues can be formalized in the form of an explicit problem statement:

> *Serious Games for changing residential energy behaviour suffer from a limited set of game design elements and do not effectively integrate behaviour change techniques in their design.*

This work aims to add to the body of knowledge in the areas of energy and Serious Games by presenting a novel method for designing a behaviour change theory-informed Serious Game. Given the novel nature of the proposed opportunity to improve Serious Games, it is important to also discuss the challenges and issues involved in the design and implementation process, and to provide an empirically-tested matching set of recommendations to future researchers. This goal is represented in the following purpose statement:

> *The purpose of this work is to explore the opportunity to integrate games design and behaviour change techniques to develop a Serious Game for changing residential energy behaviour, and to provide a set of empirically tested recommendations for doing so.*

To help guide the design of the methodology for this project, an overarching research question is provided. Answering this research question addresses the problem statement, and actions the purpose statement. The overarching research question for the thesis asks:

> *What are the opportunities and challenges in integrating both games design and behaviour change techniques towards the development of a Serious Game for changing residential energy behaviour?*

This research question provides a guide for the rest of this work, is further dissected into sub-research questions in the following chapter in order to more effectively guide the methodology which ultimately illustrates how researchers can develop Serious Games in a more informed way. Specifically, the question is broken down into five sub-research questions which are described in detail later in Table 1.

## 2.5 Chapter Summary

This chapter first introduced the concept of video games, and identified them to be an extremely popular form of modern media which builds upon the age-old concept of *play*. This popularity has seen video games become ubiquitous in today's society, a phenomenon referred to as a *Ludification of Culture.* An academic community has risen up around the concepts of video games, with researchers exploring how to improve video game technology, what makes video games so engaging, and how to use games in non-gaming contexts to solve problems and bring about behaviour change in the form of Games for Change, via both sub-disciplines of Gamification and Serious Games.

Examples of Games for Change were presented, and the limitations of these were identified—particularly a lack of psychological theory, and a bias towards points, badges, and leaderboards. The PBL triad has shown to not have a meaningful long-term effect, and may indeed be de-motivating in the long term.

As previously noted in this chapter, to attempt to prescribe changes for Games for Change on the whole without a specific focus would result in only vague recommendations, and a "one-size-fits-all" solution is not likely to exist given the wide range of purposes and non-gaming contexts Serious Games and Gamification reach. Thus, there is a need to scope the project to a particular application domain, yet still provide insights which can be applied to Games for Change as a whole.

To this end, this chapter identified that a promising avenue for scoping was that of energy conservation. Bringing about energy conservation behaviours is most definitely a serious purpose: energy conservation is a prominent aspect in the fight to mitigate Climate Change. This chapter has provided a review of the literature on energy conservation, and it has shown that residential energy conservation stands to be one of the biggest areas in which we can reduce $CO_2$ emissions. Part of this review covered traditional, non-technology based strategies for bringing about energy conservation behaviours in people, the most prominent of which is the application of Social Normative Theory.

Video games are exceptional at providing feedback to players, and thus the integration of energy conservation and games appears promising. Indeed, initial results from Games for Change in the energy domain are encouraging, with Kukui Cup and Energy Battle illustrating impressive near-term outcomes in particular. However, the limitations and criticisms identified for Games for Change in general are still present, with a strong reliance on basic Gamification approaches and a lack of robust underpinning psychological theory grounding the work. The latter is particularly significant given the focus on driving behaviour change, and it is unsurprising that none of the surveyed games identified long-term behaviour change. It is also interesting to note that social normative theory does not feature in the design of the Serious Games examined, missing a key opportunity to leverage intrinsic and extrinsic drivers.

The chapter concluded by presenting a problem statement which summarised the issues identified with Games for Change implementations. The importance of addressing this problem has been described in this chapter. Effective residential energy conservation stands to reduce carbon emissions by the equivalent of 14.7 million cars in the US alone (Ehrhardt-Martinez et al. 2010). Research from both an energy perspective (Nolan et al. 2008; Schultz et al. 2007; Ehrhardt-Martinez et al. 2010), and a Games for Change perspective (Robertson 2010; Deterding 2011; Nacke & Deterding 2017) has called for improvements in energy feedback displays and behaviour change games respectively.

Using the problem statement as a guide, a purpose statement was presented which was used to formulate the guiding main research question of the thesis:

> *What are the opportunities and challenges in integrating both games design and behaviour change techniques towards the development of a Serious Game for changing residential energy behaviour?*

The following chapter explores this question detail in the form of sub research questions, followed by a description of the methodology used for addressing these questions.

# 3 Methodology

The previous chapter provided an understanding of how video games in the form of Serious Games and Gamification can be used in non-gaming and non-entertainment contexts to bring about social and environmental good in a number of domains, including energy conservation. The literature shows that residential energy consumption is a promising area for reducing carbon emissions (Ehrhardt-Martinez et al. 2010), and that both the application of behaviour change theories and Serious Games are promising ways of reducing this consumption. Serious Games however have yet to truly make use of behaviour change theories in any formal way, and there is an opportunity to develop a Serious Game intervention which has game elements that are informed by behavioural theories, rather than merely using points, badges, and leaderboards.

This chapter builds upon the narrative of the literature review by first stating the main research question. This question is then broken down into five distinct sub-research questions, and the data requirements for each are detailed. Based upon these requirements, a research design following the Intervention Research model by Rothman & Thomas (1994) is presented, outlining stages for a *literature review*, *game design*, and *experiment*. The chapter concludes with an overview of the epistemological and ontological positions undertaken throughout the research.

## 3.1 Research Question

Chapter 2 has shown that Games for Change lack the appropriate use of behaviour change theory in their design, and often rely on points, badges, and leaderboards. The previous chapter has shown that this is true when scoping the analysis down to the application domain of energy conservation. We have seen that there is a need for improved feedback technologies in the residential energy space as a means of reducing $CO_2$ emissions to mitigate Climate Change. Recent studies on in-home displays and web portals are showing only 3–5% conservation effect in larger sample studies, compared to original estimates of around 6–10% (McKerracher & Torriti 2013).

Serious Game designs for the purpose of energy conservation are still in their early stages, and indeed some prototype designs such as the *Wattever* system (Vaijayanthi & Marur 2012), and *MAEGUS* (Nataraja & Whittinghill 2013) are beginning to show the potential steps that can be made in the area beyond just the PBL triad. This research aims to build upon lessons learned from past implementations, but also explore new avenues identified by following a defined methodology for intervention design that is based upon behavioural theory.

This leads to the guiding research question for this work:

> *What are the opportunities and challenges in integrating both game design and behaviour change techniques towards the development of a Serious Game for changing residential energy behaviour?*

At the core of this research question are the components of Serious Game design, behaviour change theories and energy conservation. The literature has shown that energy conservation in a residential setting is an important area to focus on (Ehrhardt-Martinez et al. 2010). Serious Games have been used in this setting, as has behaviour change theory in the form of Social Normative Theory in non-technology based examples, however these two concepts are yet to be combined. This work seeks to address this, and goes further by providing a introducing a broader range of psychological theories, and by developing a robust approach to design that may be replicated by other researchers in the field.

This thesis takes these three core components, brings them together, and explores both the opportunities and challenges in doing so.

From the research question, it can be seen that addressing the question is likely to contribute to the body of knowledge in the areas of Serious Games, behavioural psychology, and energy interventions in general. In order to effectively address this multi-faceted question, a number of sub-research questions have been identified, and these are described in the next section.

### 3.1.1 Sub-Research Questions

The main research question for this project seeks to determine the opportunities and challenges involved in making a Serious Game that is underpinned by well-founded behaviour change techniques. This section presents a number of sub-research questions developed to the end of breaking the main research question into more richly defined and specific components.

In total, there are five sub-research questions, and these are broadly categorised into questions about the

- *opportunities*: determining what work in the energy domain has been done before, and how we can build upon it; and
- *challenges*: exploring the issues that may arise when developing a new approach to Serious Game design and implementation in the energy conservation domain.

The following sub-sections present these two groupings of sub-research questions, before a summary aided by a diagram of the sub-research questions is provided.

#### *3.1.1.1 Opportunities*

Answering the main research question involves bringing together knowledge from a number of very different domains. This leads to the first sub-research question (*SRQ1*), concerned with the different types of approaches to using Serious Games for energy conservation.

> **SRQ1***:* *How have Serious Games been used to influence energy behaviour in the past and how could they be improved?*

This sub-research question in part can be answered by exploring the previous work in the area of Serious Games and energy conservation, and examining which elements produced the greatest impact. A greater understanding of how these implementations impact energy behaviour can guide the design of future Serious Games.

Similarly, *SRQ2* draws from previous work in the social sciences that attempted to bring about energy behaviour change.

> **SRQ2***:* *How can behaviour change theories be used to influence residential energy behaviour?*

Again, identifying opportunities for how theory can impact residential behaviour based upon the literature is an important part of understanding the main research question. It will also guide the choice of the most promising behaviour change techniques to employ in the design of the Serious Game.

In order to truly explore the opportunities (and also the challenges) afforded by designing a Serious Game that brings together game elements and behaviour change techniques, a case study of such a game should be conducted. However, as the extant literature shows, implementations of Serious Games have so far not been informed by behaviour change theories directly, leaving us with no such game to analyse. As will be described throughout this chapter, an illustrative game that draws on design principles underpinned by behaviour change, providing an empirical basis for understanding the practical performance of games stemming from a more integrated approach to design was implemented. The intent is to understand how theoretical design and practical performance interact, and to provide guidance to the wider research community as to how future Serious Games in the energy space may be optimally implemented and deployed.

This affords us the advantage of being able to deeply explore the design process, a process which constitutes a major contribution of this work as it has never been attempted before. This unique integration of Serious Game elements and behaviour change techniques is represented by *SRQ3*.

> **SRQ3***:* *How can we design a Serious Game that integrates game elements and behaviour change techniques within an energy conservation context?*

The undertaking of this new game design method is not foreseen to be easy, but rather challenging, and therein lies the value. This work aims not to just simply present a Serious Game that formally incorporates behaviour change techniques, but to also fully explore the *challenges* in doing so. The following section covers the sub-research questions pertaining to these challenges.

#### *3.1.1.2 Challenges*

Bringing together the complex areas of game design, behaviour change techniques, and energy conservation is a unique task. The previous sub-research questions have considered the opportunities of this, however it is an important output of this work to discuss the myriad challenges of doing so. As such, *SRQ4* focusses on the challenges involved with the design process.

> **SRQ4***:* *What are the challenges involved in designing a Serious Game for changing residential energy behaviour?*

To further strengthen the discussion of challenges, it is important to also cover the implementation-based issues that can arise when evaluating a Serious Game in the area of energy conservation. *SRQ5* considers the challenges relating to the experiment process, as well as the practical factors that may impede a game that was designed using the process covered by *SRQ3*.

> **SRQ5***:* *What factors can influence the likelihood of successes of a Serious Game for changing residential energy behaviour?*

Answering *SRQ4* and *SRQ5* provide value to future researchers not only looking to develop energy conservation interventions in the form of Serious Games, but developers of Serious Games in general. The output of these questions form a valuable contribution by detailing the key considerations in the delivery of a multi-disciplinary process such as this.

#### *3.1.1.3 Sub-Research Questions Summary*

To address the main research question, sub-research questions were created that in general look at the opportunities and challenges of bringing together behaviour change techniques and Serious Games. Figure 24 shows diagrammatically the ways in which the sub-research questions address the main question.

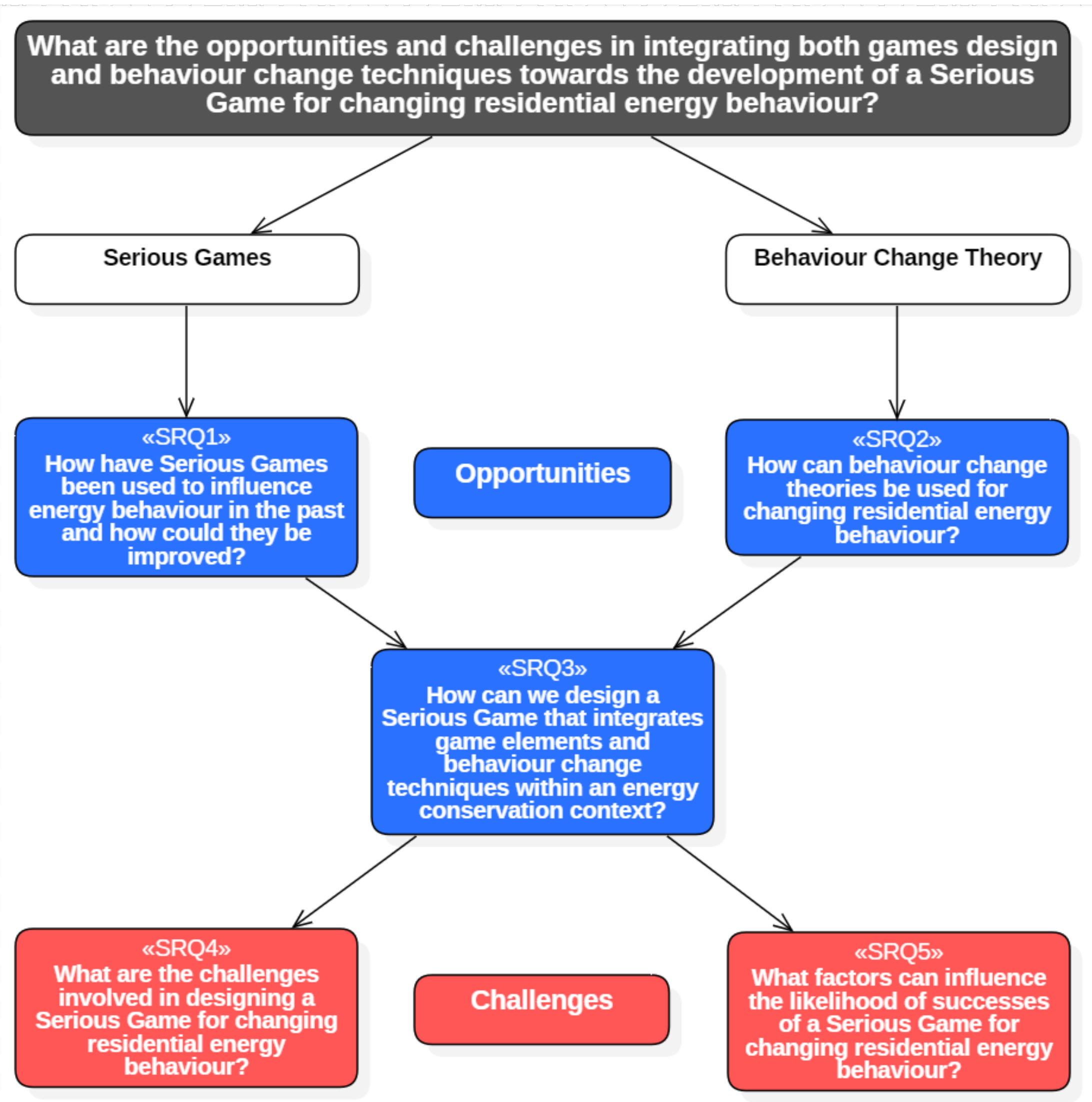



**Figure 24. Diagram of concepts of the main research question, and how these concepts relate to the sub-research questions.**

*SRQ1* and *SRQ2* consider Serious Games and behaviour change theory respectively in terms of the possibilities of applying those techniques in the area of energy conservation. *SRQ3* represents the marrying of these two concepts in the form of a novel design process. Finally, *SRQ4* addresses the challenges involved in the intervention design process, and *SRQ5* covers the practical factors that may arise when attempting to deploy such an intervention.

### 3.1.2 Research Question Summary

The guiding research question for this work has been provided in this section. The core themes of the question are Serious Games, behaviour change techniques, and residential energy conservation. The question explores both the opportunities and challenges that exist when looking at the complex and novel process of bringing Serious Game elements and behaviour change techniques together.

To aid in answering the multi-faceted main research question, sub-research questions were developed, three covering opportunities, and two covering the different kinds of challenges. With these sub-research questions in mind, in the next section identifies the data requirements for addressing these questions, and the source of that data. From these requirements, a suitable methodology and research design can be formed.

## 3.2 Data Requirements and Sources

The data requirements for each of the sub-research questions differ greatly in terms of the kind of data that is needed, and the sources and methods used for each. As illustrated by the summary of data requirements in Table 1, data was collected through literature, design, and experimentation. Table 1 also describes the main chapters responsible for addressing the sub-research questions, however it should be noted that the conclusion chapter (Chapter 9) also contributes a more explicit answer for each question.

| SRQ | Question |
|---|---|
| 1 | How have Serious Games previously been used to influence residential energy behaviour? |
| 2 | How can behaviour change theories be used to influence residential energy behaviour? |
| 3 | How can we design a Serious Game that integrates game elements and behaviour change techniques within an energy conservation context? |
| 4 | What are the challenges involved in designing a Serious Game for changing residential energy behaviour? |
| 5 | What factors can influence the likelihood of successes of a Serious Game for changing residential energy behaviour? |

| SRQ | Data Requirements | Source | Method | Chapter |
|---|---|---|---|---|
| 1 | Examples of Serious Games for changing energy behaviour | Literature search | Literature review | 2 |
| 2 | Examples of behaviour change theories employed change energy behaviour | Literature search | Literature review | 2 |
| | Possible techniques for changing energy behaviour | Behaviour Change Techniques (BCTs) | *Intervention design phase*<br>- Behaviour Change Wheel (BCW; Michie et al. 2011) systematic method to identify Behaviour Change Techniques (BCTs) | 4 |
| | Behaviour change techniques in Serious Game | Developed game | *Game design phase*<br>(see SRQ3) | 5 |
| 3 | Developed Serious Game with elements informed by behaviour change techniques | | | |
| | - Theory-informed game elements | Behaviour Change Techniques (BCTs) | *Intervention design phase*<br>- Behaviour Change Wheel | 4 |
| | | Game Elements | *Intervention design phase*<br>- Literature review<br>- Game review<br>- Brainstorming | 4 |
| | - Serious Game | Developed game | *Game design phase*<br>- Novel method linking game elements to BCTs<br>- Human Centered Design (HCD; Holloway & Kurniawan 2010) | 5 |
| | - Evaluation of Design | Smart meter data<br>Game metrics data<br>User experience questionnaire | *Experimental phase:*<br>- Pilot test<br>- pre-test/post-test control group experiment | 7 |
| 4 | Challenges in Serious Game design | Literature search | Literature review | 2 |
| | | Discussion | Reflection | 8 |
| 5 | Challenges in implementation | Literature search | Literature review | 2 |
| | | Discussion | Reflection | 8 |
| | Participant predisposition to energy conservation | CSIRO survey data | Data analysis | 6,7 |

**Table 1. Data requirements for the sub-research questions, the source of the data, and the method used for collecting that data. Sub-research questions are included at the start of the table.**

The following sub-sections examine each of the sub-research questions' data requirements, sources, and methods of collection. This is accomplished by addressing the available options, and justifying the chosen ones. From this a suitable methodology and research philosophy can be determined.

### 3.2.1 Sub-Research Question 1

How have Serious Games been used to influence energy behaviour in the past and how could they be improved?*SRQ1* was primarily literature-based and focused on presenting the current knowledge on the ways that Serious Games have been used to elicit behaviour change in the field of energy conservation. Thus, for this question the data required were previous examples of how this had been approached in the past.

The source of this data was a literature review of publications reporting on Serious Game interventions that have targeted energy conservation (see Section 2.3). An alternative source for this data would have been to play the Serious Games themselves, however, this would have been problematic due to limited access to these games. Access is limited in terms of the timeframe (i.e. trials have already closed, or are deployed on an invite-only basis), region, and the need for specific technologies (such as a particular type of smart meter).

### 3.2.2 Sub-Research Question 2

*How can behaviour change theories be used to influence residential energy behaviour?*

Similar to *SRQ1*, *SRQ2* involved a literature search of current knowledge. In order to help identify promising theories, previous applications of various behaviour change theories to the domain of energy conservation were collected as the data for this question.

The source of this data was a literature review of publications reporting on interventions using behaviour change theories in the energy conservation domain. Again, this is represented primarily in Chapter 2.

Consultation with experts in the social sciences with the CSIRO was also used as a source to guide the search for behavioural theories. This was informal in nature however, and was used only to complement and inform the literature search.

A vital first step following on from the literature phase was exploring the concept of energy conservation behaviour in detail. This involved identifying what specific kinds of energy conservation behaviours are of interest. This is superior to simply targeting energy conservation as a whole, as according to Michie et al. (2011) it is better to target a small number of specific behaviours in an intervention than to target a broader, less-defined behaviour. This process was done using the Behaviour Change Wheel (BCW) methodology by Michie et al. (2011) which is described in detail in Chapter 4.

The design of the developed Serious Game for this project also helped address this sub-research question. The implementation of the chosen BCTs (presented in Chapters 4 and 5, and tested in Chapter 7) embedded in the game design are the aspect of the game which addressed this question as further examples of behaviour change techniques used for energy conservation.

### 3.2.3 Sub-Research Question 3

> *How can we design a Serious Game that integrates game elements and behaviour change techniques within an energy conservation context?*

Previously published video game energy conservation interventions have thus far have primarily included points, badges, and leaderboards. As a result, there exists no Serious Game that can be examined to explore the integration of a range of behaviour change techniques and game elements. This sub-research question is therefore concerned with the effective design of a Serious Game that provides more than just PBL game elements, examines more substantial elements of games, and considers them in terms of a range of behaviour change techniques.

This sub-research question has data requirements relating to both the *design* of the game (i.e. how it was created; described in Chapters 4 and 5), as well as the *evaluation* of the design (described in Chapters 6 and 7) in terms of its ability to reduce energy consumption and deliver enjoyment. For readability, the data requirements for design and evaluation are presented in the following two sub-sections.

#### *3.2.3.1 Design*

*SRQ3* addresses the design of the Serious Game intervention through selection of Behaviour Change Techniques. The Behaviour Change Wheel process does not however, prescribe game elements that match these BCTs. The BCTs identified are intended to facilitate given target behaviours, and thus if game elements are chosen which support these BCTs, then the game elements in theory support changing the target behaviours. Therefore, a major contribution of this work is to identify game elements which support the chosen BCTs.

One element of data for this sub-research question comes from the application of this new method of linking game elements with BCTs. In order to do this, a source of potential game elements is required. There is no current formalised or exhaustive list of game elements in the extant literature, and so a literature search of previous Serious Game and Gamification implementations was conducted, to produce a "pool" of game elements to draw from when considering behaviour change techniques. The complete process undertaken is described in more detail in Section 4.3.

With a suitable source of game elements in hand, the process is then to examine the literature about each element to determine if an element satisfies any of the BCTs identified from the BCW process. The outcome of this is a list of the game elements which can be employed in Serious Games for energy conservation, and a mapping of the BCTs they support. The full process and the result of this is described in Chapter 4.

This mapping helped guide the development of an illustrative Serious Game for this project. The final aspect of the design data requirement for this sub-research question is drawn from the details of the Serious Game resulting from combining the game elements together. The development process of the Serious Game followed a Human-Centered Design approach by Holloway & Kurniawan (2010), described later in this chapter and in Chapter 5.

#### *3.2.3.2 Evaluation*

With a Serious Game developed, it is important to evaluate the effectiveness of the design. When considering the effectiveness of an energy conservation behaviour, it is common to consider difference in overall energy consumption during the intervention compared to another time, referred to as *conservation effect*. In terms of considering the effectiveness of the Serious Game itself, it is also important to look at the player's reaction to the game through factors such as enjoyment and length of play. This sub-section looks at the data requirements for these two broad terms of the "effectiveness" of the Serious Game. Full details of the deployment are provided in Chapter 6, and the results are presented in Chapter 7.

In order to determine if a difference in energy consumption has taken place, it follows that participants' energy consumption must be recorded. There are a few sources that were considered for obtaining this data (Johnson et al. 2017). In the past, researchers have manually taken readings of electricity meters in participants homes (Schultz et al. 2007), however this was considered to be time consuming and limiting in terms of the number of participants and the geographical location of participants that could be reached (i.e. realistically a research team could only manually read the meters of members of the population who were in the same general proximity as the team, and due to the labour involved, only a limited number could be measured in a reasonable timeframe). Such an approach would also require expert knowledge on how to read various meters, and be prone to human error (in the case of Schultz et al. (2007), in some cases readings were taken by two members of the research team to assess the reliability of the readings). Another method for measuring that has been used previously is to record energy usage as reported by electricity bills (Allcott & Rogers 2014). This could be done either automatically with access to power company records, or using a self-reporting system where participants report their power bill information. This has drawbacks in terms of only getting information at power bill intervals (usually monthly at best), and the latter option is prone to human error or misleading reports. A similar form of self-reporting was considered in terms of asking participants to assess their own energy conservation behaviour. In a review of intervention studies in the household energy conservation area, Abrahamse et al. (2005) identifies a number of studies which have used this form of self-reporting, and notes that this form of collection is affected by social desirability bias where participants may wish to appear more energy-conscious than they actually are. This lack of reliability in self-reporting was considered unacceptable, and thus was not used in this project.

The most promising source for obtaining energy consumption data is through smart meters, which are electricity meters with additional functions for recording multiple aspects of energy usage at once (different circuits, air conditioners, water, and gas), with an internet connection that allows usage data to be sent periodically to energy companies (see Section 2.2.2.2.1 for a more detailed description). Beyea (2010) note the importance of using smart meter data in a range of contexts, and indeed in the specific context of Serious Games for energy conservation, smart meters have been used for measuring energy consumption (Brewer 2013; Geelen et al. 2012; Gremaud 2013). Ultimately, for these reasons, smart meters were chosen as the source for this data requirement. As described later in this chapter—access to these devices was enabled by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). An alternative source for collecting energy usage data considered was *WattDepot* (Brewer & Johnson 2010)[57] which provides a web interface for accessing energy data from certain smart meters. However, this was not plausible to use, since it is not available in Australia. Similarly, the *Green Button*[58] project, which allow users to download their energy consumption data in a standardized XML format was considered, however the designed game would only be able to react to this data whenever the user inputted the data, as opposed to on-demand.

In order to draw scientific comparison, an experiment using a pre-test/post-test control group design was used. Those in the treatment group were provided the Serious Game, and those in the control group were not. A full description of the experimental process is provided in

[57] http://wattdepot.org/

[58] http://energy.gov/data/green-button

Section 3.3.5. According to Johnson et al. (2017) few studies on Games for Change within the energy conservation space made use of a control group design, and they identified a "clear need" for studies that examine the impact games compared to no intervention.

As previously discussed, in addition to energy consumption, player experience is a critical part of measuring the success of a Serious Game. Nacke et al. (2009) identified game analytics (also known as metrics) as an important way of objectively, quantifiably, exploring the player's interaction and experience of the game, and Johnson et al. (2017) note the use of such logging amongst extant energy conservation game studies. A quantitative analysis was conducted on specific in-game metrics to see if higher use of the game correlated with reduced energy consumption.

These quantitative components allow for the evaluation of the Serious Game as a whole, however an important part of the design of the Serious Game was to identify game element components that it is comprised of. Analysis of the individual effectiveness of each game element was conducted in terms of game analytics (see Section 6.2.2.3). The recorded game metrics will form the basis of the analysis to extract the individual effectiveness of each game element. This analysis will be in the form of the frequency of use of each element correlated with reduced energy consumption.

Additionally, a survey component obtaining player feedback on game elements was developed. Questionnaires are frequently used within Games for Change energy conservation studies (Johnson et al. 2017). A commonly used survey instrument for the purpose of exploring the game experience is the Game Experience Questionnaire (GEQ) developed by IJsselsteijn et al. (2008). The survey allows for qualitative analysis of the game experience in terms of sensory and imaginative immersion, tension, competence, flow, negative affect, positive affect, and challenge (IJsselsteijn et al. 2008). Upon further analysis of the GEQ however, the questions are poorly fit for determining the effectiveness of specific game elements, being best suited to an assessment of the engaging nature of the game as a whole.

Since there has been no previous work on linking game elements to BCTs, there are no surveys which could be employed for the purpose described above. As a result, a custom survey was developed. This survey is based upon the chosen Behaviour Change Techniques and game elements of the implemented Serious Game, and is described in Section 6.2.2.5.

#### *3.2.3.3 Sub-Research Question 3 Summary*

*SRQ3* represents the design of the Serious Game, the output of which is a mapping of Behaviour Change Techniques and game elements, which are focussed on encouraging determined target behaviours as a result of the Behaviour Change Wheel process. Game elements will be sourced from literature and popular mobile games, and each considered for their possible linkages to BCTs—a method which has not been undertaken before. This sub-research question also covers the evaluation of this design, in terms of the conservation effect delivered by the game and the overall player experience.

#### 3.2.4 Sub-Research Question 4

*What are the challenges involved in designing a Serious Game for changing residential energy behaviour?*

The final two sub-research questions represent an extensive, empirically-grounded, discussion of the challenges involved in both the design and implementation of a Serious Game which brings together game elements and BCTs. *SRQ4* focuses on the design aspect, and as such the main data requirement here was a structured discussion of the challenges encountered during the design process for this project. A reflective process was undertaken, where the main challenges of the design phase were considered. Each step of the process was reflected upon, and the issues that arose are presented. The intent of presenting the reflection process is to provide future development of Serious Games in this space with a series of lessons learned, and recommendations to avoid the issues encountered in this project.

It is important that this discussion is contextualised by literature that shows previous examples of these challenges, potential reasoning for why these challenges occur, and ways in which these challenges can be avoided, and this is accomplished in Section 8.1.

#### 3.2.5 Sub-Research Question 5

*What factors can influence the likelihood of successes of a Serious Game for changing residential energy behaviour?*

Similar to *SRQ4*, *SRQ5* had the data requirement of structured discussion of the practical issues that can have an impact on the success of a Serious Game for energy conservation. The points for this discussion were again obtained by reflecting upon the lessons learned from implementing the Serious Game for this project, including an assessment of limitations related to the experiment, technology, and game. Again, the discussion linked back to literature for examples and reasoning. The discussion is covered in Section 8.2.

When addressing this research question, additional data to support some of the identified factors was needed. Particularly, one of the factors was the potential bias in demographic and pre-existing energy conservation attitudes of the participants. Data to support this was required, and sourced from surveys completed by the CSIRO in 2012 with the same participant pool.

### 3.2.6 Data Requirements and Sources Summary

This section has shown the data requirements for each sub-research question, and introduced the methods that were employed for sourcing that data. It has shown how the data requirements relate the main research question.

In terms of the main research question, this can be addressed by combining and synthesising the following data:

- collection of literature review data in the areas of Serious Games, behaviour change theory, and energy conservation;
- the result of a BCW systematic process for designing an intervention, resulting in Behaviour Change Techniques;
- a novel linking of Behaviour Change Techniques to game elements;
- a Serious Game that is comprised of theory-informed game elements;
- the result of analysis comparing energy usage of participants given the Serious Game versus usage data of those not given the game;
- the result of analysis of game metric data and survey responses that are particularly focussed on the effectiveness of specific game elements; and
- a structured discussion of the challenges involved in the design and experiment process, underpinned by experimental findings.

From the data requirements shown in this section, it is clear that a methodology was needed that includes information discovery about the problem space, design and development of an intervention, and finally evaluation of that intervention. Given these data requirements, and the kind of methodology required, the following section describes the overarching research design that was used for this project.

## 3.3 Research Design

The previous section identified the data requirements to address the sub-research questions, the sources of that data, and the methods used to collect that data. From these requirements, it became clear that this project would be undertaken with four main phases:

- a *literature review* phase to analyse the problem space, identify and critique previous work, and discuss the opportunities that exist within the space;

- an *intervention design* phase to analyse the problem from a behavioural theory standpoint, and select behaviour change techniques and supporting game elements;
- a *game design* phase to design and develop a Serious Game comprised of these theory-informed elements, and pilot test the game; and
- an *experimental* phase to evaluate the created game in terms of its effectiveness, discuss the challenges encountered, and make recommendations to future researchers.

The next section describes the methodology that was identified which encompasses all of these phases and is also relevant to the task of designing an intervention. The methodology is introduced and how the specific phases for this project are situated within it, before details of each of the phases of the research design are presented.

### 3.3.1 Intervention Research Design

A methodology was identified that encompasses these phases, and is also relevant to the task of designing an intervention: the *Intervention Design* methodology developed by Rothman & Thomas (1994). Figure 25 represents diagrammatically how this methodology was adopted to suit the data requirements, and how this relates to the sub-research questions. The initial stages of the Intervention Design framework (planning and information gathering) encompass the literature review phase, design and development (referred to by Rothman & Thomas as *D&D*) encompass the intervention design and game design phases. The remaining stages of experimentation and dissemination are analogous to our final experimental phase. The diagram is used throughout the remainder the thesis to provide context for each chapter in terms of which part of the methodology is being presented.

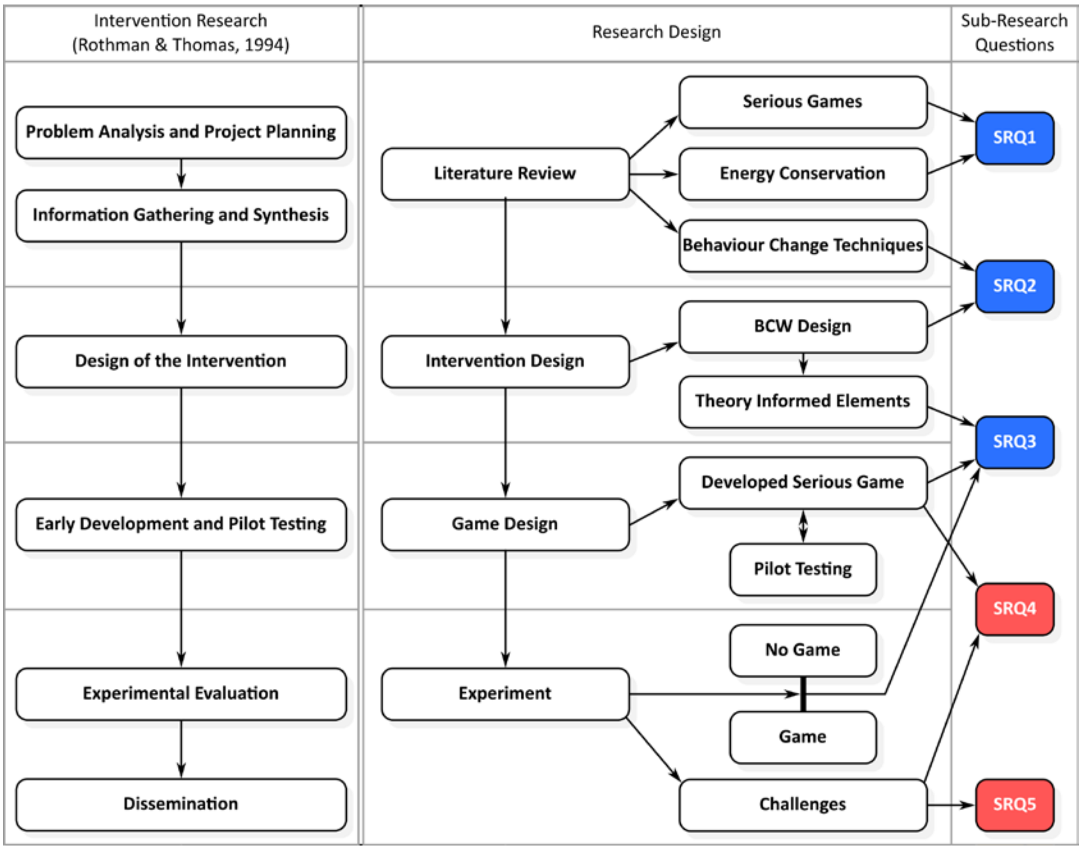



**Figure 25. The Intervention Design methodology (Rothman & Thomas 1994) stages, and their equivalent phases in the design of this research, presented in terms of the sub-research questions.**

Since its development by Ewin J. Thomas and Jack Rothman in 1994, the Intervention Research (IR) model has been used methodology for designing and evaluating various interventions. The method acknowledges the challenges and issues that stem from the fact that intervention research is usually conducted in a field setting and is a useful tool for those developing innovating or novel solutions (Comer et al. 2004).

IR was intended to be an integrated paradigm, bringing together streams of research from social innovation, social research and development, developmental research, model development, and behavioural community research.

The synthesis of these research areas resulted in a methodology comprising six sequential, cumulative phases (Rothman & Thomas 1994):

- problem analysis and project planning;
- information gathering and synthesis;
- design of the intervention;
- early development and pilot testing;
- evaluation and advanced development; and

- dissemination.

As shown in Figure 25, these phases suitably match the data requirements and methods needed for the sub-research questions. The *problem analysis and project planning* stage involves the processes of understanding the problem of concern, identifying potential intervention options for addressing this problem, understanding technical, human, and social inhibitors to the feasibility of the intervention, and developing a plan for how the intervention will be delivered. The literature review phase of the research design project focussed on this exploration of the problem space, by looking at previous work in the area of energy conservation. The initial stages of the Behaviour Change Wheel method used in the game design phase also helped to consolidate this analysis of the problem space in a systematic way.

The literature review also neatly fits within the *information gathering and synthesis* phase, which involves identifying existing relevant information in the form of previous studies, exploring the different ways in which data can be collected, and synthesising that information. This synthesis is an outcome of the literature review phase.

A goal of the literature review to identify opportunities for Serious Games to use behaviour change techniques will come naturally from the processes of problem analysis and project planning, and information gathering and synthesis described above.

Building upon this information base, the next stage of the IR model is *designing the intervention* which includes selecting the best models for bringing about change, identifying deployment options, and determining who will be involved in the actual design of the intervention. The intervention design phase of the thesis fits within the intervention design stage of the IR model as the BCW process addresses these issues, with the outcomes of determining target behaviours and the BCTs with the highest potential. The novel method of linking video game elements to these BCTs is also a part of this stage.

The game design phase represents the development of these video game elements into a cohesive Serious Game and this fits well with the *early development and pilot testing* phase of the IR model. Having a game design phase which covers the design and development phases of the IR model seems ideal due to the fact that the IR model is often referred to as a *design and development* method (Comer et al. 2004), implying that these two phases are tightly linked. Within this phase, IR includes the formulation of the procedures and instruments (in the case of this project the instrument is the Serious Game), and refining the output based upon pilot testing. For this project the testing was in the form of consultation with subject matter experts, which is an established practice in intervention design in general (Rothwell 2000), and for developing Serious Games (Hussain & Coleman 2014; Kelly et al. 2007; Raybourn 2007).

The *evaluation* and *dissemination* phases of the IR model represent the experiment phase of this project. Delivery to users, and evaluation of the intervention was conducted during this stage. The IR model acknowledges the flexibility required when testing interventions in the field, and thus do not specify if experimental, quasi-experimental, or non-experimental methods should be employed. For this project however, to maximise internal validity, a true experimental method with a pre-test/post-test control group design was chosen.

In addition to the experiment, the evaluation and dissemination phases cover the extensive discussion of challenges involved in the design and implementation of the Serious Game, and the presentation of a set of recommendations to aid future endeavours delivering Serious Games grounded in behaviour change theory. The importance of discussion in intervention research design seems perhaps underplayed in the description of the methodology, however given the value in presenting a strong discussion on the challenges, the discussion component has a strong representation within this project.

Fraser & Galinsky (2010) have suggested an intervention research design which is heavily influenced by the IR model, the main difference being a focus on developing intervention manuals. Their method is more focused on the area of social work, and given the exploratory nature of this project, a manual prescribing how to implement the intervention was not considered necessary. However, a detailed description of the lessons learned and future opportunities was considered important information to impart, in the hope of strengthening the prospects of future Serious Games not only in the area of energy conservation, but for behaviour change in general.

The following sub-sections describe the phases that comprise the research design of this work, noting that the literature review stage has previously been covered in Chapter 2.

### 3.3.2 Intervention Design Phase

Building upon the information gathering and planning stages, a rigorous design process was undertaken, to illustrate the opportunities in the fields of energy conservation and Serious Games. The design process consisted of three main components:

- an intervention design component to understand the behaviours we are trying to change, using a methodology called the Behaviour Change Wheel (BCW) by Michie et al. (2011);

- an augmentation of the BCW with a novel methodology of applying the outcome of the BCW to video game elements (see Section 3.3.3); and
- a game design component which follows Human-Centered Design (HCD) inspired framework for developing a Serious Game by Holloway & Kurniawan (2010) (see Section 3.3.4).

The BCW has been used by intervention designers as a systematic method for reviewing the full range of intervention options available to them, and to understand the behaviours they are targeting. The BCW describes intervention design in the following systematic steps: understanding the behaviour, identifying intervention options, and identifying implementation options. This process is formalised by the BCW, and supported by the Capability Opportunity Motivation Behaviour (COM-B; Michie et al. 2011) model and Theoretical Domains Framework (TDF; Can et al. 2012).

Previously, the BCW has been used in a wide range of areas such as health and health policy implementation, and pro-social behaviour, with studies focussing on melioidosis in Thailand (Chansrichavala et al. 2015), smoking cessation in England (Brown et al. 2014), increasing young adult condom use (Newby et al. 2013), improving the delivery of paediatric services in Kenyan hospitals (English 2013), and a study on public health policy for childhood obesity (Hendriks et al. 2013).

Of particular interest to this study, the BCW has also been used in the area of environmental sustainability. Curtis et al. (2013) used the BCW as a guiding theory for their exploration of home composting behaviours. Geelen (2013) looked at methods to inform residents about sustainable renovation measures in the *Livinggreen.eu* project, drawing on the concept that behaviour is predicated by capability, motivation, and opportunity. A similar theme was present in a study looking at air-conditioner usage in Chinese offices by Zhuang & Wu (2014).

For the current project, the BCW methodology was applied to the energy conservation domain by examining energy usage behaviours, and analysing various intervention functions (ways in which an intervention can be done) and deployment methods in terms of their affordability, practicability, effectiveness (including cost), acceptability, safety, and equity (the APEASE criteria, described in full in Section 4.1.4). From this a set of Behaviour Change Techniques was developed which were considered promising methods for eliciting behaviour change in a Serious Game.

The result of this process is an intervention strategy in the form of target behaviours and relevant BCTs that together become the basis from which the design of the game elements is identified. The next sub-section describes this method.

### 3.3.3 Linking Game Elements to Behaviour Change Theories

Applying the intervention strategy that results from the BCW is a unique contribution of this work. Linking game elements with BCTs is especially important since previous designs of Serious Games for energy consumption have mostly only included PBL elements.

In order to link elements with BCTs, a pool of candidate game elements was required. Since there is not an exhaustive catalogue or taxonomy of game elements in the extant literature that doesn't have a specific focus on Gamification, a list of candidate elements was produced, using two main methods: searching the literature on Serious Games and identifying the elements contained within popular mobile video games. Popular games were chosen under the assumption that the gameplay in those games was on-the-whole considered to be pleasing, and mobile games were chosen due to the chosen mode of delivery according to the BCW (see Section 4.2.8).

The game elements were each in turn examined within the literature and in consultation with subject matter experts to determine the extent to which that element may facilitate the chosen BCTs. The full process and the results are described in detail in Section 4.3.

The result of the intervention design process and linking game elements to BCTs is a set of theory-informed elements which may be used in a Serious Game, however it does not result in a Serious Game whole at this stage. This is instead the result of the *game design* phase, described in the next section. It should be noted that given the iterative nature of game design, there was some natural overlap between this stage and the game design phase.

### 3.3.4 Game Design Phase

A process of designing a game which encompassed the theory-informed elements from the intervention design phase was undertaken and this process was guided by a Human-Centered Design (HCD) approach that has been applied to Serious Game design by Holloway & Kurniawan (2010). Their version of the HCD method consists of four main interacting components, as shown in Figure 26.

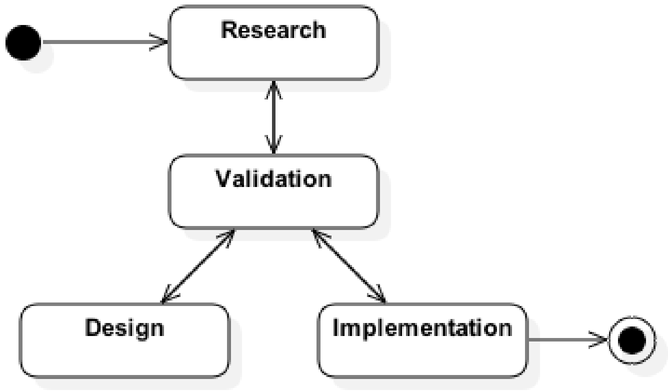



**Figure 26. The HCD approach to Serious Games developed by (Holloway & Kurniawan 2010).**

The *research* component of the Holloway and Kurniawan approach effectively represents the literature review phase of the overall research design, and the BCW component of the intervention design phase, as this stage involved literature searches.

The *validation* component involves consultation with experts of the domain, and experts in game design, and the authors suggest focus groups and interviews for this evaluation. As shown in Figure 26, researchers should return to this validation stage to validate the design and implementation in an iterative manner. For this project, this consultation was done with experts from the CSIRO Energy Flagship, social scientists experts at the CSIRO, and video game designers at the University of Tasmania.

The *design* stage consists of developing (in some cases implementing, but in others merely conceptualising) the concept of the game, the game mechanics and elements, the user interface, and the story. These are all core components of the design of the Serious Game, and as stated above, constant validation via consultation with experts was sought in an iterative process.

A similar process of validation was undertaken for the HCD method's *implementation* phase, which is intended to produce a number of prototypes, as well as a final version. The implementation and design phases complement each other through the validation phase. This is evident in the approach for this project as a number of prototypes were developed, based upon the result of validating designed elements and validating previous prototypes. Part of the prototyping involved creating a number of small-scale proof-of-concept games covering multiple popular mobile-game genres to address the feasibility of each game type, and also the iterative development of the main *Energy Explorer* prototype.

During this phase, the main Serious Game was developed in the *Unity* game engine, and a system architecture including a server with a *MySQL* database and *PHP* Web Application Programming Interface (API) was designed and created. The resultant Serious Game and the elements therein is described in detail in the next chapter.

The method by which the impact of the game was analysed is described in the following section as well as how energy consumption data was collected that the game world reacted to.

### 3.3.5 Experimental Phase

With a Serious Game designed and developed, the game was distributed to a set of participants in order to measure any change in their energy behaviour. The experimental design used was pre-test/post-test. The participants were recruited from a previous CSIRO study, the Residential Building Energy Efficiency Standards (RBEES) project (described in Section 6.2.1.1), which covered over 400 homes in Melbourne, Brisbane, and Adelaide. Participants were invited via email to play the game and those who did not accept or respond constituted the control group. It should be noted that, ideally, the control group would have been made up of people who were not contacted at all, however a large participant pool was required to suitably test the game (see Sections **Error! Reference source not found.** and 8.2.5.1 for detail on why a high participant count was required). Full details on the deployment process are covered in Chapter 6.

While using the game, data was collected for a number of variables. Like the Serious Game examples reviewed, the primary variable to be considered was electricity consumption as measured by a smart meter. This data was collected via an *EcoPulse* smart meter in the homes of participants, which were installed as part of the RBEES project. The game reads this data in the form of a number expressed in kilowatt hours (kWh) for overall consumption during a time period, as well as for different *channels* representing portions of the participant's home such as their air conditioner, lighting circuitry, and various rooms. Energy consumption data was collected for half-hourly intervals for analysis, however data at one-minute intervals was used by the game to facilitate the chosen game elements. This data exists back until 2012.

Testing of conservation effect of feedback systems requires a comparison between consumption while using the intervention system (and afterwards) to either a baseline average of the population, a baseline average of the participant, or the consumption of the participant leading up to the intervention. For this project, the latter was used in the form of a comparison to "similar days" to days pre-test/post-test. This within-subjects design is more suitable for testing of conservation effect than a randomised control trial between-subjects design since energy consumption is something which can vary greatly between participants based upon factors such as location and socio-economic status.Brewer (2013) notes the need for dynamic-baseline comparison in energy consumption analysis.

To facilitate the "similar days" calculation, weather data collected by the Bureau of Meteorology[59] for 15 weather stations (each relevant to one or more participants based upon post-code data collected by CSIRO) was obtained. The weather data collected was in half-hourly intervals, and consisted of:

- dry bulb temperature (in degrees C); and
- relative humidity (in percentage).

Since comparisons were to be made over different parts of the year (and thus in different weather conditions), a derived measure of *apparent temperature* was calculated using the following two step formula (Bureau of Meteorology 2010):

$$AT = Ta + 0.33 \times e - 0.70 \times Ws - 4.00$$

where:

- $AT$ is the apparent temperature;
- $Ta$ is the dry bulb temperature;
- $Ws$ is the wind speed, which in this case was set to 0 since the desired value is for apparent temperature indoors; and
- e is humidity, calculated as:

$$e = {}^{Rh}/_{100} \times 6.105 \times \exp\left(17.27 \times {}^{Ta}/_{(237.7 + Ta)}\right)$$

where:

- $Rh$ is relative humidity in percent; and
- $Ta$ is the dry bulb temperature;

For each station for each day (between January 1st, 2015 and January 1st, 2017), a similarity value to every other day (between January 1st, 2015 and January 1st, 2017), was calculated using

[59] http://www.bom.gov.au

the following version of the Euclidean distance formula based on the apparent temperature for the two days:

$$S = \sqrt{\sum_{i=1}^{48}(q_i - p_i)^2}$$

where:

- $S$ is the similarity value;
- $i$ is the number of half-hours past 12am (48 half-hourly segments in a single day);
- $q_i$ is the apparent temperature at time $i$ for the day to calculate similar days for; and
- $p_i$ is the apparent temperature at time $i$ for the day being comparing to.

For each station for each day, the compared days were ranked in order from most similar to least similar. Since each participant can be mapped to a day, by extension there was now a list of similar days for each participant[60]. In the calculations described below, this list of days was used to compare the difference in energy consumption across days with similar weather conditions.

For any examined day, $x$, *conservation effect* for that day was calculated as the average difference of the 48 half-hourly data points recorded by the smart meter in kWh of that day to the 48 half-hourly data points of *each* of the 20 similar days to the day $x$.

For participants in the experiment group, energy consumption on the $d$ days after[61] participants were exposed to the mobile video game was compared to their energy consumption on the first 20 similar days[62] for the given day $x$. For participants in the control group, this same comparison was made for the first $d$ days after 1 June, 2016[63] (when the majority of experiment group participants were using the game). Conservation effect for each of the days $d$ was averaged out to determine the conservation effect for that period of time.

This process is illustrated in Figure 27.

[60] This assumed that the weather station for each participant was close enough to the participant's home to provide representative weather data. Given wind speed was removed from the calculation to ensure the apparent temperature was indicative of *indoor* conditions, and the granularity of Bureau of Meteorology weather stations, this data was the best indication of weather for each participant short of installing weather measurement instruments in each household.

[61] Negative values of $x$ were used to represent days *before* being given access to the game.

[62] Given each day was compared to 1,973 other days, 20 represents the top 1% of similar days.

[63] Where negative values of $x$ were days *before* 1 June, 2016.

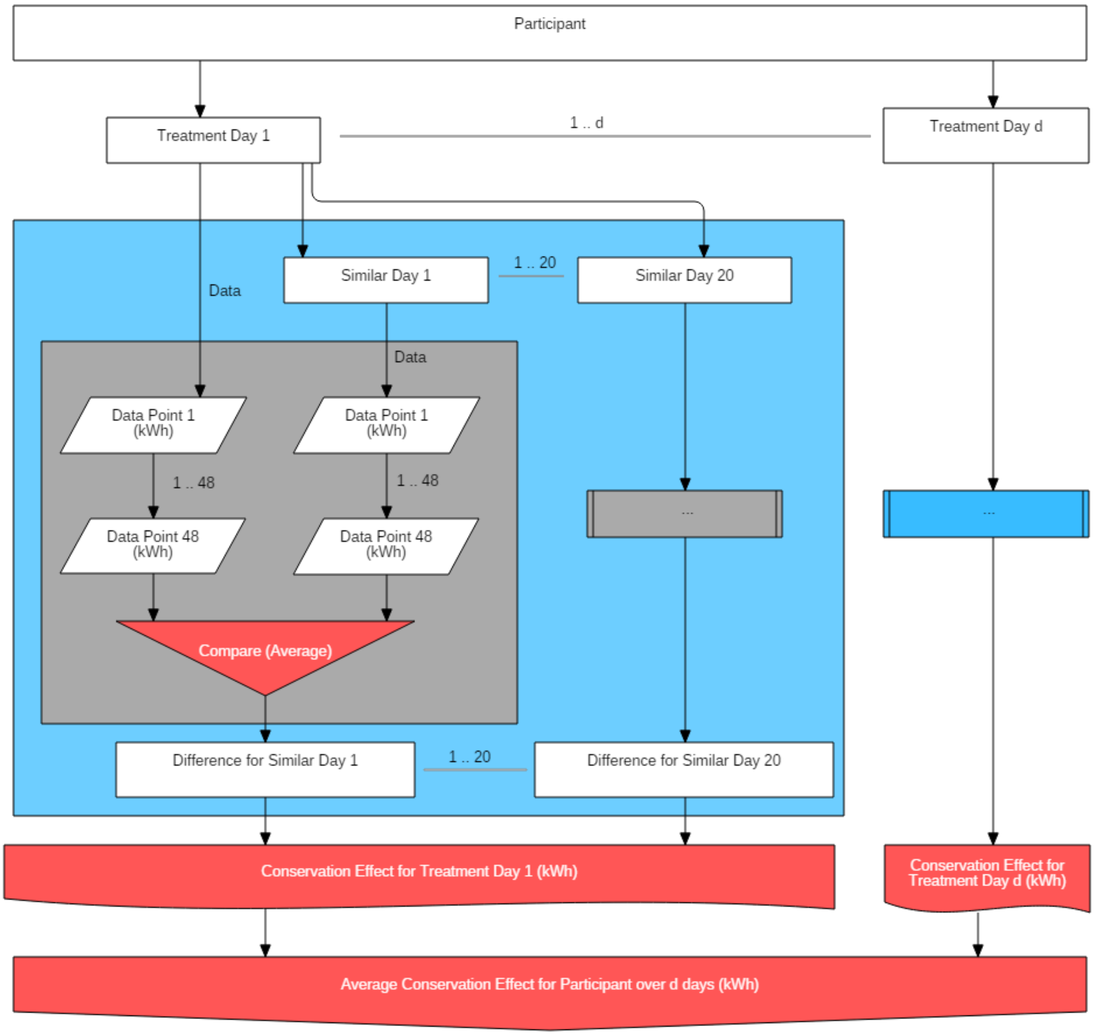



**Figure 27. Data flow diagram showing the calculation process for determining conservation effect for a given participant. The empty grey box indicates a repeat of the detailed grey box. Likewise, the empty blue box indicates a repeat of the detailed blue box. Red boxes indicate an average operation over the inputs.**

Since energy consumption may be highly variable across participants, and influenced by factors such as location, and household properties, conservation effect had to be considered within-participant (i.e. difference in conservation effect before and after). However, to determine if the Serious Game itself was a possible cause of the conservation effect (if at all there was one), comparison of the difference in conservation effect to a control group was necessary.

A form of pre-test/post-test design was used, this design is represented in Figure 28 where the control group is represented by the bottom line, and treatment group the top line. Using the notation of Campbell & Stanley (1963), *X* is the Serious Game intervention, *O* represents observations of the participants' conservation effect. Observations are taken for the periods of time before and after the intervention. A greater difference in $O_1$–$O_2$ than in $O_3$–$O_4$ would indicate a positive effect of $X$ on energy consumption (i.e. the Serious Game had a positive effect on energy consumption.

$$
\begin{array}{ccc}
O_1 & X & O_2 \\
O_3 & & O_4
\end{array}
$$

**Figure 28. Campbell & Stanley (1963) notation showing the control group experiment design including the groupings for testing the effect of the Serious Game (*X*), and a control group not given the game by pre-test/post-test observations (*O*).**

Using the description above pertaining to $x$ days before and after the intervention (and in the case of control group $d$ days before and after June 1st, 2017), $O_2$ and $O_4$ would represent *positive* values of $x$ (days *after*), and $O_1$ and $O_3$ would represent *negative* values of $x$ (days *before*). Conservation effect was compared for an equal number of days (*d)* before and after being given access to the game, as described by the following equation.

$$Before_d = \sum_{x=-d}^{-1} Effect_x$$

$$After_d = \sum_{x=1}^{d} Effect_x$$

$$Change_d = After_d - Before_d$$

For example, for $d = 3$ (testing 3 days before and 3 days after):

$$Before_3 = Effect_{-3} + Effect_{-2} + Effect_{-1}$$

$$After_3 = Effect_1 + Effect_2 + Effect_3$$

$$Change_3 = After_3 - Before_3$$

The pre-test/post-test analysis was conducted for different values of $d$, in order to understand over what period, change in behaviour was witnessed.

For example, if a participant played the game starting on the 3rd, 4th, and 7th of June 2016, the difference in conservation effect for the 7 days before and after being given access to the game. Conservation effect would first be calculated for the 3rd of June ($x = 1$). For this day, the 20 most similar days in terms of weather conditions (localised by the participant location) are determined. The average difference in energy *consumption* between the 3rd of June, and the 20 most similar days is calculated to determine a *conservation effect* for this day. This process is then repeated for the rest of the 7 days before being given access to the game (i.e. *pre-test*, the

4th, 5th, 6th,7th,8th,9th, and 10th of June), and the 7 days after being given access to the game (i.e. *post-test*, the 27th, 28th, 29th, 30th, and 31st of May, and 1st and 2nd of June). The relationship between $x$ and $d$ is explained in Figure 29. The difference between pre- and post-test values constitutes the summary conservation effect for that participant.

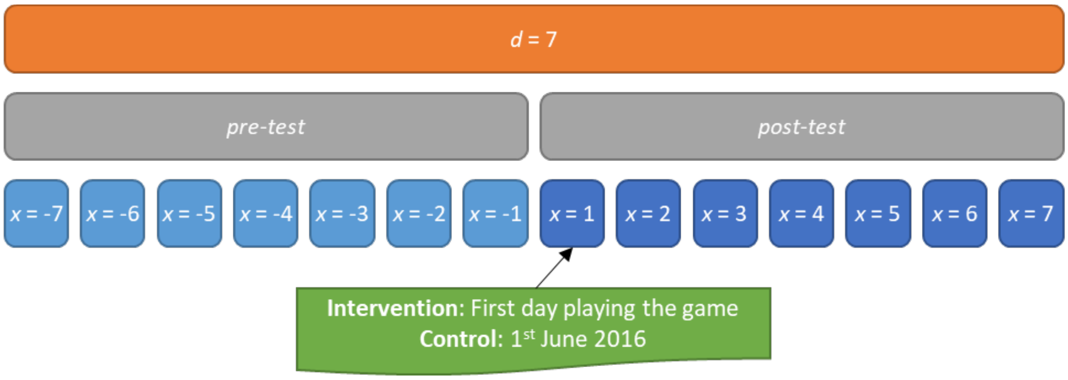



**Figure 29. The relationship between $x$ and $d$ in the conservation effect calculation, using $d = 7$ as an example.**

The use of a control group allowed for an empirical test of the impact of the Serious Game intervention on energy consumption. This approach provides the best possible internal validity for the project, as described in Section **Error! Reference source not found.**. Reduction in consumption for the treatment group that was not brought about by the treatment (i.e. the intervention) likely would have also be seen in the control group (confounds are discussed later in this section).

Player usage of the game in the form of metrics was recorded, including session logs within the game, logs of when the game notifies players (game-initiated actions), and tracking of player-initiated actions within the game such as viewing of various screens, or character actions. All of these metrics were time-stamped, which allowed for an exploratory analysis of energy consumption changes after certain actions within the game (smart meter data is timestamped, and allowing it to be aligned with in-game analytics). Instrumentation has been identified by Xu et al. (2014) as an important aspect of the design of a Serious Game to measure the use of the system. Nacke et al. (2009) note the benefit of such quantifiable and objective measures for exploring the game experience. Section6.2.2.4 describes the recorded metrics in the context of the game that was developed for this project.

Individual participants' data were examined to provide further insight into the meaning of the results. Chosen participants used the game at different levels (determined by total game actions recorded): the highest, lowest, and median usage users were chosen. Detailed statistics on conservation effect were produced for these users.

In addition to the energy consumption and game usage data, an entry and exit survey was produced, and was presented to players at the beginning and end of the trial period, respectively. The entry survey was intended to determine basic demographic information about participants (gender, age), as well as factors that may have an impact on their use of a Serious Game: familiarity with games and mobile games (see Section 6.2.2.2). The exit survey was intended to determine more information about the player's experience using the game (see Section 6.2.2.5).

Previous studies such as the *Kukui Cup* and *Power Agent* have used a similar methodology where a software intervention was developed and then deployed. For these studies, data about energy usage was collected before, during, and after the intervention, and compared using standard statistical techniques. In addition, these studies have obtained feedback from participants in the form of surveys questioning their experience interacting with the intervention. Finally, the *Power Agent* study used individual participant case studies to augment the value of the work.

With the details of the experiment in mind, it is important to explore the internal and external validity of the design, and acknowledge any biases present, and this is the focus of the next section.

In terms of internal and external validity of the project, this research design has high internal validity when considering the eight issues identified by Campbell & Stanley (1963) of history, maturation, testing, instrumentation, statistical regression, selection, experimental mortality, and selection-maturation interaction. This is primarily due to the fact that a true experimental approach was taken and where practical these common experimental issues were controlled for in some way. However, the external validity of the project has some biases that should be acknowledged, and this is discussed at length in Chapter 8. Particularly, the population from which participants were recruited is comprised of consenting participants in the Residential Building Energy Efficiency Standards project. According to Ambrose et al. (2013) these participants in general identified as energy conscious households and the mere fact that they consented to be part of another energy efficiency related study indicates that they may already be conserving more energy than the general population.

#### 3.3.6 For space reasons, a more in-depth consideration of the determining factors for internal and external validity is presented in Appendix A. Research Design Summary

This section has outlined the research design of this project which followed the Intervention Research model by Rothman & Thomas (1994). Four main phases of the project were identified: a literature review phase for gathering information about the problem domain and critiquing previous work with the purpose of identifying possible opportunities to combine Serious Games and behaviour change techniques in energy conservation, an intervention design phase which involved the development of game elements based upon theory identified using the Behaviour Change Wheel methodology, a game design phase covering the development and validation of a Serious Game using a Human-Centered-Design approach by Holloway & Kurniawan (2010), and an experimental phase using a pre-test/post-test control group design. The internal and external validity of the project was assessed, and we have seen that whilst internal biases have been minimised, the overall generalizability of the project is hindered by the selection of participants from the RBEES project.

The remainder of this chapter explores the research philosophy that was adopted as a result of the chosen methods.

## 3.4 Research Philosophy

The research design identified in the previous section for addressing the research questions necessitated a certain epistemological and ontological view. The adopted methodology is a standard approach to intervention research; however, it has a strong focus on discussing the challenges and opportunities involved in designing a Serious Game of such a novel nature.

### 3.4.1 Epistemology

From the data needs previously identified, it was clear that the experimental phase of this project would be conducted using a *quantitative* approach, with a primarily *positivist* research paradigm. As this chapter has shown, data collected was of an objective, numeric, quantitative form.

The positivist paradigm dictates the epistemological position that a deductive process be engaged in to infer new knowledge from verified empirically collected data, and that this must be done in an objective manner. Under this paradigm, new knowledge about the conservation effect of Serious Games was deductively produced by analysing collected energy usage data.

However, a considerable portion of this work focusses on presenting a detailed discussion of the challenges involved in designing the Serious Game, and the factors surrounding this particular implementation of the game. This discussion is based not only upon the derived data from the experiment, but from a reflective process of lessons learned, which is also supported by literature.

#### 3.4.2 Ontology

From an ontological perspective, under the positivist paradigm the position of *realism* was taken, meaning a view that the universe operates in terms of the laws consisting of cause and effect was subscribed to, and that these laws can be deduced by measuring empirical data. In the case of this research, this indicates that the author—through appropriate experimental design and reasoning—deduced the effect of Serious Games on energy conservation.

## 3.5 Chapter Summary

This chapter has presented the research methodology for the project which is realistic positivist in nature. The research design was based off the commonly used Intervention Research model by Rothman & Thomas (1994), with a simplified version of their six stage methodology consisting of four stages: a *literature review, intervention design, game design*, and *experiment*. The literature review, already represented in the previous chapter, focussed on Serious Games and behavioural-based approaches to energy conservation interventions seen in the literature (*SRQ1, SRQ2*). From there an intervention design phase (*SRQ3*) that uses the Behaviour Change Wheel methodology (Michie et al. 2011), and a novel approach to combine this with game elements from literature was recommended. For the game design phase, a Human-Centered Design approach (Holloway & Kurniawan 2010) was suggested to develop these game elements into a working Serious Game prototype (*SRQ3*). The final experimental phase of the project uses a pre-test/post-test control group design to measure the impact of a Serious Game (*SRQ3*) in terms of conservation effect. This experimental design was shown to have high internal validity; however, the external validity of the project is restricted by the selection of participants from the RBEES project.

From these four phases, a Serious Game intervention was designed, developed, and analysed. Using this game for reference, this work contributes to the discussion on designing Serious Games by exploring the challenges involved with designing (SRQ4) and implementing (SRQ5) a game for change using the Behaviour Change Wheel.

The following chapter presents the full process of the intervention design phase, beginning with the use of the Behaviour Change Wheel methodology, before describing the game elements and their linking to the chosen BCTs. The chapters following that discuss in detail how these elements were combined into a Serious Game, the architecture surrounding the game, and the results of the experiment phase.

# 4 Intervention Design Phase

As noted in the literature review, Serious Game implementations in the extant literature do not make effective use of behaviour change theory. As a result, this thesis explores the opportunity to embed behaviour change theory into the design of a Serious Game. This chapter presents the design process for integrating behaviour change theory into a Serious Game for energy conservation, which is a novel and key contribution of the thesis. Figure 30 shows how this chapter fits into the overall methodology of the project, by presenting the behaviour change wheel-guided design and the theory-informed elements.

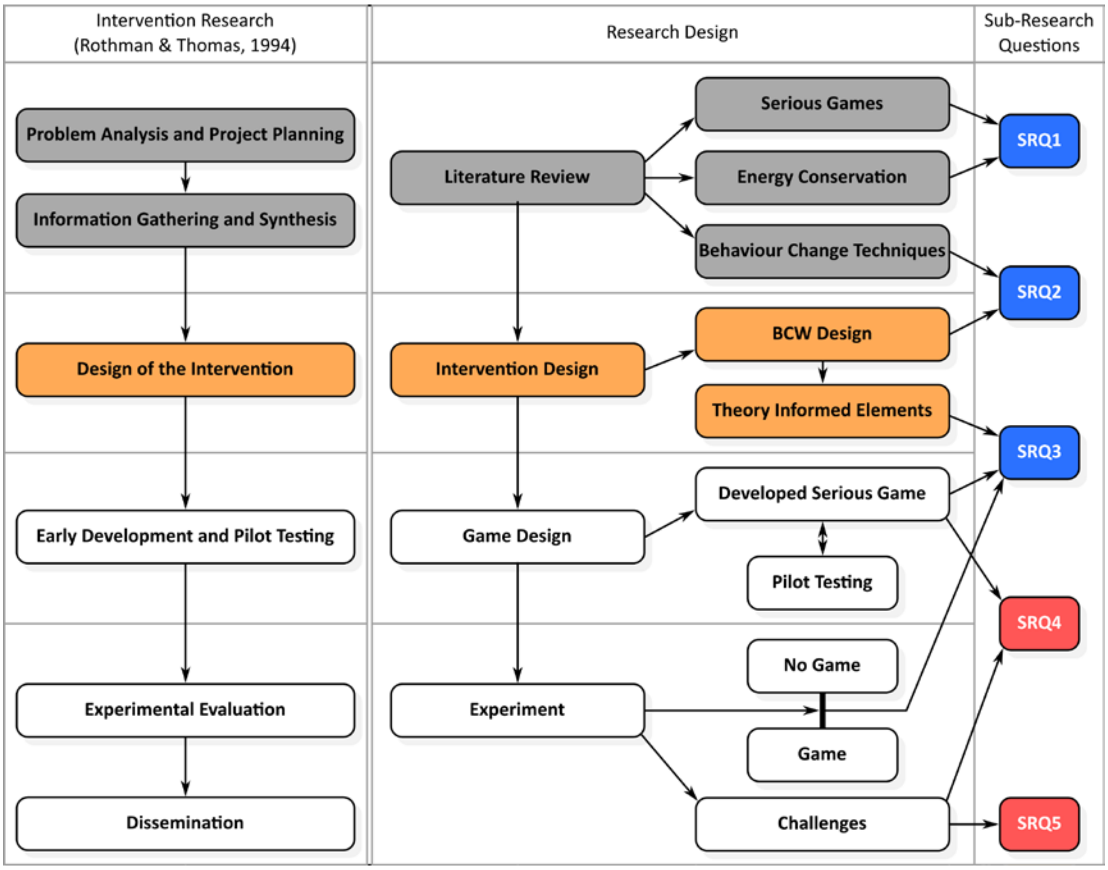



**Figure 30. The project methodology diagram, showing the components covered in in this chapter: the Behaviour Change Wheel, and the theory-informed game elements.**

The previous chapter made reference to a promising new methodology for guiding the process of behaviour change intervention design and evaluation: the Behaviour Change Wheel (BCW; Michie et al. (2011)). In introducing the Behaviour Change Wheel, this chapter justifies the choice of using it to inform a Serious Game design. We will see that it has been applied to a number of domains including energy conservation, and represents a well-defined approach to understanding behaviour, by examining behaviour from multiple perspectives: capability, opportunity, and motivation.

The chapter continues by presenting the results of following the process of the BCW methodology and how this resulted in a greater understanding of the behaviours this project aims to change. Finally, the chapter describes the additional steps implemented to apply the BCW to a Serious Game. The novel process of defining an intervention strategy is presented, which consists of linking Behaviour Change Techniques (BCTs) from the BCW to game elements based upon video game literature. The resultant intervention strategy formalises how a Serious Game design can be used to implement behaviour change theory—in this case within the domain of energy conservation.

## 4.1 The Behaviour Change Wheel Methodology

The Behaviour Change Wheel (BCW; Michie et al. 2011) is the result of a synthesis of 19 existing frameworks of behaviour change identified by Michie et al. (2011). The authors developed a methodology by which intervention designers can systematically examine the behaviours that interventions aim to target. In the book "*The Behaviour Change Wheel: A Guide To Designing Interventions*" (Michie et al. 2011), a series of worksheets are provided that are intended to guide designers through a process of thinking about the target behaviours, and these are explored in detailed later in this chapter. Part of this process includes assessing intervention functions within a social context using the affordability, practicability, effectiveness (including cost), acceptability, safety, and equity (the APEASE criteria, described in later in Section 4.1.4).

The purpose of the BCW is to allow intervention designers a systematic method for reviewing the full range of options available to them so that they may arrive at a suitable strategy. The BCW applies to both individuals and groups, and is designed to be relevant to any behaviour in any situation.

The work by Michie et al. (2011) resulted in a conceptual representation in the form of a "Behaviour Change Wheel", and is based around a popular behaviour change theory named the COM-B model. The following sections examine the wheel itself, the COM-B model, the process that is specified to design an intervention, the APEASE criteria applied at each stage of this process, as well as looking at the BCW's use in practice.

### 4.1.1 The Behaviour Change Wheel

As illustrated in Figure 31, the centre of the BCW's conceptual wheel represents the sources of behaviour which could be targeted by interventions. The surrounding layer represents the intervention functions which the intervention can use, and the outer layer specifies the types of policy changes that can be used for delivery of the intervention functions.

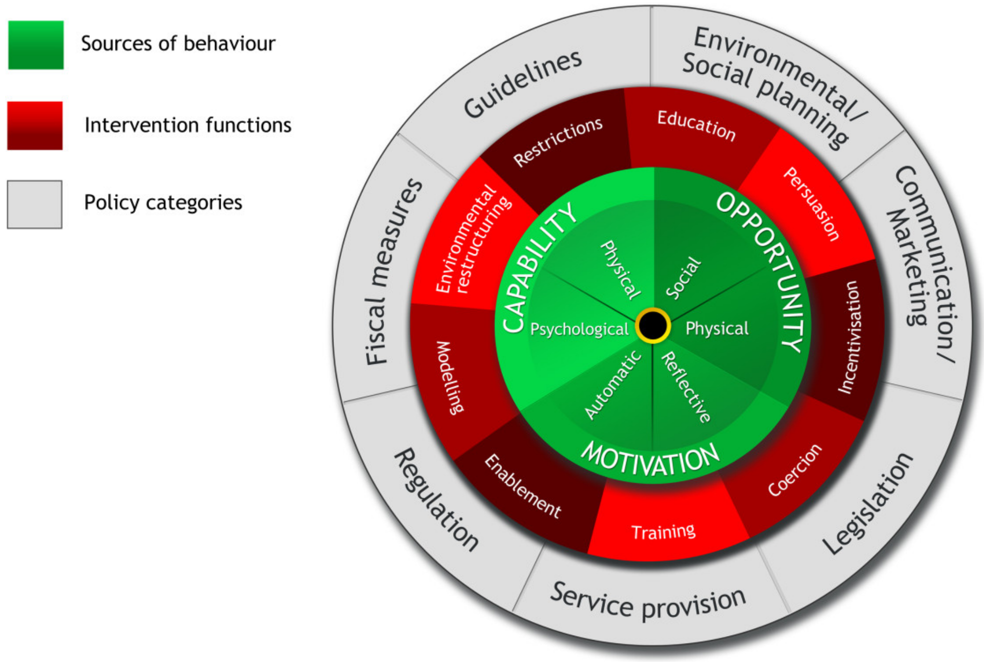



**Figure 31. The Behaviour Change Wheel (Michie et al. 2011) situating the components of capability, opportunity, and motivation as things to consider before addressing intervention functions and policy categories.**

At the centre of the BCW are items for capability, opportunity, and motivation. These concepts are defined by the COM-B model, which is described in the next section.

### 4.1.2 COM-B Model

The core behavioural theory behind the BCW is the COM-B model, and this is represented by its presence as the inner layer of the conceptual wheel. The main aspects of this model as described by Michie et al. (2011) are:

- *capability*: "an individual's […] capacity to engage in the activity concerned" (p. 46), which can be *psychological* (comprehension, reasoning, etc.) or *physical* (strength, skill, etc.);

- *opportunity*: "all factors that lie outside the individual that make the behaviour possible or prompt it" (p. 46), which can be *physical* (environmental) or *social* (afforded by culture, and what is socially acceptable); and
- *motivation*: "all those brain processes that energize and direct behaviour, not just goals and conscious decision-making" (p. 46), which can be *reflective* (evaluation, planning to do something, etc.), or *automatic* (involving emotions, impulses, etc.).

The COM-B model states that the named components work in an interacting system, and that for behaviour change to occur, a change must occur in one of the COM components. As shown in Figure 32, capability and opportunity can impact upon motivation, and all three can impact upon resulting behaviour.

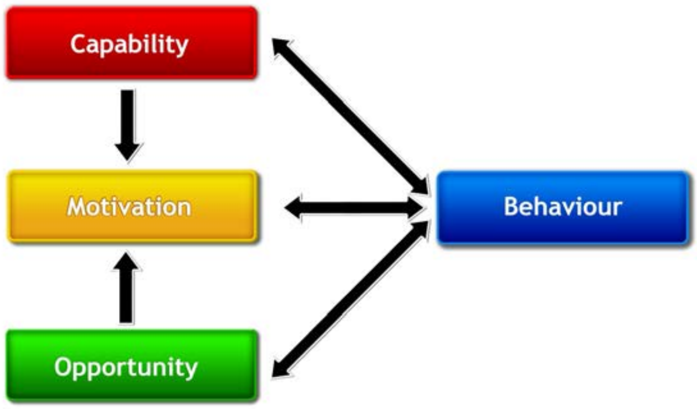



**Figure 32. Interaction between the COM-B components, showing how capability and opportunity have a one-way impact on motivation. Taken from Michie et al. (2011).**

An independent evaluation of the COM-B model found that the model provided "a more comprehensive explanation of adherence than existing models" (Jackson et al. 2014, p.12), citing the model's inclusion of automatic processes (such as habits or emotions), inclusion of systems-level factors (such as physical opportunity to engage in activity), and the specificity and intuitiveness of the relationships between the components.

A popular practice when applying the BCW is to use an extended version of the COM-B model called the Theoretical Domains Framework to further examine the target behaviours, and this is described in the following section.

It should be noted that there is an extension to the COM-B model called the Theoretical Domains Framework (TDF, Cane et al. 2012) which effectively subdivides the core components of COM-B into 14 different areas. Analysis was conducted at this lower-level but for reasons of clarity and space the full description of this process and its results has presented in Appendix B.:

The TDF and COM-B models are an important part of the initial stages of the intervention design process outlined by the BCW, and this is the subject of the next section.

### 4.1.3 Intervention Design Process

While the BCW is appropriate for analysing existing interventions, and has been used in a number of literature reviews of behaviour change interventions in various fields, perhaps its most important contribution is its use as a methodology for intervention design.

The BCW helps conceptualise the different stages of intervention design, by having behavioural details (capability, opportunity, and motivation) at the centre, followed by intervention functions (education, reinforcement, etc.), and finally policy options. If one works from the inside out, an intervention evolves from early in-depth analysis of the behaviour itself. This process is formalised by Michie et al. (2014) who specify 3 key stages, as shown in Figure 33.

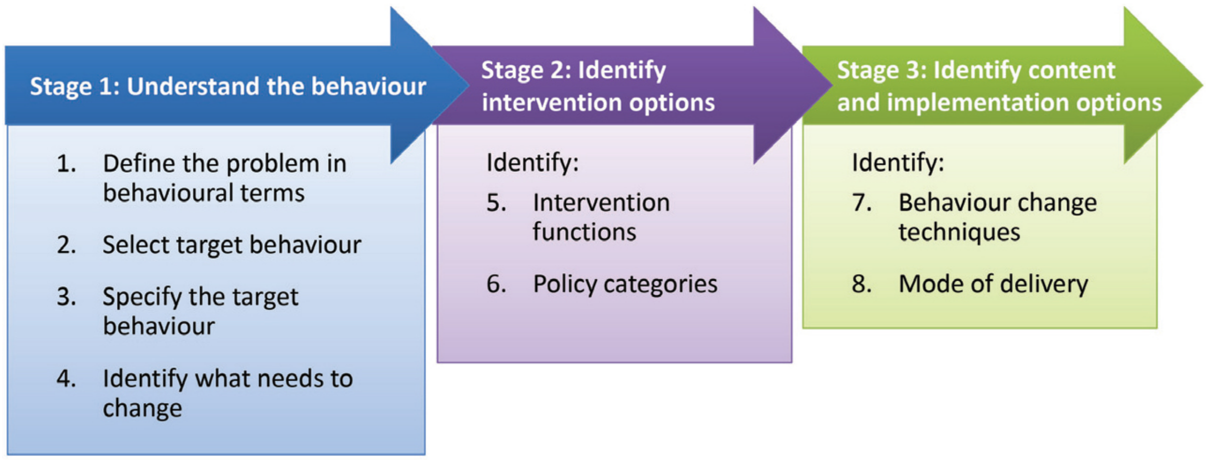



**Figure 33. The three stages to the Behaviour Change Wheel methodology. Taken from Michie, Atkins, et al. (2014).**

The stages prompt intervention designers to begin by defining the problem they want to address in terms of behaviour, and to consider that behaviour in a system of other behaviours. Using a formalised process, designers then identify which components of the COM-B model need to be addressed to bring about change. Optionally, designers look at this in more depth by using the TDF framework.

Once an area of COM-B has been identified for change, designers must then evaluate which intervention functions are appropriate to target the problem, and (if applicable) evaluate the policy categories that are promising to use[64].

The intervention functions identified by the BCW are (Michie, Atkins, et al. 2014):

- *education*: increasing knowledge or understanding;
- *persuasion*: use of communication to bring about positive or negative feelings;
- *incentivisation*: creating an expectation of reward;
- *coercion*: creating an expectation of punishment or cost;
- *training*: imparting skills;
- *restriction*: reducing the opportunity to engage in the problem behaviour;
- *environmental* restructuring: changing the physical or social context;
- *modelling*: providing an example for people to imitate; and
- *enablement*: increasing means or reducing barriers to increase capability or opportunity.

These intervention functions are only suitable for some aspects of the COM-B model, and this relationship is illustrated in matrix from in Figure 34.

[64] Policy categories are not addressed here as they are not relevant to this project (the policy category here is pre-determined by the project scope as "communication")

| | Intervention functions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| COM-B components | Education | Persuasion | Incentivisation | Coercion | Training | Restriction | Environmental restructuring | Modelling | Enablement |
| Physical capability | | | | | ■ | | | | ■ |
| Psychological capability | ■ | | | | ■ | | | | ■ |
| Physical opportunity | | | | | ■ | ■ | ■ | | ■ |
| Social opportunity | | | | | | ■ | ■ | ■ | ■ |
| Automatic motivation | | ■ | ■ | ■ | ■ | | ■ | ■ | ■ |
| Reflective motivation | ■ | ■ | ■ | ■ | | | | | |

**Figure 34. Matrix representing the relationship between intervention functions and COM-B components. Taken from Michie, Atkins, et al. (2014).**

At this point, designers are able to select Behaviour Change Techniques (BCTs) that are appropriate for the intervention functions (using the APEASE criteria, described in the next section). This is aided by the BCTTv1 (Behaviour Change Technique Taxonomy (v1)) taxonomy produced by Michie et al. (2013) based upon previous work by Abraham & Michie (2008). The taxonomy contains 93 techniques as found in a wide range of areas, and the BCW attempts to link these to the different intervention functions. Examples of BCTs include *habit formation*, *goal setting*, and *self-monitoring of behaviour.*

The designer is prompted to think about the mode of delivery for the intervention, and consider various options that are face-to-face on an individual and group level, and over distance on at an individual (e.g. phone call or mobile phone text), and population level (e.g. advertising or software).

Finally, once BCTs and delivery modes have been evaluated, intervention designers should have enough information to formalise their intervention design into an intervention strategy. From there the authors encourage designers use this strategy to help guide the process of further examining psychological theories. To aid this, a synthesis of 83 different theories of behaviour and behaviour change from the areas of psychology, anthropology, economics, and sociology created by Michie, West, et al. (2014) is suggested for use.

At each of these stages (such as when assessing possible intervention functions that address the COM-B and TDF components of the target behaviour), it is important that the evaluation considers social context. The following section describes the method provided by Michie et al. for this: the APEASE criteria.

#### 4.1.4 APEASE criteria

Michie, Atkins, et al. (2014) acknowledge that designing a behaviour change intervention is not just about measuring effectiveness, but also about consideration of the social context the intervention is to be deployed within. As a result, at various stages of the BCW methodology, designers are required to evaluate all options against the APEASE criteria designed by the authors. Explained in detail in Michie, Atkins, et al. (2014), the 6 APEASE criteria are used to ensure an intervention function is appropriate for the specific social context by considering:

- *affordability*: the intervention can be delivered to all those who would benefit from it (or would find it relevant) within an acceptable implicit or explicit budget (e.g. the cost of providing tablet computers to all those in an intervention may not be affordable);
- *practicability*: it is possible to deliver the intervention to the target population (e.g. requiring an expert trainer in multiple locations at once may not be practicable);
- *effectiveness and cost-effectiveness*: the expected effect size of the intervention when delivered within a real-world context (rather than in optimal circumstances), as well as the ratio of effect to cost (e.g. providing access to a drug which is not shown to be effective yet);
- *acceptability*: how the intervention is judged by public, professional, and political stakeholders (e.g. limiting the options of a target group may be seen as unacceptable by that group);
- *side-effects/safety*: unwanted or unintended consequences of an intervention need to be considered (e.g. restricting access to safety equipment in a workplace because it is being stolen may result in a dangerous situation if the equipment is needed in an emergency); and
- *equity*: whether the intervention will reduce or increase the disparities in standard of living, wellbeing, or health of different groups.

The APEASE criteria form an important part of the BCW process, allowing interventions designed and evaluated through it to be considered within a social context rather than just ideal clinical conditions.

#### 4.1.5 Behaviour Change Wheel Summary

The BCW is a methodology for aiding intervention design which has been used in a wide range of areas, including health and environmental sustainability. The methodology approaches behaviour from the perspective of capability, opportunity, and motivation and looks at multiple behaviours interacting as a system. By analysing behaviours and evaluating them against the APEASE criteria, the BCW ensures that an intervention design is brought about while considering all other options and consequences. The next section presents how the BCW was applied to the intervention design for this project. This application represents the first time that the BCW has been drawn upon to develop a Serious Game that is meaningfully underpinned by robust psychological theory.

## 4.2 Applying the Behaviour Change Wheel to Energy Conservation Behaviours

The BCW process for designing an intervention was used for the initial design stages of the project. The use of BCW in the energy domain prior, and the systematic and integrative nature of the method made the BCW an excellent model for this project.

The following sub-sections relate to the individual steps outlined in the BCW intervention design process described in Section 4.1.3. The tables provided are adapted from the worksheets provided as additional material to the book “The Behaviour Change Wheel: A Guide to Designing Interventions” by Michie, Atkins, et al. (2014).

#### 4.2.1 Defining the Problem in Behavioural Terms

The first step of the BCW methodology is to simply define the problem in behavioural terms. This allows the designers to be clear that all stakeholders are working on the same problem, with the same parameters including where the behaviour happens, and who is involved.

In the case of this project, the problem in focus is that of the need to reduce household energy consumption, a problem related to behaviours within the home and the actions of household members. Household members are varied in authority and capability (i.e. some may own the home whilst others may be renting, some maybe adults, and some may be children). This information is synthesised in Table 2.

| | |
|---|---|
| **What behaviour?** | Reducing household energy consumption |
| **Where does the behaviour occur?** | Residential Homes |
| **Who is involved in performing the behaviour?** | Household members: home owners, renters, children, etc. |

**Table 2. Initial representation of overall behaviour area of interest for the intervention, identifying residential household energy as the domain.**

#### 4.2.2 Select the Target Behaviour

The BCW points out that behaviours are not isolated, and indeed work within the context of other behaviours both at an inter- and intra-personal level. Therefore, the second step in the process is to identify all relevant behaviours and select the behaviour or behaviours that are most relevant to the overarching problem.

It is recommended that a long list of possible target behaviours are identified, followed by a prioritisation process to identify the final target behaviour or behaviours. The following sections illustrate the process for this project of identifying target behaviours, prioritising them.

##### *4.2.2.1 Relevant Behaviours*

A commonly used dichotomy in energy conservation behaviours is the distinction between:

- *curtailment behaviours*: which are generally every-day actions that are repeated, with each instance of the action bringing about a small usage impact and are low in cost; and
- *efficiency behaviours*: which are generally once-off or irregular actions with a large usage impact and potentially high cost (such as maintenance or replacement of appliances).

Within the domain of energy conservation, there are a plethora of behaviours that can bring about reduced energy consumption, however there is little agreement on what constitutes a complete list of meaningful and effective behaviours. Still, several attempts to categorise and rank various energy saving behaviours have been made. For this project a list of energy behaviours from various sources (Dietz et al. 2009; Fielding et al. 2010; Gardner & Stern 2008; Karlin et al. 2014) was synthesised and split into curtailment and energy efficiency behaviours. The result of this is shown in Table 3.

| **Intervention Aim: Reduce household energy consumption** | |
|---|---|
| **Curtailment Behaviours** | **Effectiveness Behaviours** |
| Adjusting air conditioner usage (thermostat setbacks) * | Weatherization |
| Line drying | Heating, ventilation, and air conditioning equipment |
| Turning off lights in unoccupied rooms * | Low-flow showerheads |
| Reducing standby electricity consumption * | Efficient water heater |
| Driving behaviour | Low rolling resistance tires |
| Carpooling and trip-chaining | Fuel-efficient vehicle |
| Switch off unused appliances | Add insulation in the home |
| Use cold water to wash | Purchasing energy efficient appliances |
| Switch off computers when not in use | Purchasing energy efficient light bulbs |
| Keep windows and doors closed when using air conditioners | Check toilet tank for leaks |
| Close curtains on hot summer days and cold winter nights | Check home for thermal leaks |
| Wait until dishwasher is full to run | |
| Shorter showers | |
| Shut down appliances at night | |

**Table 3. Possible target behaviours, categorised by curtailment and effectiveness behaviours. Behaviours targeted in this intervention are marked with an asterisk.**

#### *4.2.2.2 Behaviour Prioritisation*

With an extensive list of energy consumption behaviours identified, the next step in the process is to determine which ones are most relevant to the overarching problem and focus on developing an intervention for that behaviour. In order to do this the following criteria must be considered:

- how much of an *impact* will occur by changing the behaviour;
- the likelihood of *changing* the behaviour (considered in terms of capability, opportunity, and motivation);
- the likelihood of positive or negative *impacts* upon other behaviours (referred to as *spillover*); and
- how easy it is the *measure* the behaviour.

Each criterion was rated on a four-point scale of *very promising*, *promising*, *unpromising*, and *not acceptable.* Table 4 shows the results of the evaluation of each of the potential target behaviours, and the following section presents the results of this analysis. It should be noted that this analysis was conducted solely by the author, although at various points during this process the expert advice of other researchers in the area of social sciences from the CSIRO in Australia was sought. This limitation is discussed further in Section 8.1.9.

| Potential Target Behaviours | Impact | Likelihood of Change[65] | Spillover | Measurement | Score[66] |
|---|---|---|---|---|---|
| **Curtailment Behaviours** | | | | | |
| Turning off lights in unoccupied rooms | Very promising | Very promising (motivation) | Promising (standby, un-used appliances) | Very promising (light circuits) | 15 |
| Reducing Standby electricity consumption | Very promising | Very promising (motivation) | Promising (un-used appliances, computers) | Promising (change in resting energy consumption) | 14 |
| Adjusting air conditioner usage (thermostat setbacks) | Very promising | Unpromising (motivation) | Promising (curtains, windows, doors) | Very promising (air conditioner smart meter channel) | 13 |
| Switch off unused appliances | Promising | Promising (motivation) | Promising (standby, computers) | Promising (electricity) | 12 |
| Use cold water to wash | Promising | Promising (capability) | Promising (line drying) | Unpromising (water) | 10 |
| Switch off computers when not in use | Unpromising | Promising (opportunity) | Promising (other appliances, standby) | Promising | 10 |
| Line Drying | Unpromising | Promising (capability) | Promising (cold wash) | Unpromising | 9 |
| Keep windows and doors closed when using air conditioners | Unpromising | Very promising (motivation) | Promising (air conditioning) | Unacceptable (house temp) | 8 |
| Close curtains on hot summer days and cold winter nights | Unpromising | Very promising (motivation) | Promising (air conditioning) | Unacceptable (house temp) | 8 |
| Driving Behaviour | Very promising | Unpromising (motivation, capability) | Promising (other transport) | Unacceptable (transport) | 7 |
| Carpooling and trip-chaining | Promising | Unpromising (opportunity) | Promising (other transport) | Unacceptable (transport) | 7 |
| Wait until dishwasher is full to run | Unpromising | Promising (opportunity) | Unacceptable (no link) | Unpromising (water) | 5 |
| Shorter Showers | Promising | Unpromising (motivation) | Unacceptable (no link) | Unpromising (water) | 5 |
| **Effectiveness Behaviours** | | | | | |
| Purchasing Energy Efficient light bulbs | Promising | Very Promising (motivation) | Promising (purchase efficient appliances) | Unpromising (installation, automatic detection) | 11 |
| Purchasing Energy Efficient appliances | Promising | Promising (opportunity) | Promising (purchase efficient lights) | Unpromising (installation, automatic detection) | 10 |
| Weatherization | Promising | Unpromising (opportunity) | Promising (other effectiveness) | Unacceptable (installation) | 7 |
| HVAC equipment | Promising | Unpromising (opportunity) | Promising (other effectiveness) | Unacceptable (installation) | 7 |
| Check toilet tank for leaks | Unpromising | Promising (motivation) | Promising (other maintenance) | Unacceptable (maintenance) | 7 |
| Check home for thermal leaks | Unpromising | Unpromising (motivation, capability) | Promising (other maintenance) | Unacceptable (maintenance) | 7 |

[65] Most promising COM-B components displayed in brackets

[66] Score calculated as sum of the four variables with values (very promising = 4, promising = 3, unpromising = 1, unacceptable = 0)

| Potential Target Behaviours | Impact | Likelihood of Change[65] | Spillover | Measurement | Score[66] |
|---|---|---|---|---|---|
| Low-flow showerheads | Unpromising | Unpromising (opportunity) | Promising (other effectiveness) | Unacceptable (installation) | 5 |
| Efficient water heater | Promising | Unpromising (opportunity) | Promising (other effectiveness) | Unacceptable (installation) | 5 |
| Low rolling resistance tires | Promising | Unpromising (opportunity, $) | Promising (other transport) | Unacceptable (transport, installation) | 5 |
| Fuel-efficient vehicle | Promising | Unpromising (opportunity, $) | Promising (other transport) | Unacceptable (transport) | 5 |
| Add insulation in the home | Promising | Unpromising (opportunity) | Promising (other effectiveness) | Unacceptable (installation) | 5 |

**Table 4. Prioritisation of curtailment and efficiency behaviours based upon factors of impact upon the overarching problem, the likelihood of changing the behaviour, the likelihood of spillover effects onto other behaviours, and how easy it is to measure the behaviour.**

Three target behaviours were identified based upon the four criteria: *adjusting air conditioner usage*, *turning off lights when you are not in a room*, and *standby electricity consumption*.

#### 4.2.2.3 Summary

Twenty-three possible target behaviours were identified, and categorised as either curtailment or efficiency behaviours. With a focus on curtailment behaviours, these were evaluated on the principles of impact, likelihood of change, spillover effect, and measurement. As a result of this evaluation, the behaviours were prioritised, and three target behaviours were identified. The target behaviours selected in this stage of the methodology were *adjusting air conditioner usage*, *turning off lights when you are not in a room*, and *standby electricity consumption*. These behaviours have been examined in terms of the criteria, and will be the focus of the remainder of this chapter.

Importantly, Michie, Atkins, et al. (2014) note "less is more" (p.40), and recommend only selecting one or two target behaviours rather than intervening to a lesser extent on a large number of behaviours. This project could easily target a much wider range of behaviours as listed in Table 4, however following the ethos of Michie, we target a small number of behaviours—in our case, three. Additionally, it should be noted that the issue of *peak load* is not directly addressed by this intervention. Ehrhardt-Martinez et al. (2010) point out that previous studies which have focussed on peak-usage have been less effective in bringing about behaviour change, averaging only a 3% decrease in consumption, compared to a 10% reduction for those that did not specifically target it.

#### 4.2.3 Specify the Target Behaviours

The third step of the first stage of the BCW process is to elaborate on the selected target behaviour(s). On the surface this may seem like an obvious and unnecessary step, however a formalised systematic process for this is vital for clarity in intervention designs and facilitates comparison and evaluation at a meta-level.

Michie, Atkins, et al. (2014, p.48) prompt designers to consider the questions of:

- *who* needs to perform the behaviour?;
- *what* does the person need to do differently?;
- *when* will they do it?;
- *where* will they do it?;
- *how often* will they do it?; and
- *with whom* will they do it?

Table 5, Table 6, and Table 7 address these questions for each of the three specified target behaviours. All three behaviours require the participation of all household members, in the home, and with the support and consideration of other household members (e.g. turning off the lights when another household member is still in the room could be construed as somewhat inconsiderate).

Air conditioner usage differs in frequency to the other behaviours as there is a specific focus on adjusting the temperate on event days. Turning devices completely off to avoid standby electricity consumption is more frequent as it is at the conclusion of every appliance use, and turning off lights is potentially much more frequent (whenever a room is left unattended).

| **Target behaviour** | **Adjusting air conditioner usage** |
|---|---|
| ***Who* needs to perform the behaviour?** | Household members (where household has an air conditioner) |
| ***What* do they need to do differently to achieve the desired change?** | On hot days increase air conditioner temperature by at least 2 degrees (C) (if they have temperature control)<br>On cold days decrease air conditioner temperature by at least 2 degrees (C) (if they have temperature control)<br>On average temperature days do not use the air conditioner<br>During peak times adjust temperature by at least 2 degrees (C) (if they have temperature control) |
| ***When* do they need to do it?** | Event days (hot days, cold days, holidays) peak times, average days |
| ***Where* do they need to do it?** | In the home |
| ***How often* do they need to do it?** | Every day, in the morning and night |
| ***With whom* do they need to do it?** | Other household members should be considered and included in the decision to change temperature |

**Table 5. Analysis of target behaviour: adjusting air conditioner usage.**

| **Target behaviour** | **Turning off lights in unoccupied rooms** |
|---|---|
| ***Who* needs to perform the behaviour?** | Household members |
| ***What* do they need to do differently to achieve the desired change?** | Lights should be turned off |
| ***When* do they need to do it?** | When leaving a room for any length of time, and no one is remaining in the room |
| ***Where* do they need to do it?** | In the home |
| ***How often* do they need to do it?** | Every time they leave a room |
| ***With whom* do they need to do it?** | Other household members |

**Table 6. Analysis of target behaviour: turning off lights when you are not in a room.**

| **Target behaviour** | **Reducing standby electricity consumption** |
|---|---|
| ***Who* needs to perform the behaviour?** | Household members |
| ***What* do they need to do differently to achieve the desired change?** | Devices should be turned completely off, and not left in standby mode |
| ***When* do they need to do it?** | When finishing using a device<br>When noticing a device has been left in standby mode |
| ***Where* do they need to do it?** | In the home |
| ***How often* do they need to do it?** | Many times a day |
| ***With whom* do they need to do it?** | Other household members |

**Table 7. Analysis of target behaviour: reducing standby electricity consumption.**

### 4.2.4 Identify What Needs to Change

The first stage of the BCW finishes with an analysis of the target behaviour with reference to the COM-B model. The behaviour is analysed in terms of capability (physical and psychological), opportunity (physical and social), and motivation (reflective and automatic). These factors are described in Section 4.1.2. Areas where it is identified that change is needed are recorded at this stage, and expanded upon in subsequent steps.

It is recommended that the data be collected from potential stakeholders of the target intervention or experts for this step. In this instance, information for this section was collected from unstructured interviews with groups of experts from CSIRO Australia, with expertise in the domains of energy (from the Energy Flagship) and sociology.

Each of the target behaviours were considered in terms of COM-B, and the results of this analysis are provided in Table 8, Table 9, and Table 10.

In all cases physical capability was an area where no change was needed as the electrical devices in question are simple to use (ignoring the case of children's use). This was similar for physical opportunity, however, the cases of hard-to-reach switches, and the physical ability to determine the true outdoor temperature was considered (a similar consideration for this was also made for psychological capability).

Social opportunity was a big factor for all target behaviours as, in general, it is difficult to recognise if others with similar households are participating in the desired behaviour.

Both reflective and automatic motivation were identified as areas for change as, in general, these behaviours are not habitual (since they are curtailment behaviours, they need to become habitual). In addition, issues with belief about the consequences on the environment, the perceived impact upon comfort were identified.

| **Target Behaviour:** | **Adjusting air conditioner usage** | |
|---|---|---|
| **COM-B Components** | **What needs to happen for the target behaviour to occur?** | **Is there a need for change?** |
| **Physical capability** | Have the physical skill to adjust the temperature | No change needed as most household members have the physical capability to use the air conditioner controls (possible exceptions include children) |
| **Psychological capability** | Have the ability to set the temperature to an amount relatively higher or lower than they normally do depending on the current outside temperature | Some change needed as some people lack the ability to keep track of usual temperature settings of their air conditioner, or the ability to acknowledge that a day is not hot enough to warrant use |
| | Have the ability to recognize when it is currently a peak time for air conditioner usage | Some change needed as many people are not aware of peak times |
| **Physical opportunity** | Be able to accept the impact of a change in room temperature on individual comfort, taking into account current physical health status | No change needed as methods other than an air conditioner can be used to adjust an individual's temperature (most notably, change in clothing) |
| | Physical access to air conditioner controls | No change needed, as controls are usually remote |
| **Social opportunity** | See others with similar houses adjusting their air conditioner usage on event days | Change needed as this information is not readily available in a reliable and understandable fashion. |
| | Being able to adjust the temperature of the air conditioner appropriately even with guests in the house | Some change needed as there is social pressure when guests are in the household to ensure their comfort |
| **Reflective motivation** | Hold the belief that adjusting air conditioner temperature will make a monetary difference | No change needed as many know that better air conditioning usage should result in lower power bills |
| | Hold the belief that adjusting air conditioner temperature will make an environmental difference | Some change needed as many hold a belief that their contribution to Climate Change is negligible |
| | Hold the belief that adjusting the temperature of the air conditioner will not have a negative impact on comfort | Some change needed as many are resistant to changing air conditioner temperature due to potential negative impact on comfort |
| **Automatic motivation** | Routinely adjust the temperature of the air conditioner on a daily basis | Change needed since this behaviour is not currently a routine practice for most residents |

| **Target Behaviour:** | **Adjusting air conditioner usage** | |
|---|---|---|
| **COM-B Components** | **What needs to happen for the target behaviour to occur?** | **Is there a need for change?** |
| | Resist the desire for the comfort afforded by a stable room temperature | Change needed as many resist changing air conditioner temperature due to loss of comfort |
| **Selected COM-B components:** | Social Opportunity<br>Reflective Motivation<br>Automatic Motivation<br>Psychological Capability | |

**Table 8. COM-B analysis of target behaviour: adjusting air conditioner usage.**

| **Target Behaviour:** | **Turning off lights in unoccupied rooms** | |
|---|---|---|
| **COM-B Components** | **What needs to happen for the target behaviour to occur?** | **Is there a need for change?** |
| **Physical capability** | Have the physical skill to turn off the lights | No change needed as most household members have the physical capability to use light switches (possible exceptions include children) |
| **Psychological capability** | Have the ability to recognize that there are no other people in the room, and construct an if-then rule for turning off the lights in that room | No change needed, as most household members already possess this ability |
| **Physical opportunity** | Physical access to light switches | No change needed, as light switches are placed near exits of rooms |
| **Social opportunity** | See others with similar houses turning off their lights appropriately | Change needed as this information is not readily available in a reliable and understandable fashion |
| **Reflective motivation** | Hold the belief that turning off lights will make a monetary difference | No change needed as many know that better light usage should result in lower power bills |
| | Hold the belief that turning off lights will make an environmental difference | Some change needed as many hold a belief that their contribution to Climate Change is negligible |
| **Automatic motivation** | Routinely turn off lights when leaving a room empty on a regular basis | Change needed since this behaviour is not currently a routine practice for most residents |
| | Resist the desire for easier lifestyle where turning lights back on when re-entering a room is not needed because the lights are on from last time the room was used | Change needed as many enjoy the easiness of having a light ready for them in the room they are entering without the need to find a switch |
| **Selected COM-B components:** | Social Opportunity<br>Reflective Motivation<br>Automatic Motivation<br>Psychological Capability | |

**Table 9. COM-B analysis of target behaviour: turning off lights in unoccupied rooms.**

| **Target Behaviour:** | **Reducing standby electricity consumption** | |
|---|---|---|
| **COM-B Components** | **What needs to happen for the target behaviour to occur?** | **Is there a need for change?** |
| **Physical capability** | Have the physical skill to switch devices completely off | No change needed as most household members have the physical capability to completely switch a device off |
| **Psychological capability** | Have the ability to recognize that a device has a standby mode and completely off mode, and to distinguish which mode it is currently in | Some change needed as some people lack the ability to identify standby functions. |
| **Physical opportunity** | Physical access to completely-off functions on devices | Some change needed as access to completely power off a device may be difficult (especially if this requires access to a power socket) |
| **Social opportunity** | See others with similar houses using completely-off functionality appropriately | Change needed as this information is not readily available in a reliable and understandable fashion |
| **Reflective motivation** | Hold the belief that standby consumption will make a monetary difference | No change needed as many know that better usage should result in lower power bills |
| | Hold the belief that standby consumption will make an environmental difference | Some change needed as many hold a belief that their contribution to Climate Change is negligible |
| **Automatic motivation** | Routinely switch devices completely off, instead of just into standby mode | Change needed since this behaviour is not currently a routine practice for most residents |
| | Resist the desire for ease of use afforded by standby mode | Change needed as many resist completely turning off devices to avoid reduced ease of use (e.g. television can be turned on remotely if in standby mode) |
| **Selected COM-B components:** | Social Opportunity<br>Reflective Motivation<br>Automatic Motivation<br>Psychological Capability<br>Physical Opportunity | |

**Table 10. COM-B analysis of target behaviour: reducing standby electricity consumption.**

All behaviours have a need for change in the areas of social opportunity, reflective motivation, automatic motivation, and psychological capability.

Across all behaviours, social opportunity was identified as the main factor owing to difficulties in recognising if others with similar households are participating in the desired behaviour. Improved feedback through the form of a game could help address this.

Another key area for change was motivation: both reflective and automatic. There is a strong need to make these curtailment behaviours habitual, and to overcome the perceived impact upon comfort.

The analysis presented in this section used the COM-B model by Michie et al. (2011). At this point in the BCW process, researchers can undertake further analysis of the behaviour, by performing TDF (Theoretical Domains Framework, Michie et al. 2014) analysis. For space reasons, this analysis has been omitted from the main text, and is instead presented in full in Appendix B.

At the conclusion of this stage of the BCW framework, we have a greater understanding of what needs to change in order to attain the desired target behaviours. From here we can identify potential intervention functions, and this is covered in the next section.

#### 4.2.5 Identify Intervention Functions

With areas of COM-B in need of change identified in the previous section, the next step in the BCW is to attempt to identify promising intervention functions for these areas. This is done following the APEASE criteria described in Section 4.1.4.

Table 11, Table 12, and Table 13 present the results of examining each of the specified intervention functions against the APEASE criteria.

| **Target Behaviour:** | **Adjusting air conditioner usage** |
|---|---|
| **Candidate intervention functions** | **Does the intervention function meet the APEASE criteria?** |
| Education | Education on how to reduce air conditioner setting is unlikely to be effective as many are already aware of how to adjust their air conditioner |
| Persuasion | Yes (creating more positive beliefs and feelings about the desired behaviour is a promising option) |
| Incentivisation | Yes (incentivizing the good behaviour so individuals feel good about the behaviour, and negatively about the undesired behaviours is a promising option) |
| Coercion | Yes (creating an expectation of punishment or cost as a result of performing undesired behaviours is a promising option) |
| Training | Training for how to reduce air conditioner setting is not practical in this context as individuals already can adjust their air conditioner |
| Restriction | Not practical as there are no options to restrict in this context |
| Environmental restructuring | Not practical as options to restructure the environment are costly (e.g. install insulation, etc.) |
| Modelling | Yes (modelling the desired behaviour through feedback in a social and metaphoric way to bring about automatic imitation is a promising option) |
| Enablement | Not practical in this context as individuals already have all the physical and psychological skills required to perform the behaviour |
| Selected intervention functions: | Persuasion<br>Incentivisation<br>Coercion<br>Modelling |

**Table 11. APEASE analysis of intervention functions for target behaviour: adjusting air conditioner usage.**

| **Target Behaviour:** | **Turning off lights when you are not in a room** |
|---|---|
| **Candidate intervention functions** | **Does the intervention function meet the APEASE criteria?** |
| Education | Education on how to turn off lights when leaving a room is unlikely to be effective as many are aware of how to turn off lights |
| Persuasion | Yes (creating more positive beliefs and feelings about desired behaviour is a promising option) |
| Incentivisation | Yes (incentivizing the good behaviour so individuals feel good about the behaviour, and negatively about the undesired behaviours is a promising option) |
| Coercion | Yes (creating an expectation of punishment or cost as a result of performing undesired behaviours is a promising option) |
| Training | Training for how to turn off lights not practical in this context as individuals already can operate their lights |

| **Target Behaviour:** | **Turning off lights when you are not in a room** |
|---|---|
| **Candidate intervention functions** | **Does the intervention function meet the APEASE criteria?** |
| Restriction | Restriction in the form of lights which automatically detect the presence of people in the room is not sufficiently affordable and in many cases can be impractical |
| Environmental restructuring | Environmental restructuring in the form of relocating lights etc. not sufficiently affordable and in many cases can be impractical |
| Modelling | Yes (modelling the desired behaviour through feedback in a social and metaphoric way to bring about automatic imitation is a promising option) |
| Enablement | Not practical in this context as individuals already have all the physical and psychological skills required to perform the behaviour |
| **Selected intervention functions:** | Persuasion<br>Incentivisation<br>Coercion<br>Modelling |

**Table 12. APEASE analysis of intervention functions for target behaviour: turning off lights when you are not in a room.**

| **Target Behaviour:** | **Reducing standby electricity consumption** |
|---|---|
| **Candidate intervention functions** | **Does the intervention function meet the APEASE criteria?** |
| Education | Education on how to turn devices off unlikely to be practical as many know how to do this already |
| Persuasion | Yes (creating more positive beliefs and feelings about desired behaviour is a promising option) |
| Incentivisation | Yes (incentivizing the good behaviour so individuals feel good about the behaviour, and negatively about the undesired behaviours is a promising option) |
| Coercion | Yes (creating an expectation of punishment or cost as a result of performing undesired behaviours is a promising option) |
| Training | Training for how to turn devices off is not practical in this context as individuals already can turn devices off completely |
| Restriction | Restricting the ability to turn a device into standby mode is not practical, and would not be acceptable |
| Environmental restructuring | Not applicable to this behaviour |
| Modelling | Yes (modelling the desired behaviour through feedback in a social and metaphoric way to bring about automatic imitation is a promising option) |
| Enablement | Not practical in this context as individuals already have all the physical and psychological skills required to perform the behaviour |

| **Target Behaviour:** | **Reducing standby electricity consumption** |
|---|---|
| **Candidate intervention functions** | **Does the intervention function meet the APEASE criteria?** |
| **Selected intervention functions:** | Persuasion<br>Incentivisation<br>Coercion<br>Modelling |

**Table 13. APEASE analysis of intervention functions for target behaviour: standby electricity consumption.**

In all cases, the most promising intervention functions were considered to be *persuasion, incentivisation, coercion,* and *modelling.* Some functions such as environmental restructuring and enablement were not considered practical given the context of a Serious Game. Persuasion was found to be a promising intervention function as it is about creating more positive beliefs and feelings about desired the desired behaviour. Making individuals feel good about positive behaviour and negatively about undesired behaviours through incentivisation and coercion was considered promising. Finally, modelling was considered promising since previous research has shown providing energy feedback has been effective (as discussed in Section 2.2.2.2).

#### 4.2.6 Identify Policy Categories

With access to various means of policy change, this step of the BCW is intended to select appropriate changes to policy. The authors acknowledge that some may be limited to a specific policy change category, and advise them to skip this step (Michie, Atkins, et al. 2014, p.128). In the case of this project, the intervention was limited to a form of communication policy (i.e. the designed game will communicate information about the behaviour to the player in the form of feedback and incentivisation).

The following section builds upon the current understanding of the target behaviours and associated intervention functions to identify promising techniques for change.

#### 4.2.7 Identify BCTs

Now that an understanding of what intervention functions are appropriate, it is now possible to identify promising Behaviour Change Techniques (BCTs) for the intervention. A BCT is defined as "an active component of an intervention designed to change behaviour" (Michie, Atkins, et al. 2014, p.145).

Using the mapping of BCTs to intervention functions defined in Michie, Atkins, et al. (2014), individual BCTs were evaluated against the APEASE criteria, and the results of this analysis are provided in Table 14 and summarised in Table 15.

| Intervention function | COM-B component | Individual BCTs | Does the BCT meet the APEASE criteria? |
|---|---|---|---|
| Persuasion | Psychological Capability | Health Consequences | Not practical/not relevant |
| | | **Feedback on behaviour** | Yes (providing feedback on performance of the behaviour is a promising BCT) |
| | | Biofeedback | Not practical/not relevant |
| | Social Opportunity | **Social comparison** | Yes (showing other users performance and using it for comparison is promising) |
| | | **Identity associated with changed behaviour** | Yes (allowing a person to construct a new self-identity related to the new behaviour is promising) |
| | | **Information about others' approval** | Yes (providing information about the approval/disapproval of the behaviour has shown to be successful in this area in the past) |
| | | **Identification of self as role model** | Yes (using someone's behaviour as a positive example for others is promising) |
| | Reflective Motivation | **Salience of consequences** | Yes (providing a way of showing the consequences of energy consumption is promising – rather than just informing) |
| | | **Information about social and environmental consequences** | Yes (providing a way of showing the consequences of energy consumption on the environment is promising) |
| | | Information about emotional consequences | Not practical for the target delivery method |
| Incentivisation | Psychological Capability | **Feedback on behaviour** | Yes (see above) |
| | | Biofeedback | Not practical/not relevant |
| | | Remove punishment | Not practical or affordable within the energy consumption context |
| | Social Opportunity | **Social reward** | Yes (providing a non-verbal reward for doing the behaviour is promising) |

| **Intervention function** | **COM-B component** | **Individual BCTs** | **Does the BCT meet the APEASE criteria?** |
|---|---|---|---|
| | Automatic Motivation | **Incentive** | Yes (see above) |
| | | Material reward | Not affordable in this project |
| | | Material reward (outcome) | Not affordable in this project |
| | | **Social reward** | Yes (see above) |
| | | Non-specific reward | Not affordable in this project |
| | | **Reward (outcome)** | Yes, although in-game rewards are considered non-tangible |
| Coercion | Psychological Capability | **Feedback on behaviour** | Yes (see above) |
| | | Self monitoring of behaviour | Not likely to be acceptable to users, but still promising |
| | | Biofeedback | Not practical because not relevant |
| | Reflective Motivation | **Discrepancy between current behaviour and goal** | Yes (providing feedback that shows difference in the form/frequency/ duration/intensity of behaviour to previous attempts is promising) |
| | | Monitoring of behaviour by others without evidence of feedback | Not practical/not relevant |
| | | Monitoring outcome of behaviour by others without evidence of feedback | Not practical/not relevant |
| | | Self-monitoring of behaviour | No (see above) |
| | Automatic Motivation | **Punishment** | Yes (providing punishment for failing to do the behaviour is a promising BCT) |
| | | **Behaviour cost** | Yes (see above) |
| | | Remove reward | No (beyond scope) |
| | | **Future punishment** | Yes (see above) |
| | | Anticipated regret | Not practical |
| | | Imaginary punishment | No (beyond scope) |
| Modelling | Psychological Capability | Demonstration of the behaviour | Not practical |

**Table 14. APEASE analysis of behaviour change techniques for the relevant intervention functions. Selected BCTs are highlighted in bold.**

| Behaviour Change Techniques |
| --- |
| Feedback on behaviour |
| Social comparison |
| Identity associated with changed behaviour |
| Information about others' approval |
| Identification of self as role model |
| Salience of consequences |
| Information about social and environmental consequences |
| Reward (outcome) |
| Social reward |
| Incentive |
| Discrepancy between current behaviour and goal |
| Punishment |
| Behaviour cost |
| Future punishment |

**Table 15. Summary of APEASE analysis of behaviour change techniques, showing promising behaviour change techniques.**

As mentioned in Chapter 2, non-gaming implementations of behaviour change for energy conservation have used some of the BCTs listed in Table 15. Ehrhardt-Martinez et al. (2010) note that it is not just the type of feedback provided that has impact on the amount of energy savings. They identify that tailored feedback, multiple sources of information, meaningful feedback, and motivational techniques such as goal setting, social norms, commitments, and social comparison are things that must be considered in the design of an effective feedback system in the energy domain.

At this point in the BCW process, intervention designers are prompted to develop an intervention strategy based upon the selected BCTs. For this project it was decided to deviate slightly from this process and complete this step at the end of the process. The reasoning behind this decision was that the intervention strategy for this project makes heavy reference to the mode of delivery, which is the focus of the next section (and the final step in the original BCW process).

#### 4.2.8 Identify Mode of Delivery

Now that appropriate BCTs have been selected, the final step in the BCW process is to identify the way in which these techniques can be delivered. This step prompts the designer to consider possible methods of delivery, and evaluate them against the APEASE criteria. The results of this analysis for this project are presented in Table 16.

| Mode of delivery | | Does the mode of delivery meet the APEASE criteria? |
| --- | --- | --- |
| **Face-to-face** | **Individual** | |

| Mode of delivery | | | | Does the mode of delivery meet the APEASE criteria? |
|---|---|---|---|---|
| | **Group** | | | These modes of delivery are not practical because the intervention is intended to be delivered via distance. |
| **Distance** | **Population-level** | **Broadcast media** | **TV** | Not practical as it is hard/impossible to provide direct personalized feedback to individuals |
| | | | **Radio** | |
| | | **Digital media** | **Internet** | Effectiveness a problem as previous attempts in this area have already used the internet as a feedback device (medium is saturated) |
| | | | **Mobile phone app** | **Yes, a mobile phone delivery target is promising as household members are likely to have a phone, and personalized feedback can easily and immediately be given on the device** |
| | | **Print media** | **Newspaper** | Not practical as individual feedback is impossible to provide |
| | | | **Leaflet** | Not affordable or practical to provide individual feedback to many using a leaflet |
| | | **Outdoor media** | **Billboard** | Not practical as individual feedback is impossible to provide. |
| | | | **Poster** | |
| | **Individual-level** | **Phone** | **Phone helpline** | Not practical to individually call all household members with individual feedback<br>Not likely to be effective as only limited feedback can be provided |
| | | | **Mobile phone text** | Not likely to be effective as only limited feedback can be provided |
| | | **Individually accessed computer program** | | Not likely to be effective as a mobile application |

**Table 16. APEASE analysis of delivery methods showing digital media to be most promising.**

As for delivery methods, face-to-face delivery modes were considered impractical due to the large number of homes that are targeted (ideally all homes would be targeted). Among distance-based delivery methods, individual phone-based methods were considered to be unlikely to be effective as only limited feedback can be provided. Outdoor media such as billboards and posters, print media such as newspapers and leaflets, and broadcast media were considered impractical, as it is essentially impossible to provide personalised feedback to individuals.

Digital media was considered the be the optimal delivery mechanism, particularly medium of a mobile phone app, since household members are likely to have a phone, and personalized feedback can easily and immediately be given on the device. Different types of mobile applications were considered. A common form of mobile application is a video game. Video games excel at providing their players with useful feedback. Complicated strategy games can provide detailed feedback on the status of thousands of player-controlled units, and the player is able to manipulate entire armies at once with ease due to the well-established feedback mechanisms in games. Of the 24 energy conservation game studies reviewed by Johnson et al. (2017), 9 featured a mobile application.

Nolan et al. (2008) identify a potential pitfall to current studies on energy conservation. They claim, *"many people are already engaging in conservation efforts* [and] *appealing to these motivational bases merely preaches to the choir"* (p. 921). They go on to suggest that in order to reach those not already engaging in conservation efforts, that an alternative motivational basis is needed that can appeal *"to a different portion of the population*". In introducing the idea of a Serious Game with the purpose of energy conservation (that goes beyond the simple gamification implementations described previously), it is argued that the motivational power of video games and the wide audience of people they appeal to make them an extremely viable candidate for such a motivational basis.

The choice of mobile platform comes from the many benefits its use entails. The most obvious of these benefits is the ability of the platform to be played anywhere (e.g. at home, work)—in particular the way in which mobile games lend themselves to be played in interstitial time due to the fact that users keep their phones on their person most of the time (Google 2013; Samuel & Pfahl 2016). The latest statistics suggest that the mobile penetration rate as of 2016 in Australia was 84%, up from 76% in 2014 (Deloitte 2016).

Another intended feature of the game design is that the game will be possible to be played at the user's "own pace". This is in keeping with many current casual mobile game designs, which present the gameplay in a manner that can be played for a few minutes in between other tasks. This is traditionally done via either small level designs where progress is saved at the end of a level, or a "persistent" game with no time pressure and consist of a single world, the state of which is updated and saved with every user action.

Using video games as delivery method, an intervention strategy can be developed which incorporates the identified intervention functions and BCTs, and this is the focus of the following section.

#### 4.2.9 Intervention Strategy

Based upon the identified intervention functions and BCTs, an intervention strategy was designed for the selected delivery method. To accomplish this, for each of the BCTs, potential video game elements needed to be identified. This new process is multifaceted, requires justification, and constitutes a major contribution to this work. Creating an intervention strategy in the form of a set of theory-informed game elements stands to improve the way behaviour change Serious Games are designed. The detail and results of this process are described at length in the next section.

## 4.3 Linking Behaviour Change Techniques and Game Elements

The standard output for most works using the Behaviour Change Wheel methodology from a design perspective is an intervention strategy which pulls together the identified Behaviour Change Techniques into an actionable format. This work is unique in its application of the BCW to a Serious Game intervention strategy, and along with this comes the challenge ensuring the game elements that comprise the Serious Game appropriately facilitate the chosen BCTs. Figure 35 shows diagrammatically the process that links the BCW to multiple possible Serious Game designs.

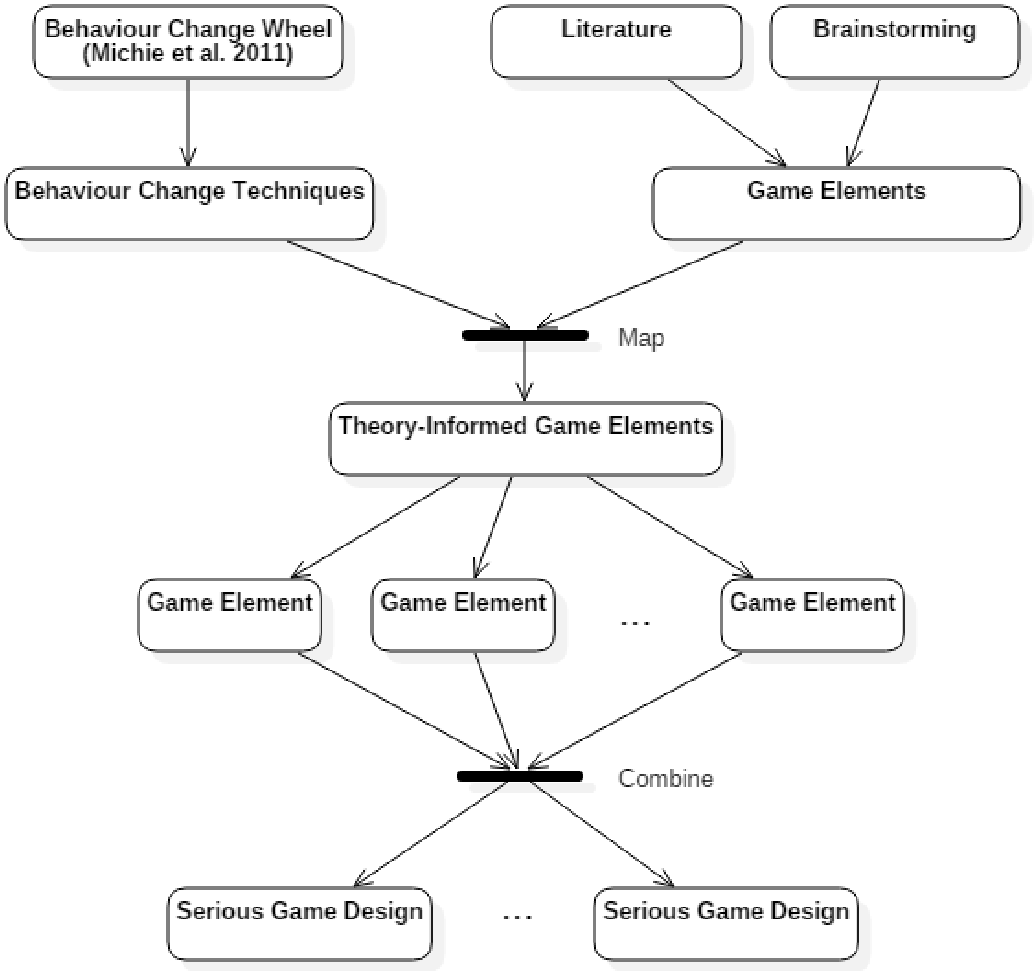



**Figure 35. The process linking the Behaviour Change Wheel to the final Serious Game design.**

At time of writing there is no extant literature handling the direct linkage of BCTs and game elements, and although not referring directly to the BCW process, Nacke & Deterding (2017, p.4) state in no uncertain terms the need for further research in this area:

> *"we need validated theories* [on] *how design elements function and interact with individual dispositions, situational circumstances, and the characteristics of particular target activities"* (p. 4).

Instead we must look to the body of knowledge of Serious Games and Gamification for indications of how various game elements can affect behaviour. Using the information gathered, it may then be possible to theorise how game elements may be utilised to action various BCTs.

This section first explores the literature on classifying game elements, before presenting the extant literature on how individual game elements can affect behaviour. Then, as a result of this literature search, a mapping of the chosen BCTs for this project to game elements is given, effectively formalising the intervention strategy for the Serious Game, and concluding the Behaviour Change Wheel process for designing this intervention.

#### 4.3.1 Game Elements Literature

Given the sheer volume of possible game elements, it makes sense to work backwards from the chosen BCTs and determine suitable elements, rather than creating an exhaustive list and excluding elements that do not match the BCTs. The primary sources of game elements in literature were Deterding et al. (2011), Chou (2016), Rapp (2017), Reeves & Read (2009), Gamified.UK (2017), and Johnson et al. (2017). Elements were described in many other sources, as referenced in the following sections. Deterding et al. (2011) provides broad examples for increasing levels of abstraction (*interface*, *mechanics*, *principles*, and *models*), in a similar way to the MDA Framework (Hunicke et al. 2004) which categorises components of games broadly as *mechanics*, *dynamics*, and *aesthetics*.

Chou (2016) provides a large number of examples categorised into *accomplishment*, *ownership*, *scarcity*, *avoidance, unpredictability, social influence, empowerment,* and *meaning*. It should be noted however, that the examples provided by Chou (2016) are often presented in the form of stories, rather than concisely defined elements. In addition, a considerable number of the elements described in his work are purported to have certain effects, despite only anecdotal evidence being provided in some cases.

Although his work is scoped primarily to *World of Warcraft* (Blizzard Entertainment 2004), the recommendations by Rapp (2017) are still very relevant for a number of factors. *World of Warcraft* is very popular, and clearly implements features that interest a large number of players. It has also been studied by many different researchers, making it ideal for academic use. Finally, the quality of recommendations provided by Rapp (2017) are high, and supported by literature. In summary, Rapp (2017, p.476) make six recommendations for use in interventions:

- *identification and empathy*, and identification of *past and future selves*: primarily accomplished via player avatars;
- *rewards*;
- *social presence*: via social systems;
- *self-organisation:* through guilds (also referred to as clans);
- *cooperation and friendship* as well as *competition*: again, through social features such as clans, chat, and newsfeeds; and
- *freedom* and *journey:* through exploration, quests, achievements, and levelling-up.

Rapp (2017) highlighted the applicability of *Expectancy-Value Theory* (Wigfield & Eccles 2000), *Avatar Identification* (Hefner et al. 2007; Gee 2003), and the *Transtheoretical Model* (Prochaska & Velicer 1997) to video games.

Reeves & Read (2009) identify 10 core elements: *avatars*, *three-dimensional environments*, *narrative*, *feedback*, *levelling-up*, *economy*, *rules*, *teams* (or *clans*), *social systems*, and *time pressure*. Their list of elements has been used in other work for examining game elements (Lister et al. 2014).

Although not a peer-reviewed source, another catalogue of game elements used was the one developed by *Gamified.UK* (2017). This source lists 52 game elements categorized by the player type that element is most suited to: *general, scheduling, socializer, free spirit* (focussing on exploration and content creation), *achiever,* and *philanthropists* (similar to socializer but with a focus on gifting and trading), *disruptor* (concerned with anonymity, hacking, and modding), and *player* (focussing on points, badges, and leaderboards). This source is the closest to an exhaustive list of elements found in the literature search, however it was deemed that it could be used as the only source due to its lack of academic basis, detail in the meaning and description of the elements, and the overall focus of the work being from a Gamification perspective. It should be noted that this is a step in the right direction for Gamification implementations as described throughout this thesis most examples only use elements from the *player* category.

Finally, the list of elements found in existing Serious Game studies for energy conservation by Johnson et al. (2017) was used. They found that previous games used *avatars, badges, challenges, feedback, leaderboards, levels, rewards, social sharing, points, tips, rankings,* and *user-generated content.*

A large number of other studies compiling lists of game elements were heavily biased towards the PBL triad, such as Schobel et al. (2016) and Sailer et al. (2017). Given the shortcomings of Games for Change explained earlier in Section 2.1.4, and the limited number of elements found in literature, the academically-sourced game elements were supplemented with elements unearthed as a result of brainstorming. A study of 25 Gamification experts by Morschheuser et al. (2017) found that brainstorming was a commonly used process in determining game elements to use in applications, and Deterding (2015) identifies ideation of ideas through brainstorming as part of his recommended process of *Gameful Design* (Deterding 2015).

A full list of elements that resulted from the brainstorming and literature search is presented in Appendix C.

#### 4.3.2 Mapping to Behaviour Change Techniques

For each BCT, suitable game elements were considered from the sources described in the previous section and as identified through a brainstorming process. The following sub-sections explore each BCT in detail, with suitable elements described in terms of the BCT. It should be noted that the descriptions of elements in this section are abstract in nature. Since elements are best contextualised through a video game whole, more detailed descriptions, and their integration into a complete are described in Section 5.2.

Game elements are presented in sub-sections, however the relative length of each of these may be shorter if that element has already been introduced in a previous section. Elements are described in the context of an intervention for energy conservation, however, for the most part, the mapping and rationale should apply to most other domains.

##### *4.3.2.1 Feedback on Behaviour*

Possibly the simplest to understand, yet also most broad of the BCTs, *feedback on behaviour* is described by Michie et al. (2013) as a process to

> *"monitor and provide informative or evaluative feedback on performance of the behaviour (e.g. form, frequency, duration, intensity)"* (p. 4)[67]

To accompany the definition, Michie et al. (2013) provide the example of using measurement tools (e.g. pedometer, questionnaires, etc.), and presenting the resulting information to the person. This behaviour change technique is of particular importance to this project, given the previous calls for improved and tailored feedback cited in Chapter 2 (Ehrhardt-Martinez et al. 2010).

For this project, the behaviour of focus is energy consumption, thus the feedback provided to users would be the amount of energy they are using as measured by their smart meter, but also derived data, such as the difference in conservation compared to the previous day, and compared to other users (although the latter is the subject of the next BCT, social comparison). This section describes, in general, game elements that could facilitate this BCT. It should be

[67] Note that the page numbers used in the reference to Michie et al. (2013) throughout this section (4.3) refer to the "Electronic Supplementary Materials" of that document, where page numbering restarts at 1.

noted that this is the main BCT for the project, and so the game experience as a whole is intended to facilitate this BCT.

##### 4.3.2.1.1 Daily Login Screen

A *daily login screen* could be drawn upon to provide the player information about their energy usage. Daily login screens are used in games often to contextualise the experience, and provide a sense of routine and familiarity for players by ensuring each playthrough starts in a particular way, before branching off into each individual session. Games can use daily login screens to provide feedback to the player on how many days in a row they have opened the game (this practice is common in mobile games where individual sessions are short, but are accompanied by long-term pay-offs). A Serious Game could utilise this screen to provide feedback on energy usage to players. Since this screen is seen at the start of every session, players are guaranteed to witness the feedback as long as they choose to open the game. In designing this screen, it is important to ensure it does not limit the player's ability to access the game, otherwise feelings of resentment toward the delay brought about by this screen may arise. Showing this screen reinforces to players that their usage is linked to the game experience.

##### 4.3.2.1.2 Statistics Screen

Among many reasons, games can use *statistics screens* to display performance metrics so that players can identify (or confirm) playstyles that they succeed with, and areas they may need to improve. At other times, statistics screens simply provide players with a record of what their time investment in the game has consisted of. In-Home Displays provide the best examples of statistics screens (see Section 2.2.2.2.2).

A statistics screen could be augmented with statistics from outside of the game context, such as energy consumption. This also provides an opportunity to display more detailed feedback than could be displayed on the daily login screen (since this is not part of the initial launching of the game phase, where detailed feedback may be perceived as preventing the player from reaching the point where gameplay starts), as well as a way of players being able to easily see their feedback without the need to restart the game (and see the login screen again).

##### 4.3.2.1.3 Impact on Game Resources

The feedback mechanisms described so far have explicitly displayed energy consumption and related measures directly. An alternative approach is to provide feedback *indirectly* such that energy consumption has an impact on the way the game itself plays. This could be achieved by altering the game elements of *resources* and *environment*.

*Resources* in the intervention game may be impacted in a number of ways to provide indirect feedback, such as bonuses, rare items, drains, and accessibility. Meeting certain criteria (such as using less energy than the previous day, or using below a certain set amount in the next hour) could result in bonuses amounts of resources being provided to the player. Similarly, meeting certain exceptional criteria (such as not using the air conditioner for the whole day) could result in rewards in the form of items which are considered rare in the context of the game (i.e. they are hard to find in the game world, require a difficult puzzle to be completed, or can only be achieved using this reward system). Rare items can provide players with a sense of accomplishment or competency within the game (Yee 2006; King et al. 2010), and when the ability to share the fact you own such items with other players exist, can provide players with a form of social capital. Rare items may also unlock new actions or ways to play that form some kind of tangible in-game reward (e.g. a sword that flings enemies into the sky). The same of rare items is true for large amounts of standard resources, as these may be traded for rare items or have social capital associated with them. Conversely, when a player fails to meet a positive criterion or they meet a negative criterion (such as exceeding their maximum peak load for the week) resources may be drained or even completely removed. This negative occurrence may act as a deterrent for future bad behaviour, however should be used sparingly, and with caution given the warnings in literature over using the avoidance of punishment as an incentive (i.e. as an extrinsic motivator) being potentially demotivating (Deci et al. 2001). In essence, feedback is provided to the player such that they may associate additional resources, rarer items, and further progression with positive behaviour, and slower/no/negative resource gain with negative behaviour. Accessibility of resources could be achieved in the game by manipulating the game environment, as described in the next section.

#### 4.3.2.1.4 Impact on Game Environment

The game *environment* can be changed in a plethora of ways to provide feedback, and the specific ways in which this can be achieved depend on the game being developed both in terms of its setting and genre. In general, the intention of linking the game environment element to feedback for the player is to again reward positive behaviour with additional access to in-game areas, items, and functionality, and to limit or impede this access when negative behaviour is exhibited. This may manifest itself in the form of weather changes in the game, artificial barriers in place (with or without explanation), or changes in the game storyline. *Power House* (Reeves et al. 2012) in Section 2.3.2.5 provides the best example of an existing Serious Game that makes use of this idea.

Changes in game environment does not always need to have an impact on gameplay. Changes could be made in cosmetic ways (e.g. dark clouds, unhappy characters).

##### 4.3.2.1.5 Notification System

Mobile video games often make use of the *notification system* of devices (i.e. push notifications) to interact with players when the application is not open. Implementations of this vary from game to game. Many games send notifications daily to remind players to play the game (this is usually coupled with daily "streak" rewards for playing on consecutive days). Other games use more sophisticated notifications which tie in with in-game events. A good example of this is in *The Simpsons: Tapped Out* (Electronic Arts 2012) where in-game actions may take a number of real-world hours to complete (e.g. a building may only be accessible 4 hours after it has been placed in the world), and notifications appear when this action has been completed (as the player cannot reasonably be expected to keep their game open for 4 hours, and indeed the game is not designed for this). Another example of this is *Candy Crush Saga* (King 2012), which provides a notification when the player's "lives" have been replenished. The intervention could use the notification system to provide feedback to players by embedding energy usage information into the content of the push notification, or present notifications when certain criteria are met in the usage data. For example, notifications could appear when the player is close to exceeding the previous day's peak usage, or when a sudden increase in energy usage is detected. When energy consumption satisfies an in-game requirement (e.g. a quest requirement, see Section 4.3.2.7.2), a notification linking the two could be sent, thus reinforcing the relationship between game and energy conservation behaviour.

##### 4.3.2.1.6 Level-Up System

Predominately used as a form of incentive, and a way of providing rewards to players for continued use, a *level-up system* can also be a form of feedback to the player. In many games, a player has a *level* associated with them (or their character), which is generally intended to be an indicator of their progress or strength within the game. When a player "levels-up", feedback is usually shown on screen, and rewards are given. In an intervention that rewards players for good behaviour, and this ultimately progresses them further in the game, a level-up display can become a form of feedback related to their real-world behaviour. The frequency (or lack thereof) of their "level-ups" provides feedback to the player on their progression in the game, and on their behaviour.

Level-up systems are described in further detail in the coming sections, with reference to associated rewards, and player comparison.

###### 4.3.2.1.7 Normative Leaderboards

Leaderboards with energy consumption information can be a form of feedback to players to suit this BCT. Gamification literature makes heavy use of the *leaderboard* game element (Bogost 2011; Robertson 2010), however an extension of this element is to display the leaderboard in ways informed by Social Normative Theory (Perkins & Berkowitz 1986). This is covered in detail in relation to the *social comparison* BCT in Section 4.3.2.2.1.

#### *4.3.2.2 Social Comparison*

A very promising BCT identified during the BCW process was that of *social comparison*. Again, this BCT is simple to comprehend, and has proven to be very powerful as described in chapter 2. Michie et al. (2013) broadly intend this BCT to be implemented by:

> *"draw[ing] attention to others' performance to allow comparison with the person's own performance"* (p. 8).

Chapter 2 highlighted the importance of social comparison, and indeed Ehrhardt-Martinez et al. (2010) list such comparison as a promising way of bringing about effective energy conservation. An example of normative feedback in the energy domain is the *Wattsup* application (Foster et al. 2010) that provided social comparison of energy usage powered by Facebook. They found a significant reduction in energy consumption for participants given the social comparison feedback compared to a control group who were not given it.

Arguably, video games have always had a social component, and even early video games had social aspects coded into them. *Tennis For Two* (William Higinbotham 1958), one of the first video games, was a social experience for two players. Arcade games were social as a result of the environment they were played in, as well as the use of leaderboards to provide comparison. Early PC games such as *Quake* (id Software 1996) featured online multiplayer play, and with the advent of social media, modern video games—particularly on mobile devices—frequently integrate with services such as Facebook and Twitter to facilitate social comparison. Console games are required to integrate with the social networks implemented on those systems (e.g. PlayStation Network, XboxLive, etc.).

###### 4.3.2.2.1 Normative Leaderboards

*Normative leaderboards*—leaderboards which differ from "superstar" leaderboards (where users are simply sorted from best to worst, with the player typically not shown on the first page of the leaderboard), in that they are filtered by relevant others, and show the users that are immediately above and below them on the scoreboard. Normative leaderboards can be used for the feedback on behaviour BCT, however the intervention would primarily use them for providing social comparison.

This kind of leaderboard plays off the theory by Festinger (1954) that we gain motivation and guidance from those better-off than us and self-esteem from those worse-off, all while attempting to address the demotivating effects of superstar leaderboards where users feel they have fallen too far behind the leading players. Additionally, this style of leaderboard promotes competition among players of (potentially) the same skill level, but also gives a sense of similarity to players who are less competitively-inclined by showing people with the same or similar score to them. Gollwitzer & Oettingen (2012) found that the showing leaderboards with scores that are difficult or impossible to achieve was equivalent to presenting people with difficult or impossible tasks.

The intervention could implement a normative leaderboard that shows players others who are at a similar level of energy consumption to them. There is a danger here that a normative message that other people are also exhibiting poor energy consumption behaviours could be given by this kind of feedback, potentially making the player believe their behaviour is less harmful than it really is. However, combining this with an injunctive norm showing that the people with these poor energy consumption behaviours are well below average and are doing poorly in terms of game progression may combat this. Additionally, if the player previously saw another user who was in their usage range but on a subsequent look at the leaderboard found that player had since improved their usage, then a message that others are disapproving of being at this level may be sent.

The intervention could also tie these normative leaderboards with in-game rewards, and this is described later for the BCT *social reward*.

##### 4.3.2.2.2 Community Score

Modern video games have begun implementing *community challenges* which, in general, incentivise players to contribute toward some common goal in order to receive a reward. Implemented differently across games, one example is *Tom Clancy's Ghost Recon: Wildlands* (Ubisoft Paris 2017) where players are given a week to complete a certain challenge (e.g. "Destroy 1,200,000 Unidad helicopters in any province") which when completed unlocks a reward (e.g. access to "combat helicopters"). In this example, players are able to see just how many helicopters have been destroyed since the challenge started. Other games such as the *Call of Duty* series present information on total statistics of the community since the game was started (e.g. how many bullets have been fired cumulatively by all players).

By providing information such as this in the intervention, additional information describing the energy consumption of other players could also be included, such as the average consumption per day of the community, or average peak load of players. In order for this form of normative feedback to useful however, it is likely that this would need to filtered by relevant others, much like those seen in the Goldstein et al. (2008) and Loock et al. (2012) studies in Section 2.2.2.1.

The idea of displaying average consumption from others has been shown in a non-game, non-technology-based study conducted by Schultz et al. (2007). They showed the participants their energy consumption for previous weeks, alongside a descriptive norm that showed participants the average energy consumption of other people in their area (i.e. they were shown what the norm for energy consumption by similar others was). This may arguably work better in Serious Games rather than traditional entertainment-purposed video games as a "desire to be average" mentality is rarely exhibited in traditional games, since entertainment and "scoreboard domination" is not usually the goal of a Serious Game.

The boomerang effect (where usage levels tend to gravitate toward the average figure shown in the descriptive norm; see Cialdini & Trost (1998), Torriti (2012), and (Elliott 2012)) may still be present if using normative feedback in this way for a Serious Game. This could be combatted by providing an injunctive norm, in much the same way Schultz et al. (2007) did in their study (i.e. providing a hand-drawn smiley face or sad face depending on if consumption was higher or lower than the average). One simple way may be to provide an injunctive norm in the form of approval for being above the average by way of special reward. The challenge in providing these rewards that is often overlooked in game reward systems is trying to ensure that these rewards are *meaningful*. Simply providing badges or achievements may not be enough to provide enough meaning that the reward is perceived to be an injunctive norm of approval.

In the implementation of a Serious Game for energy conservation, relevant reference groups could represent neighbours, friends, or houses with the same number and type of occupants (including family structure, i.e. 2 parents and 3 children would have different usage habits to share-house of 5 young adults) within a similar socio-economic grouping. Indeed, the algorithm for determining relevant reference groups for the various forms of normative feedback could be informed by a *social system*, described in the next section.

#### 4.3.2.2.3 Social System

Most multiplayer games feature some form of *social system*. This facilitates matchmaking, and promotes comparison and competition between players as game statistics and achievements can be shared using this system. These social systems may be built directly into the game, rely on the underlying platform's system (e.g. Steam Community, PlayStation Network, Xbox LIVE, etc.), be external to the game in the form of a website, span multiple games from a series/developer/publisher, or be some combination of these forms. The end result is a social network where players can make connections with other players (either bi-directional relationships, or unidirectional follow-relationships), and view the gameplay statistics and game-defined skill-level (generally using the previously described *level-up system*) of other players. The most advanced of these systems also allow for sharing of in-game achievements and moments (e.g. screenshots or video clips), as well the ability to comment or "like" these posts. The Reeves et al. (2012) and Brewer (2013) studies are the closest existing examples of a Serious Games for energy conservation with a social system.

An intervention could allow for posting of energy conservation-related achievements generated by the system (e.g. "today I used 50% less energy than I normally do on similar days"), and players witnessing this would be able to examine these actions in comparison to their own.

Profiles on a social system can help contextualise the "others" that are presented to players when describing energy usage (i.e. the number of people in the household, and location of the household can help the user *and* an automated system determine the relevancy of another player for comparison). The more a profile can be customized, the clearer the image the viewer may have of that person, which may potentially increase their will to "beat" that person, or associate with them. The profile may also serve as a landing page for a viewer before determining if they wish to befriend them on the system.

Further to the friendship feature of social systems in games, many games feature the concept of *clans* in one form or another. Clans (or "guilds") are groupings of players who generally play together on a team (Williams et al. 2006). At their simplest, clans are "meta" to the actual game and are managed through third-party websites or chat, and manifest themselves in-game in the form of "player tags" appended to usernames, or common cosmetic items acting as a team uniform. Some games implement features that facilitate clans, with a prominent example being *EVE Online* (CCP Games 2003), which allows players to form "corporations" and work together to complete objectives. *Clash of Clans* (Supercell 2013), as the name implies, is another example of a game with clan features, and indeed the core gameplay revolves around players competing with other clans in wars. Other games such as *Drive Club* (Evolution Studios 2014) and *Guild Wars* (ArenaNet 2005) also feature clans heavily, although refer to them as both "clubs" and "guilds" respectively.

Within clans, players can compete to have standing within their clan for a given position (for example in *EVE Online*, players are assigned different roles, such as the CEO or accountant). Depending on the game's level of clan features, and on how the clan itself operates, player position in a clan may be determined by actual skill level, time in the clan, or popularity, among many other reasons.

An intervention could use clans in the social system to implement social comparison by embedding energy conservation data into the clan system. Clans could be formed automatically by using the "relevant others" algorithm previously mentioned, and competition could occur both within the clan and between clans. The *community score* element from the previous section could use clans as a filtering mechanism, and rewards for completing clan challenges or beating other clans based upon some criterion could be given.

##### 4.3.2.2.4 Level-Up System

This section has previously introduced *level-up systems* as a way of providing feedback to the player. A level-up system may also be used for social comparison, and indeed in many games the easiest piece of information to obtain about a player other than their name is usually their in-game level. If you encounter another player in a "player vs player" (PvP) environment, the display of player level can influence your decision to engage or flee. Player level can indicate many things about the other player depending on the game, including the items or abilities they have access to, the amount of time they have played the game, their skill level, or even the elements of the story or environment they have been exposed to.

In an intervention which tightly links energy conservation to game progress (and thus to player level), a player's level facilitates an easy form of comparison, and also one which is presented in a "game like" fashion, rather than one coated in energy conservation messaging.

Player level may also help inform the "relevant grouping" described in previous sections.

#### *4.3.2.3 Identity Associated with Changed Behaviour*

Michie et al. (2013) write that the BCT *identity associated with changed behaviour* should be implemented as

> *"advis[ing] the person to construct a new self-identity as someone who 'used to engage with the unwanted behaviour'"* (p 17).

An example of doing this is provided by Michie et al. (2013) for smoking behaviours as getting the person to think of themselves as an “ex-smoker”, and to use this identity among friends.

Games have various ways in which players can express their “identity”. Role-playing games often provide players with “blank-slate” characters which they can customize, and dictate how they react and speak in the game world. Other games let players express their identity through the player’s actions, e.g. by allowing the player varying levels of freedom in what they can build in the game world.

#### 4.3.2.3.1 Avatar

While many games feature specific protagonist main characters which the player controls, others provide players with *avatars* which they can name, and customize. These two broad methods may offer different forms of story-telling in games, however the latter facilitates the association of the player’s identity with the avatar, compared to the need for empathy with the former. There is scattered literature on the topic of player avatars, and there is still a lot to learn on how having “blank-slate” characters which the player imprints on can affect player motivation. A good starting point on this is the work by Gee (2003) who describes a “three identity model” (p. 54), which consists of:

- a *virtual* identity, which is represented by the in-game character;
- a *real-world* identity, which is represented by the human player; and
- a *projective* identity, which represents the relationship between the virtual and real-world identities such that one both “*project*s one’s values and desires onto the virtual character”, and “seeing the character as one’s own *project*”.

The projective identity relates to how players can allow their virtual identity to be influenced by their real-world identity, as a result of the known limitations of the player’s human existence. The virtual identity is allowed to fail in ways that the real-world identity can not. Gee (2003, p.58) describes how players can feel they “let their character down”. Gee goes on to describe how such identity can be leveraged for learning.

An intervention could make use of a player avatar which uses the player’s name to partake in energy conserving actions in the game, or reap the benefits of positive energy behaviours in the game (such as turning off the air conditioner in their virtual house). Doing so may afford the player with the opportunity to associate those positive actions with their own self. In addition, having positive outcomes occur for the avatar, such as increased resources, or existing in a more vibrant environment may help the player realise that positive outcomes may also occur for them in the real world. This is discussed further in Section 4.3.2.6 about the salience of consequences BCT.

Many modern games offer a plethora of customization options for avatars. While predominately cosmetic, these options can allow players to build their avatar to look like them, like their ideal image, another person, or anything at all. The intervention could include customization options to help strengthen the identity association effect.

##### 4.3.2.3.2 World Building

In much the same way that avatar customization allows players to produce characters which mirror (or do not mirror) their true or ideal selves, world building mechanics can allow the player to create environments that match locations that are meaningful to them, or represent places of interest or fantasy. World building is typically found in sandbox games such as *Minecraft* (Mojang 2009), simulation games such as *The Sims* series (Maxis 2000), *The Simpsons: Tapped Out* (Electronic Arts 2012), and *Farmville* (Zynga 2009), but also in more limited or focussed forms in games such as *Fallout 4* (Bethesda Game Studios 2015).

An intervention could combine world building mechanics with the consequences of the impact on game environment to result in interesting interactions such as deterioration of player-built buildings or improved building output. Additionally, the consequences of the impact on game resources would change how many buildings the player could create, or the quality of resources used to create those buildings.

#### *4.3.2.4 Information about Others' Approval*

Providing *information about others' approval* is a BCT described by Michie et al. (2013) that helps "clarif[y] whether others will like, approve or disapprove of what the person is doing or will do". The example in Michie et al. (2013) is to tell hospital workers that workers at other hospitals *approve* of washing hands. This again draws from Social Normative Theory (Perkins & Berkowitz 1986), and it would be interesting to see if the study by Goldstein et al. (2008) which made effective use of social norms for a towel reuse program by placing signs in hotel bathrooms could be built upon by using a sign stating that others "approve of reusing towels".

##### 4.3.2.4.1 Narrative

Most games choose to present some form of narrative to players. In some cases, they can be simple in order to contextualize gameplay-heavy experiences, in others, narrative is the main driving force behind the entire game. In the context of the approval BCT, narrative could be used in two main ways: to present a story which glorifies or promotes positive energy behaviours (particularly by allowing characters to voice opinions that reinforce this), and to dynamically influence the dialog spoken by characters, based upon player behaviour.

There have been a number of studies on narrative in Serious Games, particularly in its use to promote specific behaviours.

An intervention could present characters that state in various ways that they approve of energy conservation, and if presented within an appealing narrative, could be persuasive.

Additionally, a more dynamic approach could be used, where the dialog spoken by in-game characters is approving in nature when the player exhibits conservation behaviours, and disapproving when they fail to do so. This is also explored further in the *social reward* BCT.

The approval referred to in this section has been from fictional characters, and beyond messages "made up" by researchers in previous studies, at time of writing there has been no research exploring the difference between approval from fictional persons, and that from perceived real people. The following section looks at approval from real people via a social system in the game.

###### 4.3.2.4.2 Social System

The BCT for social comparison introduced the concept of a *social system* element for the intervention. This system could facilitate feedback about the approval of others in a number of ways as it affords users with the ability to react to certain energy conservation-related activities. As mentioned previously, the system could include posts from players indicating they have had achieved some kind of conservation-related goal. A fully-featured social system would allow other players to comment on or "like" the post—ideally to indicate their approval or admiration. Feedback on this could be made more immediate by integrating this functionality with the *notification system* element.

The JouleBug (Elliott 2012) Gamification implementation provides a suitable example of a social feed to facilitate approval of others.

##### *4.3.2.5 Identification of Self as Role Model*

*Identification of self as a role model* is a BCT that is intended to promote positive behaviours by informing the person that their behaviour may be an example to others (Michie et al. 2013). The example provided by Michie et al. (2013) makes use of the parent-child relationship, where healthy eating is a good example to set for your children.

##### 4.3.2.5.1 Social System

If player behaviour is shared on the social system previously described, and players know that representations of their positive behaviour is shown to others, then it follows that players may be able to feel like they are a role model to others on the system. This however is predicated by the fact that others see the activity, and react positively to it, rather than being demotivated by not being as good as the player. Comments and "likes" on the post may help the player realise that they are having a positive impact on other players of the game.

##### 4.3.2.5.2 Normative Leaderboards

Similar to how the knowledge that positive behaviours appear on the social system, the knowledge that a player might appear higher on a *normative leaderboard* than others may in some way allow the player to see themselves as a role model to those lower than them on the leaderboard.

##### 4.3.2.5.3 Monuments

Although not commonly seen in games, depictions of avatars belonging to high-achieving characters in the game world in the form of a statue is one way that players could perceive themselves to be a role model to others. A documented case of this in a game is *Warhammer Online* (Mythic Entertainment 2008) which featured dynamic statues of the top ten players placed in in-game city centres (Charlk 2008). *World of Warcraft* (Blizzard Entertainment 2004) features in-game memorials to real people who have passed away including players, designers, artists, programmers, and people who inspired the development team (Kemaria 2013). In the same vein, many games such as *Doom* (id Software 2016), and *Battlefield One* (EA DICE 2016) shows the physical avatar or display picture of the player who has just won the match as a form of monument to other players.

The intervention could feature the player avatars of those who meet certain energy conservation targets in the form of statues situated throughout the game world. In-game characters could respond to the statue to show that the player is a role model to fictional others. Additionally, the player could be informed that the monument is visible to other players, potentially allowing the player to feel they are a role model to non-fictional others.

#### *4.3.2.6 Information about Social and Environmental Consequences and Salience of Consequences*

Michie et al. (2013) state that BCT *salience of consequences* is the

> *"use* [of] *methods specifically designed to emphasise the consequences of performing the behaviour with the aim of making them more memorable (goes beyond informing about consequences)"* (p. 7).

This BCT is closely related to the *information about social and environmental consequences* BCT, which is self-explanatory in nature. Such information may be presented in a written, verbal, or visual form.

An example of this is the cigarette packaging used in Australia which shows the potential outcome of smoking in the form of diseased lungs etc. (Hammond et al. 2007).

##### 4.3.2.6.1 Impact on Game Resources

A consequence of greater real-world energy consumption in general is an impact on a person's real-world resources (i.e. money). This effect, however, is a long-term one, and is often not realised until the power bill arrives. A staple of most video games is some form of currency, or even multiple resources which need to be managed. The intervention could make clear the impact energy use can have on resources by *affecting in-game resources*. This impact would be much more accelerated then the impact on real-world resources, and the metaphor of this may help players realise how much their day-to-day actions are costing them.

The intervention could affect resources other than the player's in-game currency (if they exist in the game, and are appropriate to the game).

The implementation of this impact on resources depends greatly on the type of game developed, and thus further description here is difficult. Feedback on the impact on resources is likely best achieved via the *daily login screen* described earlier for decrease in resources, and *daily reward* element described in more detail in the *reward* BCT for increase in resources.

##### 4.3.2.6.2 Impact on Game Environment

Chapter 2 described the issue of Climate Change, and how energy consumption is contributing to the degradation of Earth's environment. These consequences are long-term, and many people find it difficult to directly link their energy usage to the emission of green-house gasses. Video game environments are becoming more and more dynamic, with improving game engine technology allowing for destructible environments, realistic day-night cycles, weather effects, and procedurally generated layouts. The intervention could leverage this dynamism to allow the game environment to change based upon energy consumption, as described earlier in Section 4.3.2.1.4. The change in environment would again happen at a much faster or magnified rate than the changes currently occurring on Earth, and would occur solely as a result of the player's real-world actions. The impact could not only be visual, but also restrictive in terms of areas of the game world becoming inaccessible due to weather conditions. There could be a social impact on the fictional characters within the game environment if the game style supports it, e.g. the quality of life of in-game characters could be reduced based upon the changed environment, again facilitating restriction to certain dialogues or quests.

#### *4.3.2.7 Reward (Outcome)*

A common BCT intervention use is *reward*. Michie et al. (2013) specify a number of different types of reward, including *social*, *material*, *self-reward*, *non-specific*, and *imaginary*. For the purpose of this work, the general reward BCT was expanded to include the non-tangible rewards provided in-game by the intervention.

Video games provide a wide range of rewards, and any reward in the intervention game can be considered to facilitate the reward BCT. The elements listed in the following sub-sections are examples of rewards in games, however they are not exhaustive.

##### 4.3.2.7.1 Daily Login Screen

The *daily login screen* element described previously is frequently used to distribute a *daily reward*. Most games that implement this use a base reward that is guaranteed to appear on this screen, and then multiply or add to the award to reward logins on consecutive days. Instead of, or in addition to this standard implementation, the intervention could modify the reward based upon energy conservation. The specifics of this calculation depend on both the game being implemented (specifically the economics of the resources being given as the reward), and the format of the energy consumption data available (e.g. additional rewards could be given for meeting targets on specific smart meter channels).

##### 4.3.2.7.2 Quests

*Quests* are a common element in games where players are given an objective to complete, and player are usually notified of the rewards they can expect for doing so, and a commonly used definition by Howard (2008) is that they represent a "*goal-oriented search for something of value*".

Quest rewards (i.e. the "something of value") can simply be additional resources, but can also be rare or otherwise unobtainable items (which are perhaps needed for another quest, or have unique properties). Additionally, quest rewards may unlock new quests (referred to as a *quest line*) either by further dialog with the character who gave the quest, or by unlocking new areas which have characters to provide new quests.

Many mobile games using a "freemium" model (free to play, monetized with micro-transactions (Evans 2016)) feature quests where the requirements are possible without paying for resources, but for example require quantities that are really only plausible to obtain via payment. The intervention could feature quests, and for some of them have the required resources be only obtainable via positive conservation behaviours.

Quests can also be dynamically created, and tailored to skill level, to allow games to have increased longevity and replayability. The intervention could use these dynamic quests to provide goals to the player based upon their current usage and needs. For example, if the game detects high usage on the air conditioner channel, then a quest could be generated where the requirements are met by reducing air conditioner usage. Similar to these dynamic quests are the idea of *personal quests* or goals, described later in this chapter.

#### 4.3.2.7.3 Checklist

Similar to badges or achievements, *checklists* are lists of objectives that can be completed at any time and in any order. While the rewards in achievement systems are usually simply points towards a "GamerScore" or similar (Ian Lewis & Wells 2013) checklist rewards differ in that they are in-game. Depending on the player type, and pre-existing interest and engagement in the game, having in-game rewards can arguably be more meaningful to players than points (Brewer 2013, p.34).

Checklist items in the intervention could include asking players to find in-game items that are only obtained by completing a certain quest. By making the requirements for that quest linked to energy conservation, the checklist item becomes less about monitoring air conditioner usage (and reducing comfort), and more about completing the in-game task.

#### 4.3.2.7.4 Level-Up System

As Chapter 2 has covered, the common game elements in Gamification literature are points, badges, and leaderboards. Outside these three, *level-up systems* are also commonly described, and most implementations are effectively a more complex form of points distribution, in that a certain number of points are required to increase the player's *level*. In traditional Gamification, this increased level was coupled only with the added reward of social capital or recognition among other users of the system (for more see Molyneux et al. (2015)). Nacke & Deterding (2017) point out that the rewards for level-up systems should be meaningful, and also made clear to the player. One way to accomplish this that is often not used in Gamification, is to provide in-game rewards such as virtual currency, items, or further access to quests and game areas. Many role-playing games provide "perks" such as *World of Warcraft* (Blizzard Entertainment 2004) which rewards players upon level-up, allowing the player to increase the skill-set of their avatar at regular intervals as they progress through the game (Rapp 2016).

If the level-up event in the intervention is tightly linked to positive conservation behaviours, then the reward associated with levelling-up is an ideal way of facilitating the reward BCT.

#### *4.3.2.8 Social Reward*

Michie et al. (2013) describe *social rewards* as being verbal/non-verbal, and provide the example of congratulating a person when they have performed the desired behaviour.

##### 4.3.2.8.1 Normative Leaderboards

When *normative leaderboards* are shown to the player as described earlier (see Section 4.3.2.1.7), an injunctive norm representing social approval of being higher than others on the leaderboard can act as a form of social reward. Rewards could be given for increasing rank on the leaderboard. An additional feature may be to pair players automatically with similar others and prompt them to battle with that other player during a time period to consume less energy than them. The player in the pair with the lower consumption by the end of the time period is given an in-game reward. As previously discussed, it is important to ensure this reward is meaningful.

##### 4.3.2.8.2 Quests

*Quest* completion in games typically features a congratulatory message. If the intervention uses quests that feature dialog from in-game characters, this congratulatory message may be enhanced as it is coming from an in-game character (see Section 4.3.2.4.1).

##### 4.3.2.8.3 Social System

The previously described *social system* may include the feature to “like” or comment on posts pertaining to meeting energy conservation milestones. A player may perceive getting a comment or “like” from another person as a social reward for their behaviour.

#### *4.3.2.9 Incentive*

The BCTs described in the previous sections referred to rewards. Michie et al. (2013) describe the BCT of *incentive* as

> “*inform*[ing] *that a reward will be delivered if and only if there has been effort and/or progress in achieving the behavioural outcome*” (p. 14).

Part of this BCT includes the indication of what criteria must be met to be given the reward, and optionally a description of what rewards will be given. Video games often use incentive to bring about in-game actions. The intervention could mirror this use of incentive, but instead target real-world actions.

In general, the game elements that suit this BCT have already been previously described for the *reward* BCT (see Section 4.3.2.7), and so the detail of sub-sections has been excluded here for brevity. The only comment to be made about these elements is that for them to serve the incentive BCT, the player must be informed that a reward will be given to them if they exhibit positive behaviour. This may be accomplished on the *daily login screen* by indicating the reward that will be given to them on the next day, and the requirements for obtaining such a reward. For *quests* this is simply following the norm in games to show the requirements and rewards upon quest start, and on demand when a player wishes to examine their "open" quests. *Checklist* items can be examined to know what rewards will be given upon completion, and also the player should learn to expect a reward after completing their first few checklist items. Similarly, players will expect a reward upon *levelling-up*.

#### 4.3.2.10 Discrepancy between Current Behaviour and Goal

When a person sets out a behavioural goal for themselves, the BCT *discrepancy between current behaviour and goal* can be used (Michie et al. 2013). This more than simply self-monitoring behaviour, but rather providing feedback on the differences between actual behaviour and goal behaviour (Michie et al. 2013).

##### 4.3.2.10.1 Quests

*Quests* often show players their progress toward the quest goal. This is usually available while the quest is still "open" (e.g. the timeframe required has not expired, or the requirements have not yet been met). Additionally, if a game allows a player to *fail* a quest, feedback is usually shown in terms of how far away from the goal the player was.

The intervention could make use of both of these forms of feedback for quests, and this would serve the purpose of this BCT if quest requirements are tightly linked to energy behaviour. The feedback could show the player's current behaviour, as well as the required behaviour to meet quest goals. Depending on the game being made, this could be in addition to the in-game requirements (e.g. items or actions required).

Feedback shown while the quest is "open" can afford players with the ability to adjust their behaviour to meet the goal (possibly including a calculation of how to meet the goal from where they are). Feedback shown when the quest is over acts an explanation for why the reward was not given.

##### 4.3.2.10.2 Goal Setting

Many fitness and health Gamification apps use the concept of *goal setting* to allow users to specify a target that suits them, and rewards them when they reach this target (Bindoff et al.

2016). Goal setting and making commitments to save energy featured in the list of promising ways in which technology can facilitate energy conservation presented by Ehrhardt-Martinez et al. (2010). Strangely, despite goal setting being frequently mentioned in literature (Locke & Latham 2002), there were no prominent examples of traditional video games that allow players to set custom goals (although there are examples of games where you can set goals for *other* players such as posting a "challenge" to the social system). Other close analogies to this in games are the ability to set custom "waypoints" in games (markers on the map beyond what are prescribed by the main game objectives), or the ability to filter all "open" quests to focus on those that are considered important by the player.

A novel addition to the intervention game could be to allow players to specify a certain energy conservation target within a certain timeframe. The game could calculate an appropriate reward for meeting this requirement. This new personal goal could use the feedback mechanisms described for quests above, as a way of implementing this BCT.

Goal setting may also be accomplished implicitly via the leaderboards element. According to Gollwitzer & Oettingen (2012), leaderboards may allow users to set goals based upon values they see higher up on the leaderboard.

#### *4.3.2.11 Punishment and Behaviour Cost*

Conversely to how the reward BCTs can be used when positive behaviour is exhibited, *punishment* (or aversive consequences (Michie et al. 2013)) can be used when negative behaviour occurs. In addition, the BCT *behaviour cost* is considered to be a form of punishment. It is important to note that the literature suggests that providing punishment mechanisms gives people the opportunity for extrinsic rewards through the avoidance of punishment, and may have a negative impact on intrinsic motivation (Deci et al. 2001). As a result of these concerns, these BCTs should be used sparingly.

##### 4.3.2.11.1 Impact on Game Resources

Previous sections have described how positive behaviour can result in increased resources through rewards. To accomplish the punishment BCT, negative behaviour could be met with reduction of resources. Depending on the game being developed, reduction of resources may be appropriate, but given the potentially negative impact on punishment on motivation it is likely that this should implemented more as a *lack* of reward, rather than a reduction.

##### 4.3.2.11.2 Impact on Game Environment

If the intervention uses a dynamic environment and described above, negative behaviours could have a negative impact on the environment. This could result in restrictions to certain areas which have rewards or characters in them. Poorer environments may be more difficult to traverse, or requirement more resources to handle. It is important to note that change in difficulty needs to be implemented carefully, as some players may be incentivised to use *more* energy in order to get access to a more difficult environment.

###### 4.3.2.11.3 Quests

If the intervention implements quests that have a failure case, the punishment BCT may be enacted after quest failure. Again, this could be simply the *lack* of reward being given for the quest, or an explicit reduction in resources. Games rarely have quest failures that preclude the player from completing future quests or other tasks, and often give players the opportunity to repeat the quest.

##### *4.3.2.12 Future Punishment*

The *future punishment* BCT is effectively the inverse of the incentive BCT, however it is intended to have the same effect. This informs the person that

> *"future punishment or removal of reward will be a consequence of performance of an unwanted behaviour"* (Michie et al. 2013, p. 15).

As described in the previous section, literature suggests that the extrinsic motivation provided by trying to avoid punishment may have negative impacts, and thus punishment should be used sparingly. The same game elements as described in the Section 4.3.2.11 are applicable here, however the main point to note here is that players are *informed* of the potential for punishment. The intervention should tell the player that negative behaviours will result in a lack of (or reduction of) game *resources*. Similarly, the impact on the game *environment* should be made clear. As with their rewards, *quests* should indicate the punishments that may occur.

### 4.3.3 Summary of Linking BCTs to Game Elements Process

Game elements which were identified to be promising ways of delivering the selected BCTs included provision of *rewards*, dynamic linking of *resources* and *environment* to behaviour, a robust *social system* (including *friends*, *clans*, and "*likes*"), *normative leaderboards, narrative, avatars, world building*, *level-up system*, *quests*, and making use of the *mobile notification system*. Table 17 summarises the mapping of these game elements to the selected BCTs.

| Behaviour Change Technique | Game Elements | Section |
|---|---|---|
| Feedback on behaviour | Daily login screen | 5.2.3 |
| | Statistics screen | 5.2.10 |
| | Impact on game resources | 5.2.2 |
| | Impact on game environment | 5.2.1 |
| | Notification System | 5.2.12, |

| Behaviour Change Technique | Game Elements | Section |
|---|---|---|
| | | E.5 |
| | Level-up system | 5.2.5 |
| | Normative leaderboards | 5.2.11 |
| Social comparison | Normative leaderboards | 5.2.11 |
| | Community score * | --- |
| | Social system (friends, clans*) | 5.2.8, E.1, E.4 |
| | Level-up system | 5.2.5 |
| Identity associated with changed behaviour | Avatar | 5.2.3 |
| | World building * | E.2 |
| Information about others' approval | Narrative (dialog) | 5.2.6 |
| | Social system ("likes") * | E.3 |
| Identification of self as role model | Normative leaderboards | 5.2.11 |
| | Social system ("likes") * | E.3 |
| | Monuments * | --- |
| Information about social and environmental consequences / Salience of consequences | Impact on game resources | 5.2.2 |
| | Impact on game environment | 5.2.1 |
| Reward | Daily login screen (reward) | 5.2.3 |
| | Quests (rewards) | 5.2.7 |
| | Checklist (rewards) | 5.2.8 |
| | Level-up system | 5.2.5 |
| Social reward | Normative leaderboards (rewards) | 5.2.11 |
| | Quests (dialog) | 5.2.7 |
| | Social system ("likes") * | E.3 |
| Incentive | Daily login screen (reward) | 5.2.3 |
| | Quest (reward) | 5.2.7 |
| | Checklist | 5.2.8 |
| | Normative leaderboards (rewards) | 5.2.11 |
| Discrepancy between current behaviour and goal | Quests (progress) | 5.2.7 |
| | Goal Setting * | --- |
| Punishment / Behaviour Cost | Impact on game resources | 5.2.2 |
| | Impact on game environment | 5.2.1 |
| | Quests (failure) | 5.2.7 |
| Future punishment | Quests (failure) | 5.2.7 |

**Table 17. Mapping of Behaviour Change Techniques to Game Elements. The relevant section in which the element is described in the context of the implemented intervention is listed in the final column. Where an element *was not* implemented in this thesis (indicated by an asterisk), the relevant section in the Appendix E about how that element could have been is given.**

## 4.4 Chapter Summary

This chapter has introduced the Behaviour Change Wheel methodology devised by Michie et al. (2011) which can be used for both analysing existing interventions, and designing them.

Using the BCW for the latter, a systematic process of examining the behaviour of energy conservation was presented. *Social opportunity*, *reflective motivation*, *automatic motivation*, and *psychological capability* were identified as the core ways in which the common energy behaviours of *air conditioner temperature*, *turning off lights*, and *standby electricity consumption* could be changed. The next step in the systematic process was to determine the intervention functions that would help us select appropriate Behaviour Change Techniques (BCTs). The process revealed that a combination of *persuasion, incentivisation, coercion,* and *modelling* intervention functions were suitable. Fourteen distinct BCTs were selected to implement these intervention functions.

A novel application of the BCW was then presented in which an intervention strategy was developed for a mobile video game delivery method by identifying suitable *game elements* which would facilitate the chosen BCTs. A detailed exploration of various elements from both the literature and from extant video games was given, justifying the potential existence of these elements in an intervention game. These elements were described in terms of the BCTs and in the domain of energy conservation, however the process and the specific mapping used is believed to apply to most Serious Games in general. It is the author's hope that future researchers draw upon the methods and findings presented in this chapter for the design of future Serious Games that seek to leverage psychological theory to achieve behaviour change outcomes.

Equipped with a complete intervention strategy and psychologically-grounded game elements, a complete game can be constructed, which is the focus of the next chapter.

# 5 Game Design Phase

The Behaviour Change Wheel methodology resulted in an intervention strategy in the form of a set of game elements that were linked to fourteen Behaviour Change Techniques (BCTs). As alluded to in the previous chapter, these elements do not comprise a Serious Game whole however, and this chapter outlines the process of implementing these elements from prototyping through to the final game *Energy Explorer*. Figure 36 shows how the game design phase fits into the overarching methodology for this project.

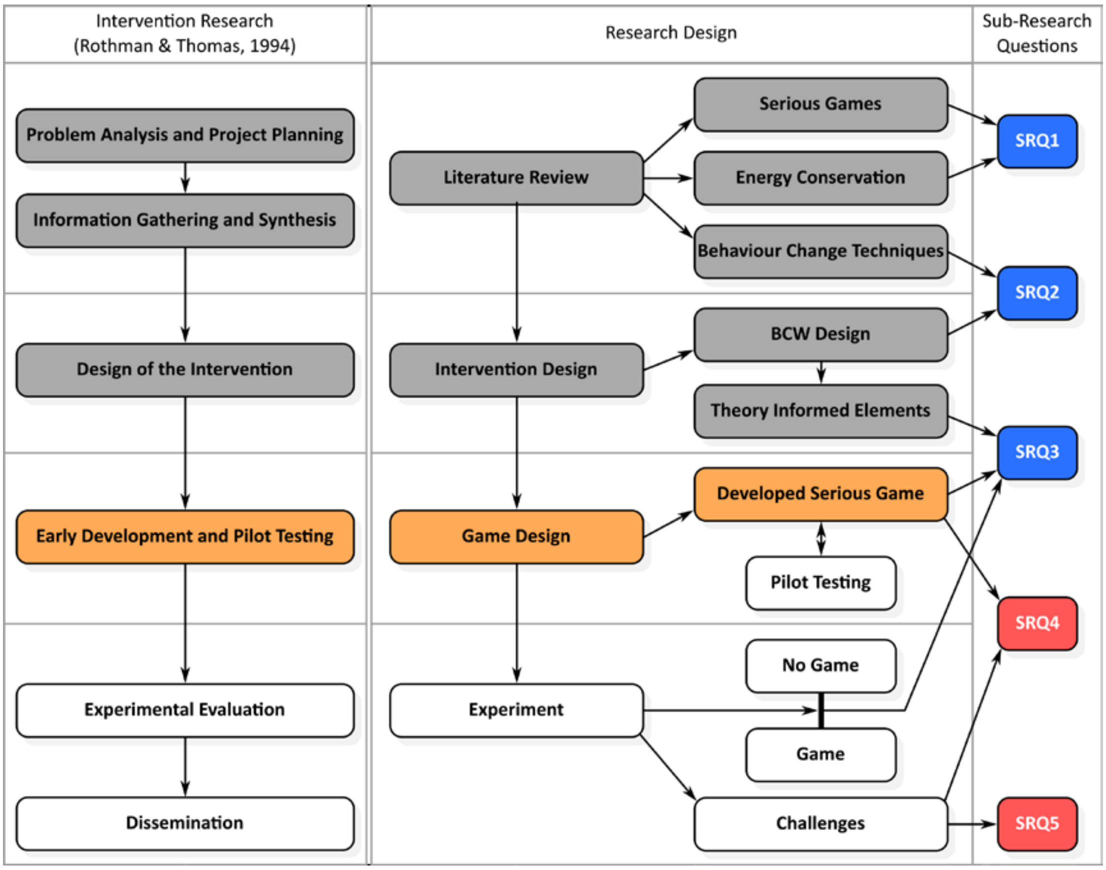



**Figure 36. The project methodology diagram, showing the component covered in in this chapter: the development of the Serious Game.**

This chapter first describes the initial prototyping stage, which involved an exploration of the top games on the Google Play Store to extract popular game types, and analysing their suitability for the chosen game elements (among other criteria). Functional prototypes were developed for four of these game types, and these are described in detail for not only completeness, but in the hope future researchers may consider developing those prototypes further for a Serious Game.

After presenting the prototypes and their respective advantages and disadvantages, the remainder of the chapter is devoted to a description of the final game that was inspired by a combination of the two most promising initial prototypes: *Energy Explorer*. The game is described first in overview form, before each individual game element from the BCW process is described in terms of how it was implemented in *Energy Explorer*. The chapter concludes with a description of the system architecture that facilitated the integration of smart meter data into the running of the game.

## 5.1 Game Prototypes

Based upon the BCTs identified in the previous chapter, two important requirements were considered for the overall design of the Serious Game intervention: that the game provided feedback in terms of energy usage and environmental cost, and that the game was entertaining. Feedback was considered important so that users could better understand the consequences of their real-world actions in a virtual environment, and entertainment was important so that users would want to play the game in the first place and want to continue playing the game. In the past, many Serious Games have lacked the entertainment that traditional video games bring about, and recently there are calls to ensure Serious Games are entertaining even if by definition entertainment is not their primary purpose (van der Spek et al. 2014).

This section describes the process of determining a suitable game genre to implement the chosen game elements. First the selection criteria developed for making this choice are presented in detail, followed by the chosen prototypes which were developed. The section concludes with a description of the transition from these initial prototypes to the chosen game design *Energy Explorer*, which is the focus of the remainder of this chapter.

### 5.1.1 Selection Criteria

Initial choices for the type of game to create were inspired by systematically examining the top 50 games on the Google Play Store (which is the primary distribution method for Android mobile devices). It should be noted that this analysis was conducted solely by the author, although at various points during this process the expert advice of other researchers within the gaming space was sought. This limitation is discussed further in Section 8.1.9. The process for game selection in this project considered the following factors:

- the ability required to *develop* a fully-playable version of the game;
- the *suitability* of the chosen game elements to exist in the game;

- the *required skill level* to play that style of game; and
- the *entertainment/appeal factor* of the game, in terms of the expected enjoyment players would get from the game.

For the *development* criteria, games were examined and rated based upon the expected amount of time it would take to create a game like that. To estimate this, the content of the game was examined, and components considered vital to the game were determined. If a game contained vital components which were complex such as artificial intelligence, multiplayer gameplay, complex or highly artistic graphics, or a large number of interactive in-game items with specific statistics, then the game would score low on this criterion. The ability to procedurally generate levels for a game type was rated highly, so that game replayability could be maximised, without the need to curate a large number hand-crafted levels.

For the *suitability* criterion, games were considered in terms of the existence of the game elements from Section 4.3 already in the game, and the impact on the game experience of including game elements that were not present in the game. Games would score highly on this criterion if there was flexibility to incorporate the required game elements into the design. Additionally, games were evaluated on what components could be enhanced by the integration with smart meter data at varying levels of frequency and granularity. Games that had components which could benefit from close-to-real-time updates in usage data scored higher on this criterion than games which did not. Games scored higher if playtime could be limited or extended based upon positive and negative energy behaviour respectively. If a game had variable difficulty, and environments which could be impacted by smart meter data, then the suitability criterion would be high.

*Required skill level* was examined for each game. The interface, gameplay, and rules were considered for the game in general, but also the variation of these components throughout the progression of the game was taken into account. Beyond this, the *perceived* required skill level of a game—i.e. how difficult the game appears—was assessed. Games that appear difficult (despite potentially being less difficult when actually played) were avoided, lest invitees choose to not participate because the game looked "too hard" or frustrating.

The *entertainment* and *appeal* factor for a game was determined by enjoyment of the author while playing the game. The more objective measure of rating on the Google Play store was not used, since the games examined all had inherently high ratings due to the fact the sample was the top 50 free games. The quality of the visuals in the game were considered, as well as how enjoyable the gameplay was. The perceived popularity of the game genre was considered, and if the game used well-known characters, this increased the score for this criterion.

A score out of 10 for each of the factors *development ability*, *suitability*, *required skill level*, and *entertainment* was determined by playing each game, and examining online information about the game (including the store description, promotional websites about the game, and YouTube videos). Ease of use for participants was intended to be maximised, so as to not exclude participants with low skill levels, so the skill level factor was inverted. Thus, the summary score value for each game was:

$$Score = Development + Suitability + (10 - Skill\ Level) + Entertainment$$

Games were ranked on this *score* value, and the top 5 (10%) games were selected. A discussion of the selected games is provided in the next section. Recorded with each game was its genre, and thus the genres of the top 5 selected games were used as a starting point for development.

### 5.1.2 Selected Games

Table 18 shows the games which were ultimately selected (Appendix D lists all the games installed and evaluated based upon the criteria). In addition, the table lists the genre, and identified ways in which a custom version of that game could be modified to respond to smart meter data (i.e. what major aspects of that game are variable and were practical to make dependent on energy usage data recorded by a smart meter).

| Game Name | Genre | Ease of Development | Suitability for Game Elements | Skill Level Required | Appeal / Entertainment | Score | Potential Ways Smart Meter Data could be Integrated into Gameplay |
|---|---|---|---|---|---|---|---|
| **Candy Crush Saga** | Match 3 | 9 | 6 | 2 | **10** | 33 | Times to play, difficulty |
| **Flow Free** | Puzzle | **10** | 8 | 1 | 5 | 32 | Times to play, difficulty, powerups |
| **The Simpsons Tapped Out** | Simulation | 5 | **10** | 2 | 9 | 32 | Levels/time, distance of pipes that can be used |
| **Temple Run 2** | Endless runner | 8 | **10** | 5 | 8 | 31 | Distance/powerups/plays |
| **Jetpack Joyride** | Endless runner | 8 | **9** | 6 | 10 | 31 | Resources, building access |

**Table 18. List of selected games examined on the Google Play Store, with scores for various criteria (see Appendix D for full table).**

Prototypes were developed for different genres of games: *puzzle* (based on *Flow* (Big Duck Games LLC 2012)), *endless runner* (based on *Temple Run* (Imangi Studios 2011), and *Jetpack Joyride* (Halfbrick Studios 2011)), *match-3* (based on *Candy Crush Saga* (King 2012)), and *simulation* (based on *The Simpsons: Tapped Out* (Electronic Arts 2012)). The developed prototypes are described in full in Appendix D, and a brief summary is provided below. The games are presented in some detail in the appendix in the hope that future researchers in Serious Games may find inspiration from these game types.

The *puzzle* game was a simple single-screen grid-based game where players needed to connect a variable number of matching end points. Players also had to fill in every grid space in the game. Difficulty was varied by the number of end points, and the size of the game world. Energy usage could influence the number of puzzles a player was allowed to view in a day, as well as how higher difficulty levels could be unlocked. Procedural generation for these puzzles was developed, however components such as quests and characters were not suited to this game.

Two *endless runner* games were developed with similar functionality; however, one was a two-dimensional, side-scrolling game, and the other was a three-dimension, third-person perspective game. Smart meter data would influence the number of lives players had (i.e. the number of times they could attempt a run), and the game environment in terms of number of obstacles, and weather conditions.

The *match 3* prototype used the mechanics popularized by *Bejeweled* (PopCap Games 2001) and *Candy Crush Saga* (King 2012), where players can swap items on a grid with their neighbours to try and create adjacent groups of matching coloured items. The size of the grid, number of colours, grid layout (including blank spaces), and availability of power-ups were the modifiable components of the game, and these could all be affected by energy usage. Again, some elements such as quests and characters were not suited to this style of game, however levels could be procedurally generated. It should be noted that some of the appeal of *Candy Crush* comes from the challenging design of levels, and so procedural generation in this style of game may have been detrimental to enjoyment of the game.

The *simulation* game type allowed players to build and maintain a small city, with the goal of placing as many different types of buildings as they can. Buildings require resources to be built, which can be collected from other buildings and characters over a certain amount of real time. To guide players through this, quests from the city's characters were developed to create buildings such as hospitals or parks to improve moral in the city. The game environment in this prototype would react to smart meter data, where poor weather would damage or destroy buildings. Damaged buildings would produce less, or no resources compared to non-damaged ones.

### 5.1.3 Transition from Game Prototypes to Final Game

Four different game types were prototyped for the project and assessed in terms of how much additional development time would be required to realise a full version of the game, the required skill level of players, how the game would appeal to potential participants, how much entertainment players were likely to get from the games, and the suitability of the game type to contain the game elements chosen from the BCW process.

In general, the puzzle game and match 3 prototypes were considered too simple for moving forward with as they did not suit the chosen game elements well, despite requiring the least amount of additional development time. The endless runner and simulation games were well suited towards the chosen game elements, however were expected to incur greater development time. Given the environments of the endless runner and simulation prototypes, they were suited to the intervention function of modelling consequences of behaviour.

While the endless runner game used procedural generation to cut-down on development time, this reduction was not seen to be enough given the large amount of level chunks required. The simulation game could not use procedural generation, and a large number of assets were needed.

The core chosen game elements (and most novel) were the linkage between game environment and energy consumption, and game resources and energy consumption. The prototype that best suited these elements was the simulation game type. The main disadvantages of the simulation prototype were the development time needed to produce artwork for the buildings, and balance the resource output of each building. Additionally, perceived complexity of a simulation game may have been high.

A new prototype was developed that used the environment and resource linking elements, but featured simpler gameplay. Procedural generation was used to reduce level design burden. The new prototype focussed on exploration as the core mechanic to suit not only the procedural generation, but to emphasise the game environment. The exploration mechanic was also tightly linked to an expendable "energy" resource. The game style seemed to be best suited to all chosen game elements, and was deemed to require less development time to turn into a full game. The game was expected to be easy to play, and was expected to entertain players with narrative. The Serious Game, *Energy Explorer*, is explained generally in the following section, and is the focus of the remainder of this chapter.

## 5.2 Energy Explorer

*Energy Explorer* is an exploration game, which is played from a 2D top-down perspective. The player controls an avatar that traverses a procedurally generated world (a typical in-game screenshot is shown in Figure 37). Sections of the world (referred to as zones) are generated using cellular automaton techniques to produce unique shapes of mountains, rivers, caves, and forest. Other characters and animals populate the world and can be interacted with. Some sections of the world are pre-generated and contain puzzles that the player needs to complete to access new items or characters.

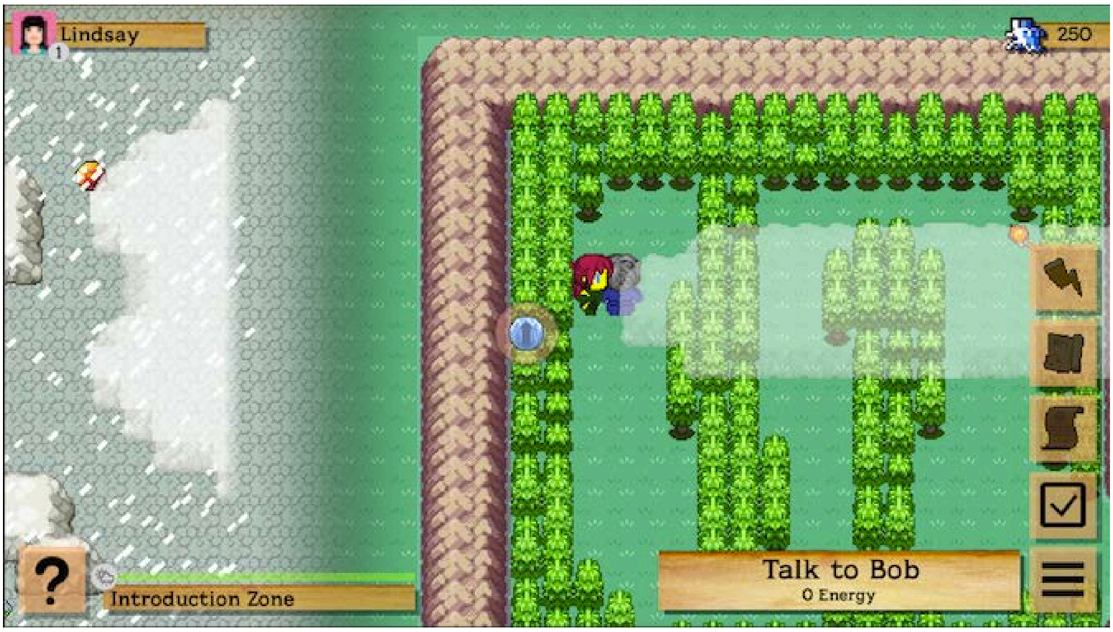



**Figure 37. Screenshot of the introduction level in *Energy Explorer*.**

The controls for *Energy Explorer* are simple, allowing for ease of use by players of all skill levels. The player drags a path from their character's position to the location they want to travel to. The path is a contiguous line between neighbouring grid spaces, however the path cannot go in a diagonal direction. To interact with a character or object, the path must end on that character or object. Once a path is drawn, the player is shown how much of the energy resource will be consumed by taking that path (many factors effect this, and are described throughout this chapter). The player can confirm the action by tapping the "Action" button on the user interface, or draw a new path. All other interaction with the game is done by tapping on buttons on the UI, which are designed to be easy to navigate.

The player is given a large checklist of tasks to complete in the world and the aim of the game is to explore as much as possible of the generated world, in order to complete items on this checklist. The checklist items are completed by finding characters and animals who provide the player with quests, and by finding in-game resources and items scattered throughout the world.

In order to explore and complete actions however, the player must use energy. Energy is the player's main resource and is governed directly by real world energy usage as recorded by an in-home smart energy meter. Once a player runs out of energy, they cannot complete any more actions or travel any further until they earn more energy (by saving real world energy).

The state of the environment of the virtual world is also governed directly by real world energy consumption in the form of an exaggerated Climate Change simulation. The target behaviours relating to air conditioning, light usage, and standby electricity are part of this intervention as these components of consumption are recorded individually by the smart meter and handled separately by the game. For example, the ice resource in the game is directly related to air conditioner usage, and quests in the game where characters need ice target this behaviour.

Conservation results in better weather throughout the game that means that areas cost less to traverse, are safer, and more visually appealing, whereas lack of conservation results in areas that are difficult to traverse and unsafe. Good weather allows access to new characters and items. These initially inaccessible characters and items are visible to show the player what improving the weather will help them access, and incentivise them to conserve energy.

From this description it is clear that *Energy Explorer* represents a Serious Game as it is a whole game proper, compared to the majority of existing work which bring game elements into a different context, constituting Gamification.

The following sub-sections describe, in detail, the game elements chosen as a result of the Behaviour Change Wheel process. The sections make reference to the elements described in Section 4.3, and discusses how they were implemented in the context of *Energy Explorer*.

### 5.2.1 Game World

The world in *Energy Explorer* is composed of a series of *zones*, which are arranged in a grid. Each individual player has a unique game world as the arrangement of zones is randomised. Zones can be either *generated* or *pre-generated*. Each zone has a specific biome (desert, forest, cave), and has a variable weather level—both of which influence the visuals of the zone, as depicted in Figure 38. Zones contain *spaces* that are arranged in a 25x25 grid. Players can move their avatar (see Section 5.2.3) between spaces that are adjacent to each other as long as a space is valid.

**Figure 38. Screenshots of the *Energy Explorer* game, showing the different weather conditions in the game (dictated by real world energy consumption). Screenshots are of procedrually generated areas of the game.**

The following sub-sections describe the examples of what can be on particular spaces, the generation algorithm used to create generated zones, the properties of pre-generated zones, and how the weather impacts the game world.

#### *5.2.1.1 Spaces*

A space may contain any kind object at all, including but not limited to trees, mountain slopes, other characters, water, rocks, etc. and these have an impact on whether the player can visit that space, and the energy cost associated with visiting the space or interacting with the space.

Mountain slopes and cave walls can be removed if the player performs a "dig" action[68] on them. Trees normally act the same as walls, however performing the "chop down" action on them leaves a stump, which the player can then pass. Trees grow back after 24 hours real time. Rocks and rock-falls cannot be passed by the player, and only the latter can be removed as a result of changes in the weather (see Section 5.2.1.4). Some spaces represent mud or ice. Mud costs additional energy resources to pass, whereas entering an ice space will result in the character making another move in the same direction they just moved (to simulate sliding on ice). Figure 39 shows examples of mountain slopes, cave walls, ice, and rocks, for different areas in the game.

**Figure 39. Examples of space types in the form of a "spritesheet" used to create zones[69].**

Spaces may also be the "spawn" location of items, represented by an icon of the item on that space. If the player moves onto that space, they will be given a pre-determined quantity of that item (usually 1). Another way of obtaining items from spaces is from "treasure chest" spaces. A player can perform an "open" action on a treasure chest, and is presented with a display of what is in the chest, before choosing to keep the items.

A puzzle element was added to the game by including "movable boxes" on some spaces. If a player tries to enter a space with a movable box, that box is pushed in the same direction the player moved, and keeps moving until it hits another immovable object or box (if it cannot

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[68] Players complete actions by tapping a context-sensitive button on the screen that shows the applicable action for any adjacent spaces.

[69] The spritesheets represent the graphics which were used in the *Pokémon* series of games by Nintendo. Spritesheets were sourced from third-party artists. The main spritesheet used was created for the now-defunct *Topaz Project* (http://www.pokemontopaz.net/forums/), specifically the image located at: http://www.freewebs.com/pokemontopazproject/pokemon sprites 1111112222233333444445555566666677777888889999900000.bmp
Other sprites were sourced from https://www.spriters-resource.com/

move from its initial position, it acts as a wall to the player). This mechanic was inspired by an early Japanese puzzle game titled *Sokoban* (Hiroyuki Imabayashi 1982).

Spaces may be the "spawn" location of characters, described later in Section 5.2.6. Multiple spaces may represent buildings, however in the implemented version of the game, these simply act as immovable walls. Future iterations of the game may allow buildings to be entered, as well as placed by players.

#### *5.2.1.2 Generated Zones*

To make exploration in the game interesting, a large game world with a lot of things to discover is required. In order to reduce the time required to develop these in a massive game world, a procedurally generated method for areas of the world was used. This had the added advantage that players can be given completely different worlds to each other, which is a desirable aspect in video games to many, as evidenced by the popularity of games such as *Minecraft* (Mojang 2009) and *No Man's Sky* (Hello Games 2016).

By the categorization of Sweetser & Wiles (2005) is a form of *emergence* in game level design as opposed to the more traditional *scripting* method which requires designers to hand-craft levels. Sweetser & Wiles (2005) go on to explain that scripting and emergence are polar opposites on a continuum of level design, and recommend researchers and developers find some middle-ground between these competing approaches. The design of *Energy Explorer* fits within this recommendation, as a combination of emergent (or generated) level designs and scripted designs is employed. The scripted designs described in the previous section facilitate the narrative and more rigid components of the experience (such as the tutorial), while the combinatorial possibilities and curiosity that emergent designs provide is leveraged in the generated sections described in this section.

As a result, the most common type of zone in *Energy Explorer* is a generated zone. This type of zone uses a two-dimensional cellular automaton technique to generate unique shapes for environment elements given a specified set of simple rules. The process used is similar to *Conway's Game of Life* (Gardner 1970). The process involves beginning with a set of cells (matching the grid of spaces in the zone) which can be in one of two states: *alive* or *dead*. The cells then change states based upon simple rules relating to the number of neighbouring alive cells:

- if the number of alive neighbours is *too high*, the cell will die;
- if the number of alive neighbours is *too low*, the cell will die; and

- if the number of alive neighbours is *exactly* a certain amount, and the cell is dead, the cell will become alive.

These rules are applied repeatedly for a number of iterations, resulting often in a considerably different set of cells than the initial set. In *Conway's Game of Life,* the specific number of neighbours required for birth are 2 and 3 (Gardner 1970), however the method used for procedurally generated shapes uses different numbers for different effects (e.g. low thresholds for death result in sparser environments). Neighbouring cells are defined as a *Moore* neighbourhood ($r = 1$), which is square-shaped and contains cells which are diagonally, vertically, and horizontally adjacent to the cell (Gardner 1970). The set of cells begin with a probability of being alive, and this randomness ensures that a different shape is generated each time.

Each particular space type (e.g. cave wall, tree, rock, etc.) uses the cellular automaton with different values for:

- *birth* threshold;
- *death* threshold;
- *probability* of cell beginning alive; and
- number of *iterations* of the rules;

The resulting on or off state for that cell is used for the corresponding space to determine if that space should contain the particular shape type (rock, mud, wall, water, etc). The results of the individual processes for each space type are then combined for the zone to determine the final blended space type which appears in the game. It is possible for a space to have multiple elements selected for it, and rules are applied to result in a space which makes logical sense. For example, the generation of the cave wall layer and the trees layer may both tag a particular space as "on", however it is impossible for a space to contain a cave wall and a tree. All layers have a given priority over each other, and in this case the tree would take precedence over the cave wall. Other elements may co-exist on the same space, such as trees and mud.

Each generated zone uses a different combination of space types and cellular automaton values to achieved different effects. This combination is called a *biome*, and is used to allow different zones to represent different environments such as deserts, mountains, and forests. Biomes also define different probabilities for spawning various animals, and non-essential game characters in the zone (see Section 5.2.6 on characters). Certain animals, and non-essential characters are only considered for generation once the player has reached a certain *level* (see Section 5.2.5 on levelling up ). To allow some items which are not available at the player's current level to appear later in these areas when the player's level is higher, the spaces are tagged with the item, but the item does not spawn until the player returns with the requisite level.

#### *5.2.1.3 Pre-Generated Zones*

Generated zones allow for a random and unique experience for each player, however there were some specific experiences that it was desirable for all players to have (such as tutorial zones, or quest-related zones), and some experiences which could not be effectively achieved as a result of the random nature of the cellular automaton technique (such as specific puzzles, or islands shaped like animals). In order to address this, *Energy Explorer* has pre-generated zones which were designed in the *Unity* game editor.

When the player is in one of these zones, the user interface shows the title and a brief description of that zone that hints at the purpose of the zone.

These pre-generated zones took many forms. In the simplest case they were used to ensure that certain pleasing layouts of mountains and trees etc. were guaranteed to appear in the game without relying upon random chance, however more complicated experiences were possible such as pre-defined mazes (see Figure 40) and puzzles.

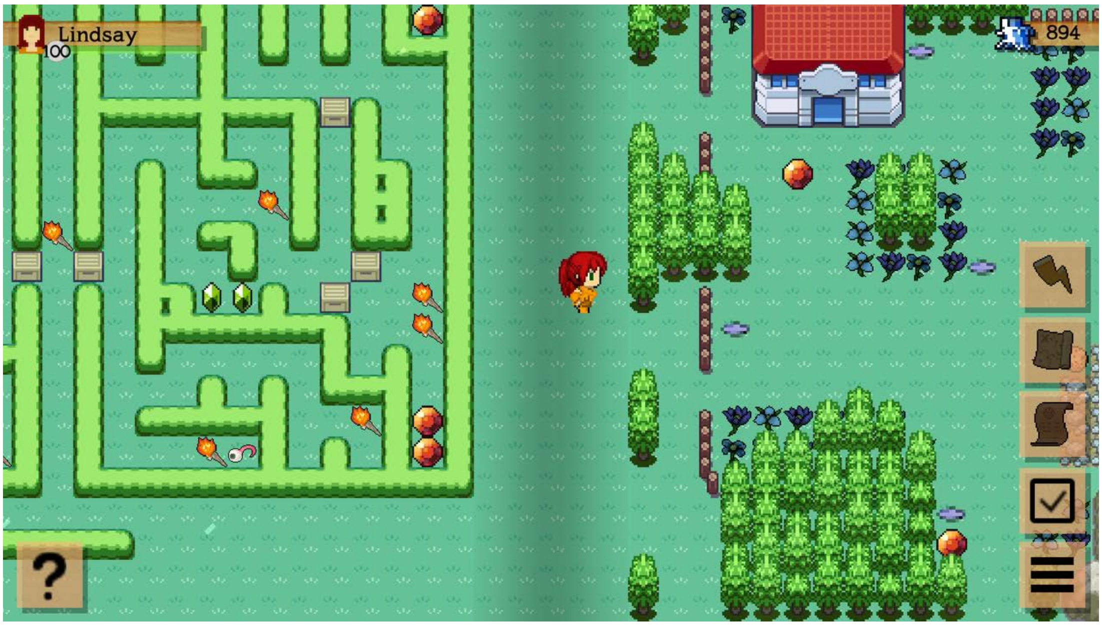



**Figure 40. Two pre-generated zones in *Energy Explorer*: A maze zone, and a quest-related zone with specifically placed items to be collected to progress the quest.**

Many of the important in-game characters such as *Ellie the Giraffe*, or *Bob* (the first character the player speaks to) are only accessed through a pre-generated zone. For example, the first zone the player visits is a pre-generated zone to ensure that the player's first experience in the game is not effected by random generation, and to allow us to determine exactly what space types and features the player is immediately introduced to.

Pre-generated zones allow us to create custom terrain shapes that the players could discover (such as a mountain shaped like a fish, or a river which curves in the shape of a dragon). Some pre-generated zones are pre-determined to be chosen for certain game world coordinates and in this case, they are immediately selected. An example of this is the placement at the start of the game where pre-generated zones representing tutorial parts of the game including the *Bob* and *Tiffany* characters spawn. Pre-generated zones which are not pre-determined to be placed at certain game world coordinates have minimum requirements that need to be met before they can be considered for selection: the *level* of the player (see Section 5.2.5) and the minimum *distance* from the origin of the world that the new zone can be placed at. Additionally, some zones cannot be repeated, whereas other zones can be placed multiple times.

#### 5.2.1.4 Weather Effects

Effects on in-game weather was intended facilitate the *feedback on behaviour (*Section 4.3.2.1.4), *information about social and environment consequences* (Section 4.3.2.6.2), and *punishment and behaviour cost* (Section 4.3.2.11.2) BCTs. In order to implement this, all zones have a single weather value (expressed as a percentage), which indicates the desirability of the weather in that zone where 100% is perfect weather, and 0% is terrible weather. Each zone uses one of a number of pre-defined weather patterns which allow different zones to have their weather range between various extremes (e.g. from sunny to snowy, rainy to overcast, or heatwave to light snow). When viewing the "Zone Info" window (Figure 41), the player can see the expected weather at each percentage, and the current weather conditions. Viewing the weather in the game, but also specifically viewing this screen provides players with a form of feedback on their behaviour. It is intended that this feedback would be more engaging (since it is linked all aspects of the game and also presented in a visually appealing way) than the type of feedback provided by simple graphs and numbers.


**Figure 41. The "Zone Info" window in *Energy Explorer.***

The weather has a considerable visual effect on the game. Visual weather effects include *snow*, *rain*, *cloud amount*, and *cloud colour.* Examples of these different weather effects are shown in Figure 42 for a pre-generated zone. Improved weather conditions resulted in energy-free traversal of the zone (0x multiplier), whereas bad conditions multiplied energy-use in the area by 3 (due to the desert storm). The rockfalls in the area in bad conditions are impassable, and thus the character cannot be reached, however in good conditions the rocks are washed away and the player is able to interact with the character. In this case, reaching the character completes a quest, and rewards are given. The quest is started by entering the zone, which triggers a dialog with the character, despite the player not being directly adjacent. Quests are covered in more detail in Section 5.2.7.

These effects on the weather are intended to provide a simplified and accelerated Climate Change simulation. The weather has an effect on what is possible in the game, as well as the attitudes and moods of the characters in *Energy Explorer*. The intent of this is to facilitate the consequences-related BCTs described in Section 4.3.2.6.2.


**Figure 42. An example of the weather effects in *Energy Explorer*. On the left is a pre-generated zone with poor weather conditions, on the right is the same zone with better conditions.**

The weather dictates a wide range of aspects throughout a zone, and this is referred to throughout this chapter, however at a broad level the following things are affected:

- the *energy cost* of visiting a space (can range from 3x multiplier through to free);
- if a space is an *obstacle* (e.g. in poor weather some water cannot be travelled through because it is too rough, whereas in good weather the player can swim through it); and
- if a space is *slippery* (i.e. the player can visit the space, but they are immediately moved onto the next adjacent space in the direction they were travelling).

These changes are intended to be a form of *punishment* the player, as previously mentioned in Section 4.3.2.11.2).

The weather value for a zone is changed based upon the player's energy consumption as measured by their smart meter. When a zone is generated, a random available smart meter channel for the player is selected to govern the weather for that zone. If the player improves on their consumption for that channel (defined by the difference in the last time period compared to that same time period on the previous day) then the weather will improve, and if they do worse the weather will degrade. The player is able to see which smart meter channel governs the weather for a zone by viewing the "Zone Info" window.

### 5.2.2 Resources

Similar to game weather described in the previous section, in-game resources were identified in Chapter 4 as a promising way of providing feedback, rewards, salience of consequences, and punishment. As the player traverses the *Energy Explorer* game world, they will accumulate in-game resources, either through gameplay events or based upon their energy consumption.

The core resource in *Energy Explorer* is *energy.* This resource governs how far the player can travel and their ability to interact with most things in the game world. Described later in Section 5.2.3, energy is heavily linked to the player's energy consumption, in that positive conservation will result in more energy to use, whereas negative conservation will result in less energy to use. Thus, energy conservation directly impacts the amount of interaction and travel the player can do in the game, but also serves to provide the player with feedback on their behaviour as intended by the design in Section 4.3.2.1.3. Energy is represented differently to other resources on the UI, in a larger font, and is always visible in the top right corner of the screen.

The other core resource in *Energy Explorer* is *XP* (a common term in video games for *experience*). This resource constantly goes up, and cannot go down, and is gained in varying amounts by interacting with objects, completing quests, and completing checklist items. XP is designed to be indicative of the player's progression through the game. XP is at the core of *levelling-up* (see Section 5.2.5).

Aside from energy and XP, the main resources in the game are *wood*, *stone*, *water*, and *food*. The majority of quests (see Section 5.2.7) that do not require particular items or for an action to occur use these main resources for requirements. The main resources (i.e. energy, wood, food, etc.) are directly linked to the player's smart meter data via the "Daily Login" screen described in Section 5.2.3.

All other resources are represented on the UI through the "Inventory" screen (Figure 43). This includes items such as *diamonds*, *emeralds*, *rubies*, and *sapphires*, or quest items given to the player. These resources have differing levels of rarity in the game (e.g. diamonds are rarer than emeralds), and some items are only available via completing a specific quest. Appendix I describes all of the available resources and items in *Energy Explorer*, and their associated rarities.


**Figure 43. The "Inventory" screen in *Energy Explorer*.**

Travelling between two adjacent spaces has a base cost of 1 energy, however the weather and space type can multiply this amount (this can range between 5 times the cost, or 0 times the cost, enabling free movement). If the player does not have the requisite energy to complete the movement, they will not be allowed to execute that movement. Interaction with various in-game items also have an energy cost associated with them. If the player does not have the requisite amount of energy, then the UI will indicate to the player that they cannot complete that interaction. This modification of in-game energy usage determined by smart meter data is intended to act as both a reward and a punishment (depending on the direction of the change) in order to facilitate the BCTs described in Section 4.3.2.11.1.

Players have a single "get out of jail free card" which they can use to give themselves an additional 200 energy resource. This is a single use item and exists to help players who may have not been aware of the energy limit. This element was not part of the BCT linkage, but was included in order to allow the design of the game to be forgiving for new players, and prevent them from getting into situations early on where they are unable to recover from their choices.

The player earns resources in three main ways:

- by completing *quests* (see Section 5.2.7);
- by reducing *real-world energy consumption* (see Section 5.2.3); and
- by collecting resources in the *game world*.

Some resources are found on the ground, others in treasure chests, and other resources are obtained from the game world by completing actions. For example, the player can perform a "chop" action on a tree to obtain 10 of the wood resource. Tapping on "XP bubbles" in the game world results in an amount of XP between 10 and 100, depending on the timing of the tap to the brightness of the pulsating bubble.

A full list of the game resources with indications of how the resources are obtained is provided in Appendix I.

### 5.2.3 Daily Login Screen

Energy and the main resources are governed by the player's energy consumption as recorded by their smart meter (Section 5.3.4 talks about how this data is moved from the smart meter to the game). Feedback on this change in resources is displayed on the "Daily Login" screen (Figure 44). As previously mentioned in Section 4.3.2.1.1, daily login screens are a common staple in mobile games, usually rewarding players for repeat visits, but also providing them with *feedback* on what has happened since they last played. Thus they are an ideal way of facilitating the *feedback on behaviour* BCT.


**Figure 44. The "Daily Login" screen in *Energy Explorer*.**

When the player begins a session of *Energy Explorer*, they are provided with resources as part of the daily login screen. They are given a base amount of each of the resources based upon the amount of time since their last session (to ensure the player always can play the game a base amount even if they have performed poorly), and an additional amount based upon their energy savings as recorded by the smart meter. This additional amount operationalizes the *reward* BCT, described in Section 4.3.2.7.1.

### 5.2.4 Player Avatar

Section 4.3.2.3.1 highlighted the promising use of *identity associated with changed behaviour* BCT. A player avatar system allows for a *virtual* identity which is allowed to fail in ways in which the *real-world* identity cannot (Gee 2003, p.58).

The main character in *Energy Explorer* is the player-controller avatar. This avatar has a *username* associated with it, which the player creates while signing up to play the game. This username is used by players to assign some form of identity to themselves and other players and their actions. Players are represented in the UI to other players using a profile picture, and via an in-game character.

This avatar is customisable by the player in a number of ways:

- the colour of the avatar's *hat*, *jumper*, *pants*, and *skin*;
- the *gender* of the avatar; and
- the *picture* the avatar has in the UI.

Players were able to modify their character's visuals using the "Create Character" screen, which appears after the login screen (Figure 45). Examples of player avatars with different customisations are provided in Figure 46.

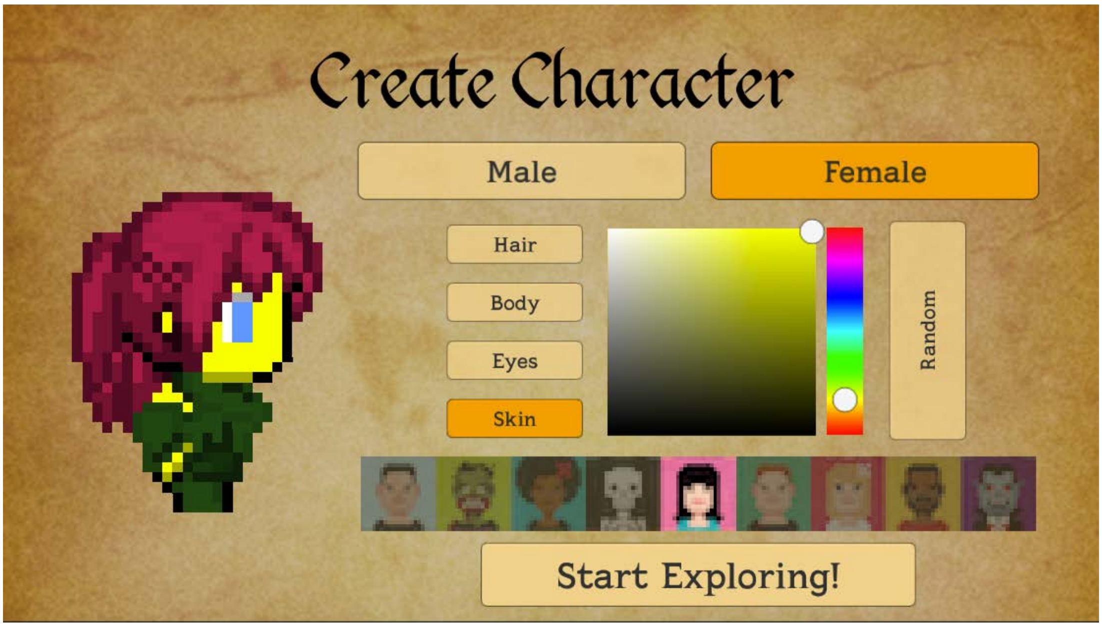



**Figure 45. The "Create Character" screen in *Energy Explorer*.**

**Figure 46. Player avatar customization in *Energy Explorer*[70].**

### 5.2.5 Level-Up System

Almost every interaction in the game is awards the player with a certain amount of the *XP* resource which is based upon the frequency and difficulty of the action. The XP resource directly influences the player's *level* in the game which is used as indicator for progress in the game, allowing the system to help facilitate the *feedback on behaviour* BCT as described earlier in Section 4.3.2.1.6.

A player's level is also visible to other players through the *social system* which provides a form of *social comparison* (Section 4.3.2.2.4).

The calculation used for the amount of XP resource required for each level is provided in Figure 47.

```
RequiredForLevel(level)
if level = 1
     required = 0
if level = 2
     required = 50
if level > 2
     required = 50 + (level × 10) + RequiredForLevel(level – 1)

Examples:
RequiredForLevel(5) = 320
RequiredForLevel(7) = 550
RequiredForLevel(9) = 820
```

**Figure 47. The XP requirement calculation used in *Energy Explorer*.**

The player's level influences what aspects of the game are available to the player, such as what pre-generated zones can be selected and what kind of characters can appear in generated zones (see Section 5.2.1.2). This "un-locking" of content is intended to facilitate the *reward* BCT as described in Section 4.3.2.7.4, and goes beyond the level-up systems seen in traditional

[70] Character spritesheet was sourced from http://www.gdunlimited.net/resources/cat/rpg-maker-vx-ace/character-sprites

Gamification as the rewards are meaningful and relevant to the game itself (i.e. new areas and abilities), rather than simply cosmetic changes.

### 5.2.6 Characters

The player will meet various characters throughout *Energy Explorer*. These characters generally have *quests* for the player to complete, and these are discussed in detail in Section 5.2.7. Characters are categorised by three different types: *essential*, *repeating*, and *emergency*.

*Essential* characters are characters of whom there can only be one instance of in the game world at any one time, and are part of the main progression of quests. An example of an essential character is *Bob,* whom the player first speaks to in the tutorial portion of the game. Bob only appears in the tutorial area, and his quests are early in the quest progression. Another example is *Ellie the Giraffe* (pictured in Figure 48), who has several quests available.

**Figure 48. *Ellie the Giraffe*, a character in *Energy Explorer*.**

As their name suggests, *repeating* characters may appear multiple times in the game world and are generic in that their character names are merely "man" or "woman", or the type of animal they are (e.g. "bunny", see Figure 49). These kinds of characters do not provide the player with quests, and exist purely for aesthetic value.

**Figure 49. Bunnies, repeated characters in *Energy Explorer*[71].**

Finally, *emergency* characters only appear near the player at certain times and do not actually reside at any one place in the game world. These characters appear only to provide the player with *specialised quests* (see Section 5.2.7.2), and disappear immediately once the quest dialog is over. They reappear at the conclusion of the quest, and their quests may be repeated.

Characters give the player feedback on their energy consumption through quest dialogue. As will be discussed later in Section **Error! Reference source not found.**, characters also served the purpose of facilitating a number of social BCTs where real-life other players were not a practical solution (see also the Social System sub-sections in Section 4.3.2, and the implementation of *social reward* in Section 4.3.2.8.2 and *information about others' approval* in Section *4.3.2.4.2*).

### 5.2.7 Quests

Characters in *Energy Explorer* provide the player with quests to complete. Generally, completing quests also completes items on the *checklist* (see Section 5.2.8) either directly by having a checklist item for that particular quest, or indirectly by having a checklist item for finding a resource that is given as a *reward* for the quest (facilitating the *reward* BCT as described in Section 4.3.2.7.2).

[71] Character spritesheets were sourced from http://www.gdunlimited.net/resources/cat/rpg-maker-vx-ace/character-sprites

In total, 43 quests were implemented for the game, and example dialog for some example quests is provided in Appendix J. As progression through this questline is highly dependent on energy conservation from the player, the way this narrative is expressed was intended to be a form of *information about others'* approval (where "others" are the characters in the game world being thankful and supportive of the player) as mentioned in Section 4.3.2.4.1.

*Energy Explorer* features two kinds of quests: *standard quests,* which are comparable to the quests seen in most video games, and *specialised quests*, which make use of smart meter integration. These two categories are the focus the following sub-sections.

#### *5.2.7.1 Standard Quests*

Quest requirements are generally to collect a certain resource, and may be a large amount of a core resource, a small amount of a rare resource, or an individual item (generally obtained by exploration, or completing a previous quest). Upon completing the requirements, the player must then interact with the character again, and another dialog is presented. The player can choose between giving the requisite resource(s) to the character in order to complete the quest, or retain the resource(s) and potentially finish the quest at a later time.

Quest rewards can be any kind of resource. Like quest requirements, they may be a large amount of a core resource (such as energy or food), a small amount of a rare resource (such as diamonds) that is needed to complete a checklist item, or an individual item resource that is a requirement for another quest.

Quest availability is dependent on having physical *access* to the quest-giving character, the player's *level*, and any *pre-requisite quests*. Pre-requisite quests allow for a quest progression to occur, and facilitates story telling over multiple acts.

The player can tell if a character has a quest for them, or if the character wants to talk to them about an on-going quest (e.g. they have completed the requirements to complete the quest) by an exclamation mark above the character's head.

The player begins a quest by interacting with the quest-giving character. A dialogue begins (Figure 50), and the character tells their story, followed by information on the requirements to complete the quest, and the rewards that will be given if the player completes the quest.

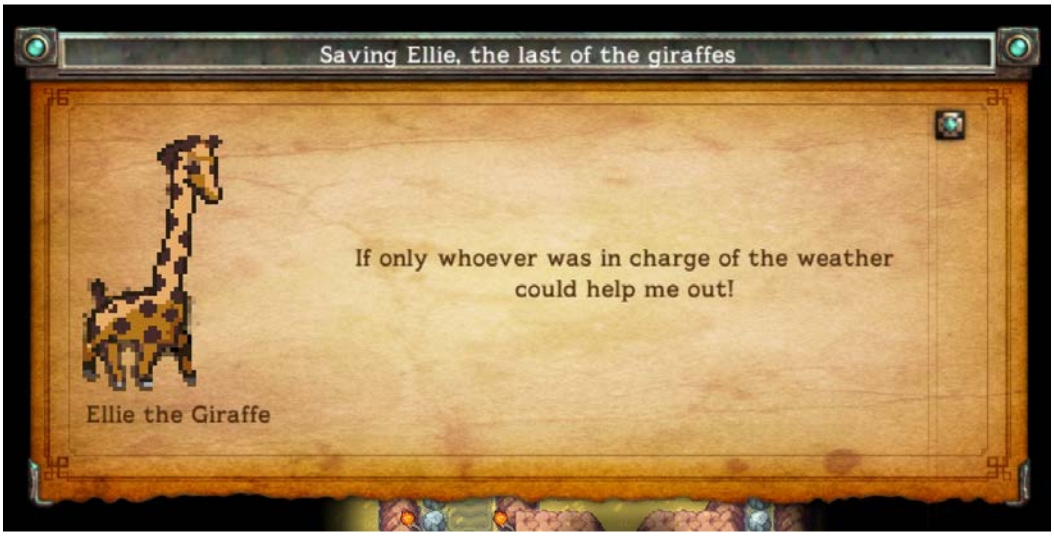



**Figure 50. Quest dialog in *Energy Explorer.***

The player may keep track of their open quests by using the "Quest Window". The "Quest Window" shows the player the quests that they have completed, the quests that are currently open, and any quests that they can start (and which character to find to start the quest).

#### *5.2.7.2 Specialised Quests*

Specialised quests are similar to standard quests; however, they have a few differences in quest availability, requirements, and rewards. Specialised quests are intended to provide incentive and context for the player to participate in positive energy conservation. The requirements of these quests are linked to various aspects of the player's energy consumption.

A specialised quest is delivered to the player by *emergency* characters (which suddenly appear and are not placed in the world like other characters) depending on a number of conditions:

- the player's consumption on a given smart meter channel is higher than normal (in which case a specialised quest for that smart meter channel is delivered);
- the player is playing *Energy Explorer* at a peak time of day (in which case a specialised quest for air conditioning over the peak period is delivered); or
- the player has opted to set themselves a goal for a certain smart meter channel (in which case a quest for that smart meter channel is delivered);

Quest requirements are linked to energy consumption in that the required resources for completion are the core resources of which the source is directly linked to smart meter channels. The required resource will be the core resource for the appropriate smart meter channel. The display for quest requirements is shown in Figure 51.


**Figure 51. The "Quest Requirements" screen for a specialised quest in *Energy Explorer.***

The desired consumption for each quest varies from getting the consumption to be equal to the same time period on the previous day, to a certain percentage better than that time period on the previous day.

Quest rewards are impacted by the user's energy behaviour in that the amount of resources given varies based upon the time taken to complete the quest. This variation is shown to the player in the quest dialog. Different dialog is given based upon completion time to act as an injunctive norm to the player (i.e. the character approves or disapproves of the players speed/lack of speed to complete the quest). This implementation of specialized quests was intended to facilitate the *discrepancy between current behaviour and goal* BCT (Section 4.3.2.10.1). Additionally, since these quests can be failed, this is intended to be an implementation of *punishment* as described in Sections 4.3.2.11.3 and 4.3.2.12).

### 5.2.8 Checklist

The main purpose for players in *Energy Explorer* is to complete items on the checklist. The checklist is designed such that completing all the items in the list is representative of exploring all different aspects of the game world, while interacting with as many items and characters as possible. Checklist items generally cover the following features of *Energy Explorer*:

- collecting *resources*;
- completing *quests*;
- finding *characters* and *animals*;
- travelling *distances*; and
- reaching a certain *player level*.

A full list of checklist items is provided in Appendix K.

Completing a checklist item results in an *XP* reward. The "Checklist" screen is shown in Figure 52. This facilitates the *reward* BCT as described in Section 4.3.2.7.3.


**Figure 52. The "Checklist" screen in *Energy Explorer.***

### 5.2.9 Social System

*Energy Explorer* features a simple social system to allow players to interact with each other. An important part of any social system is the ability to maintain an online persistent profile. In *Energy Explorer*, players are able to maintain a profile containing the following information:

- a *username* for identifying the player;
- an *avatar image* to personalise how they will appear to other players on the UI;
- a short *about message* containing information about the player and their thoughts;
- a list of other players who they consider their *friends*; and
- their *progression* through the game (in the form of their *level*).

Players have the ability become friends with other players by sending a *friend request* to another player. The player can easily view the energy consumption of players they are friends with using the "Friends" screen (facilitating the *social comparison* BCT as described in Section 4.3.2.2.3, *information about other's approval* BCT in Section 4.3.2.4.2, and *identification of self as a role-model* BCT as described in Section 4.3.2.5.14.3.2.4.2). Player friendship also factors into the normative leaderboard game element (Section 5.2.11). A player can request friendship with another player by clicking the "Add Friend" button next to a user's name. This button appears next to a player's name in most parts of the UI where a player is mentioned, and the other player is not already a friend of the player (e.g. on normative leaderboards). The other player accepting the friend request completes the process.

Players can view any friend requests that have been sent to them via the "Profile" screen. Accepting the request will register the two players as friends in the database.

### 5.2.10 Statistics Screen

At any point while playing *Energy Explorer*, players could open a "Statistics" screen which showed the player their energy usage in the form of a graph over the last 24 hours, as shown in Figure 53. This element is a clear implementation of the *feedback on behaviour* BCT as described in Section 4.3.2.1.2.

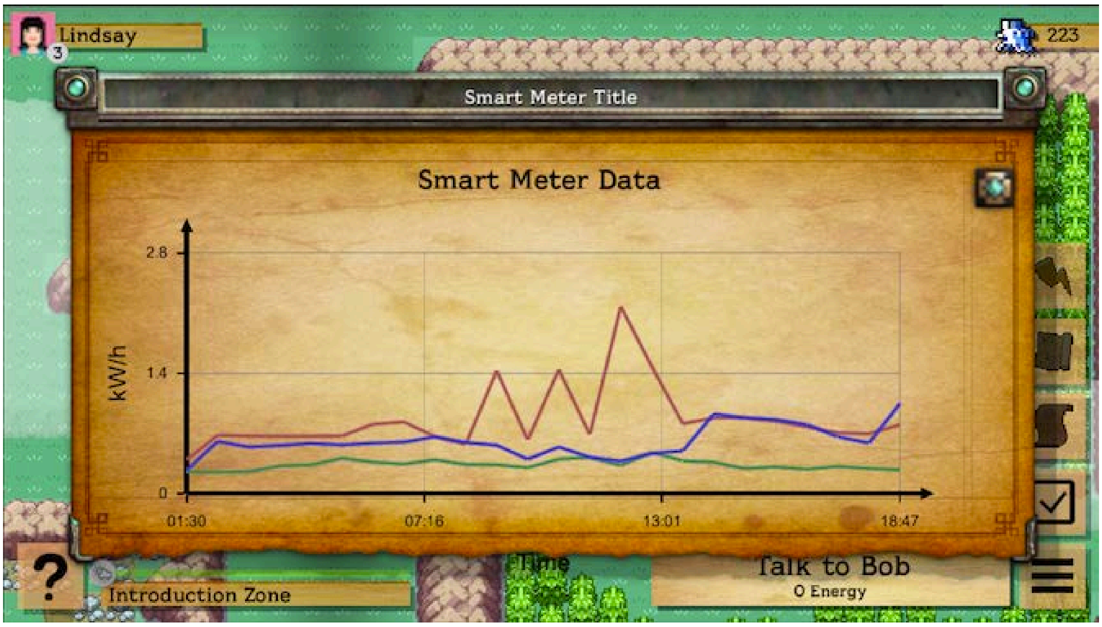



**Figure 53. The "Statistics" screen in *Energy Explorer*.**

### 5.2.11 Normative Leaderboards

After receiving the daily reward on the daily login screen, players were shown the *normative leaderboard* (shown in Figure 54). The concept of a normative leaderboard is described earlier in Section 4.3.2.1.7, which details how this element is intended to act as a form of *feedback on behaviour*, as well as *social comparison*, *identification of self as a role-model* (Section 4.3.2.5.2), and *social reward* (Section 4.3.2.8.14.3.2.5.2).

For this implementation, "similar others" to display on the leaderboard were determined based upon the following variables:

- player *age*;
- player *gender*;

- number of *household members* in the player's home;
- *house size* of the player's home;
- number of *rooms* in the player's home;
- *location* of the player's home; and
- whether or not the two players are *friends*.


**Figure 54. The normative leaderboard "Friend Comparison" screen in *Energy Explorer.***

### 5.2.12 Notification System

*Energy Explorer* took a simplistic approach to providing players with notifications. Notifications were scheduled every 24 hours for seven days after the first time the game was opened. These "scheduled" notifications simply reminded the player to return to the game. As previously described in Section 4.3.2.1.5 this element was intended to act as a form of *feedback on behaviour*, as it can provide timely information indicating if players are conserving energy or not.

Appendix E.5 describes in detail how more complex "push notifications" could have been implemented in *Energy Explorer*, which could occur when specific requirements are met such as when a new friend request is received, or the criteria for completing a specialized quest are completed.

### 5.2.13 Summary of Energy Explorer Implementation

This section has described the details of the chosen prototype Serious Game, *Energy Explorer*. Players traverse a semi-procedurally generated world completing quests and collecting items. Movement and actions cost the player in-game energy, and once a player's energy is depleted, they must wait a number of real-world hours until their energy is replenished. Completing quests unlocks further quests, revealing the narrative to the player.

Selected game elements which were introduced in Section 4.3 were described in terms of how they were implemented in the game. Energy consumption data influences the weather in the game, as well as the amount of resources given to the player. The amount of energy the player is given is also based upon energy consumption such that positive behaviours allow the player to play the game more. The level-up system was described, as well as characters, quests, and rewards. A social system was implemented, which featured normative leaderboards.

The next section describes the system architecture used that allows the elements presented in this section to function.

## 5.3 Energy Explorer System Architecture

*Energy Explorer* uses a client-server model for the system architecture. The client is a mobile phone application that interacts with a server, which was hosted in a central location by the CSIRO in Hobart, Tasmania. The client requested information about the player such as their friends or amount of resources, which was obtained from a database created for this project, as well as their smart meter data, which was obtained from a database maintained by the CSIRO, originally created for the Residential Building Energy Efficiency Survey (RBEES; for a complete description see Section 6.2.1.1). The overall structure of this architecture is presented in Figure 55. The client application, server and database for this project, and smart meter database are the focus of the following sub-sections.

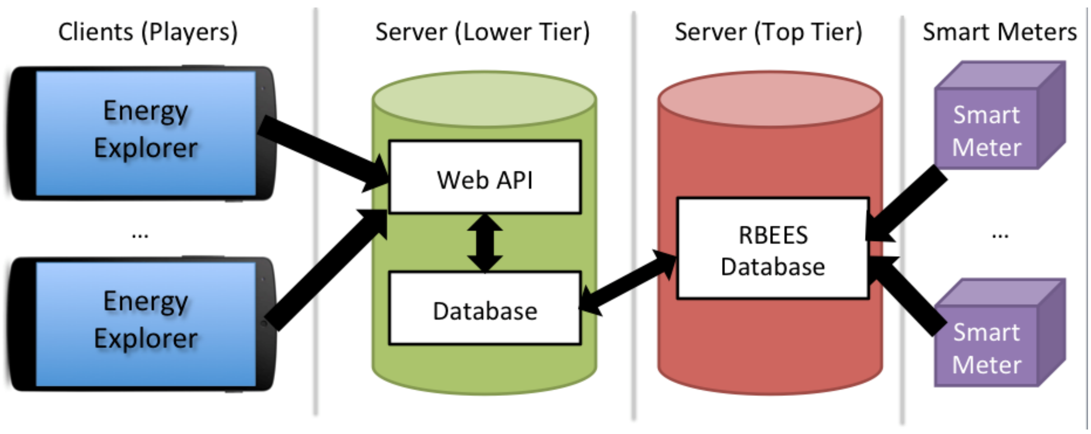



**Figure 55. System architecture for the Energy Explorer game, showing flow of information from smart meters to clients upon client request to the Web Application Programming Interface.**

### 5.3.1 Client

The *Energy Explorer* client is a mobile application, developed using the *Unity*[72] game engine, targeting the *Android* and *iOS* mobile platforms for deployment. Game assets were developed using *Paint.NET*[73], and all scripting within Unity was done using the *C#* language and compiled using *Mono*.

When the device the client application is installed on has a usable Internet connection, it requests information from the lower tier server about the player who owns the device, as well as information about other players in the study when required. Information requested includes username, energy usage, player level, distance travelled, and checklist items. To protect the energy usage data of the player and other players, this data is only stored in RAM while the game is running, and discarded once the game session is concluded.

The game is designed to run with limited functionality[74] when an active Internet connection is not present on the device, however all participants were told that they should play the game with an Internet connection as much as possible in order to have access to as many game features as possible.

The player's game world, resources, and player info are stored on the server database such that a player may install the application on any mobile device and access this information provided they present valid login information (i.e. the username and password entered as part of the registration process in Section 6.2.2.1). This allows players to have maximum access to the game, but also served as a form of backup should the local data on a device become corrupt.

The process of initially playing *Energy Explorer* on a client device is described in detail in the next chapter (Section 6.2.2.3) as this process was altered from what is normally done in commercial games to ensure valid data collection measures (i.e. it was not possible to use the Google Play Store or Apple App Store for distribution of the client application).

The server that the client interacts with, and the format of the data transferred is described in the following section.

---

[72] https://unity3d.com

[73] https://www.getpaint.net/

[74] Specifically, when there is no active internet connection, no energy usage data can be collected. As a result, the "Daily Login" screen simply provides the base amount of the energy resource to the player. The "Friends" screen only displays a message indicating that an internet connection is required, as does the "Statistics" screen.

### 5.3.2 Server

The server infrastructure for *Energy Explorer* has two tiers. The top tier was created for the RBEES project (Ambrose et al. 2013) and is maintained by the CSIRO. This database is queried by the lower tier server application developed specifically for this project. Section 5.3.4 examines the top tier, whereas this section focuses on the details of the lower tier.

The server infrastructure for *Energy Explorer* consists of a Web API (Application Program Interface) developed in *PHP*, which interacts with a *MySQL database*. The client interacts with the lower tier server via the Web API using a secure HTTPS connection, and the specific commands used are described in Appendix L. It is important to note that the server is designed to be able to work with entirely different client applications, such that, for example, any of the games described in the initial prototypes section would simply need the appropriate client-side code to connect to the server and everything would still operate correctly. The schema used for the database is also provided in Appendix L.

### 5.3.3 Communication

In order to access the database, the client requires a way to interface with the server. This is accomplished in *Energy Explorer* using a Web API. The client sends commands to the server, and the server returns output to the client which then makes use of this data. Parameters are sent to the API using *HTTP POST* arguments, and data is returned in the commonly used *JSON* format. An example of this is provided in Figure 56 below (for more detail see Appendix L).

POST `getSmartData.php?UserID=3&start=1483228800`
RESPONSE:


```
{
      "usage":
      {
            "0": 0.105,
            "48": 0.310,
            [...]
            "1344": 0.438,
            "1392": 0.361,
      },
      "yesterday":
      {
            "0": 0.617,
            "48": 0.418,
            [...]
            "1344": 0.634,
            "1392": 0.103,
      },
      "info":
      {
            "UserID": 3,
            "RBEES_ID": ###,
            "start": 1493128740,
            "end": 1493215140,
            "now": 1507595674
            "channels":
            {
                  "1":
                  {
                              "name": "CH1",
                              "timespan": "00:01:00",
                              "units": "KWH"
                  },
                  "2":
                  {
                              "name": "AirCon",
                              "timespan": "00:01:00",
                              "units": "KWH"
                  },
                  [...]
            }
      }
}
```


**Figure 56. An example response and request for to the *Energy Explorer* server. Note that an additional "secret" parameter was added to the GET request to prevent unauthorized access to the data.**

The JSON data is encrypted (using the 256-bit AES encryption algorithm) at the server side with a pre-defined passkey, and decrypted within the game client using the same passkey. All transmission is conducted using a secure HTTP connection (HTTPS) to a server hosted by the CSIRO in Newcastle, Australia.

### 5.3.4 Smart Meter Integration

In order for the client to obtain smart meter data to modify the game experience, it must query the server, which in turn queries a database developed by the CSIRO for the RBEES project (Ambrose et al. 2013). Using the *RBEES_ID* field for the given player *id*, the server is able to obtain the data from the RBEES server from within the CSIRO network. The data is transferred over HTTPS, and the data is never stored anywhere other than the RBEES server, resulting in the most secure handling of the data feasible for this project. Additionally, the server formats and de-identifies any data obtained from the RBEES server, and requests can only be made from mobile clients that have been authenticated. Given the data returned from the server is encrypted and can only be decrypted within the game client itself using a secret key, the architecture provides a solid level of protection for this potentially sensitive data.

The RBEES database contains energy consumption data for a number of channels on the users' smart meters that is updated every 24 hours. Energy consumption was measured using an *EcoPulse* smart meter provided by Envirovision Australia. The smart meter was able to measure up to eight sub-circuits within the homes by interfacing with the mains switchboard. Remote access and data downloads were enabled by the device connecting to a 3G modem with a dynamic DNS setup. Using this, the data was uploaded using a secure internet connection to be stored on CSIRO servers. This data was able to be queried by the participants using a web interface (Figure 57).

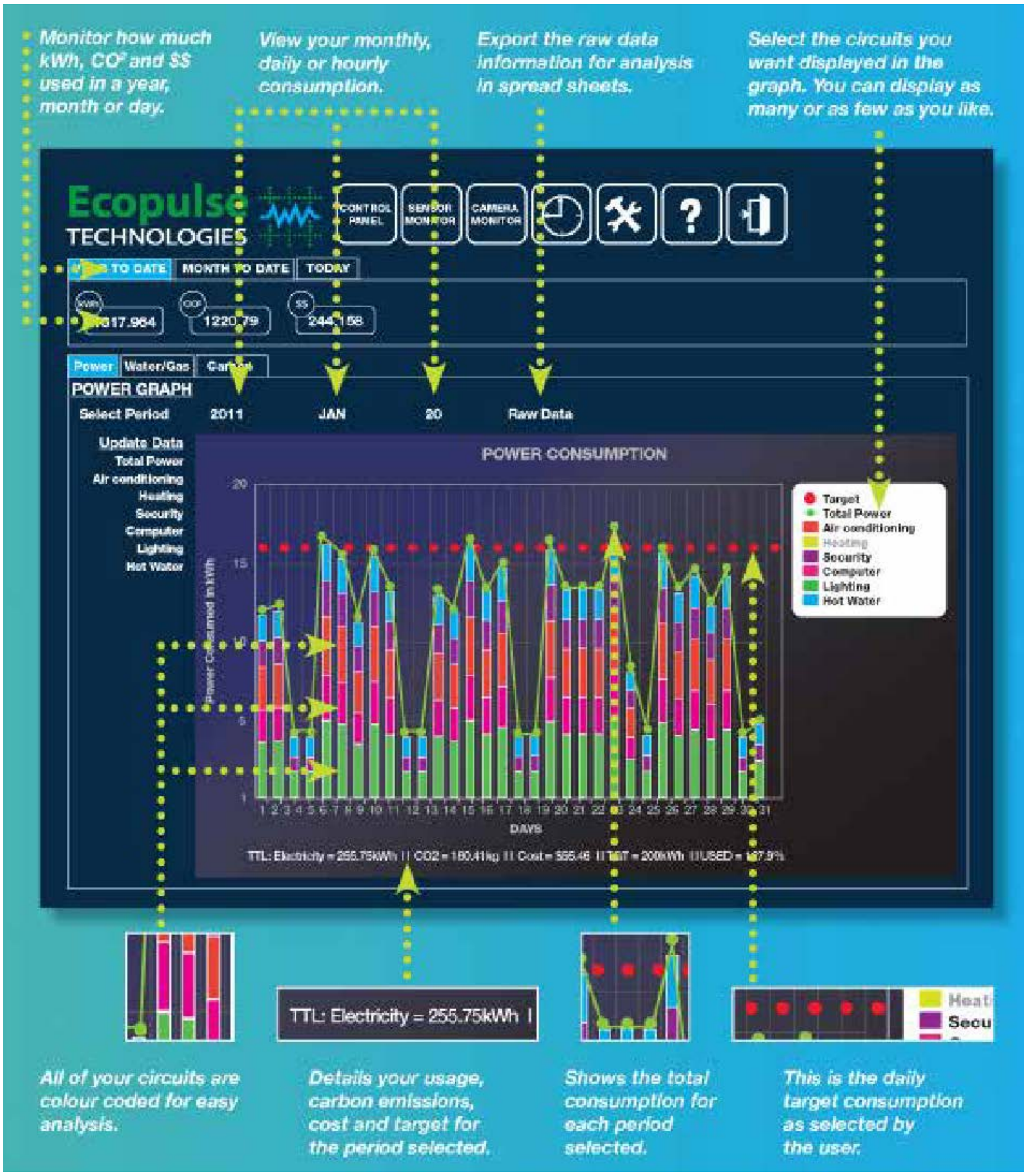



**Figure 57. The EcoPulse web interface used in the RBEES project (Ambrose et al. 2013).**

Data was automatically collected by the CSIRO, and stored in a MySQL database. Measurements at the given granularity (minute-, or half-hour-level), was stored as a tuple containing the following information:

- *measurement id;*
- *device id;*
- *timestamp;*
- *granularity level;*
- *smart meter channel id;*

- *measurement unit* (e.g. kWH); and
- *measurement value.*

For each user, interval values are stored for all available smart meter channels. Some users may be lacking smart meter channels because they do not have need for the channel (e.g. they do not own an air conditioner, and thus do not need a channel recording that), or the channel was not used when the smart meter was installed (e.g. the "LIGHTS2" channel was not used because the house did not have separate circuits for lights). *Energy Explorer* is designed to work with as many smart meter channels as possible, but also still operate when these channels are missing by not providing quests that require this channel to complete (i.e. a quest with the requirement of obtaining a resource tied to a channel the user does not have is not considered for selection). The names of channels are also non-standard, and a short setup process at the start of the game is required to determine what channels line up to commonly recorded energy constructs. The constructs include *air conditioning, lights,* and *oven.*

## 5.4 Chapter Summary

In the previous chapter, an intervention strategy consisting of game elements suited to facilitating various BCTs was created. This chapter has described the process of prototyping a number of Serious Games which could implement these elements. Prototypes were considered based upon development difficulty, suitability of elements, required skill level, appeal, and entertainment.

From these prototypes, an exploration role playing Serious Game titled *Energy Explorer* was developed, and the bulk of this chapter has explained the game in general, as well as how the game elements described in the previous chapter were implemented.

A detailed explanation was given of the game environment, resources, player avatar, and characters. Functionality of the game's quests, checklist, and level-up system were described. Additionally, the social system, statistics screen, normative leaderboards, and daily login screen were described. Finally, the system architecture that allows the game to interact with smart meter data was described. A client-server approach was taken, with a system that reads appropriate smart meter data from the CSIRO server for a specified user. While the game elements described in this chapter were within the context of the *Energy Explorer* prototype, the system architecture presented was designed to be independent of the specific Serious Game intervention, and could be used for any of the prototypes described earlier in the chapter.

The following chapter describes the process of deploying this intervention, and collecting data from the game. Following this, the results of evaluating the intervention are presented.

# 6 Intervention Deployment

Chapters 4 and 5 have given an account of the design and development of a Serious Game informed by behaviour change theory using the Behaviour Change Wheel methodology. Chapter 3 provided detail on the experiment used to address the sub-research questions regarding how Serious Games and behaviour change theory can be married to produce a Serious Game for energy conservation. In order to provide further detail for these questions, it is important to explore how such a game operates in the real world. As such, the developed game was tested in two instances: a pilot experiment using subject matter experts in the domain of energy, and a main intervention for participants representing "regular" energy users. As described previously in Section 6.1, the pilot experiment was intended to provide testing and feedback from people who understand the energy domain, so as to improve the design and functionality of the game. The main intervention tests if the designed game has an impact on energy usage. Figure 58 shows the context of this chapter within the project methodology.

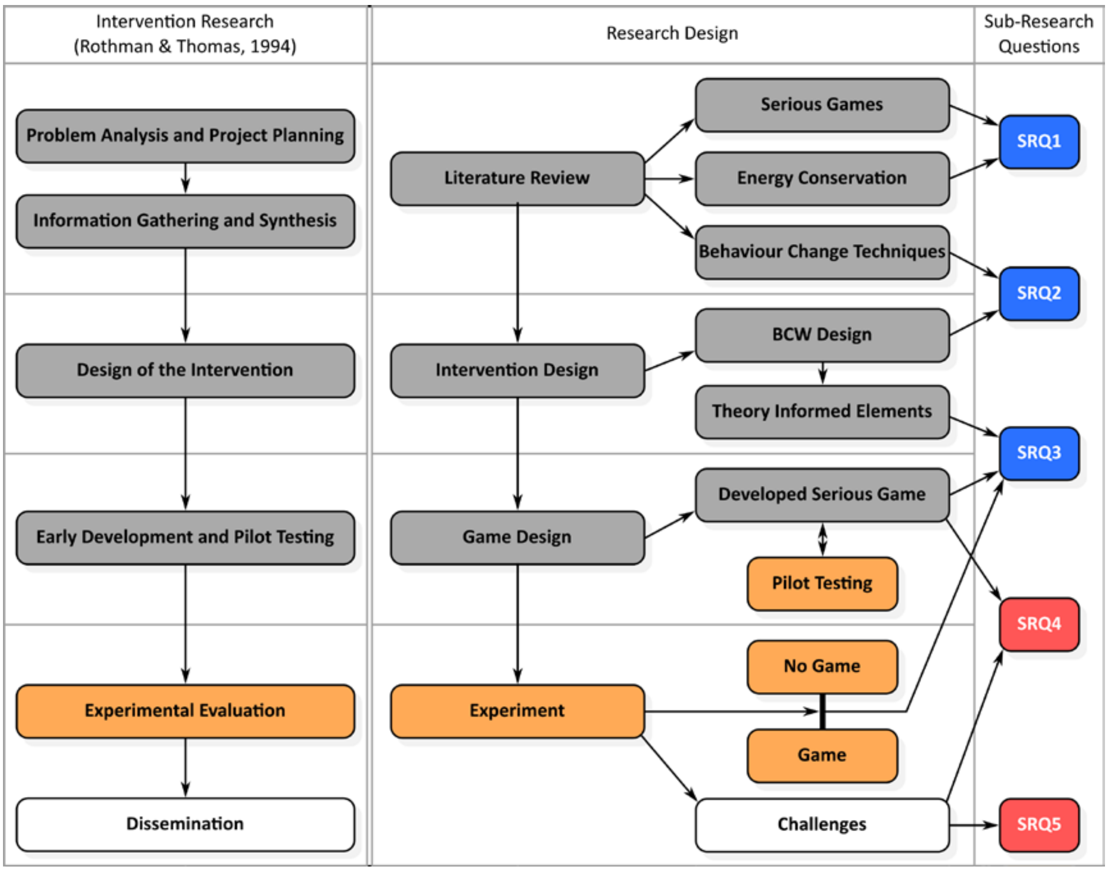



**Figure 58. The project methodology diagram, showing the components covered in this chapter: the pilot experiment and main experiment.**

This chapter first presents the details of the pilot experiment. Details of the feedback given by participants are presented, and a summary of the changes made to the game as a result of the pilot phase is given.

The deployment of the main experiment is described. First, details are provided on the participant pool invitations were sent, and the sample size of those who responded to the invitation and completed the subsequent parts of the experiment. Characteristics of the participant compared to the participant pool as a whole are described. The chapter continues by describing the components of the experiment. These are described in the order in which participants interact with them: the email invitation, registration page, entry survey, game download process, in-game login, playing the game, and the exit survey.

## 6.1 Pilot Study

Chapter 3 outlined the need for a pilot phase to be conducted before the main experiment. The pilot phase was used to obtain feedback on the gameplay and energy feedback mechanisms of *Energy Explorer*, and details on bugs present in the game. This phase allowed for testing of the game in the field on different mobile devices and smart meter configurations. Feedback was sought on the design of the game, and the presentation and effectiveness of the energy-related functions of the game. This section describes the implementation and results of the pilot experiment, before presenting the outcomes of the experiment and how the lessons learned there impacted the game. It should be noted that difference in energy consumption was not a focus of the pilot study (the focus was obtaining feedback), and therefore analysis is not presented on this.

### 6.1.1 Experimental Design

The pilot was conducted with subject matter experts from the CSIRO Energy division in Newcastle, Australia. Participants were required to have smart meters installed in their homes that had specifications matching those of the smart meters used by the future participants in the main trial (as described in Section 5.3.4). Data was collected and stored on CSIRO servers, similar to the way that data was handled for participants of the main trial (see Section 5.3).

Participants were invited to test the game with the invitation clarifying that the purpose of the pilot was to obtain feedback through playtesting from experts in the energy domain. The *Energy Explorer* website used for downloading the game featured pages facilitating bug reports, and general feedback. These pages were web forms, the content of which was sent directly to the author, and had an option to include a screenshot attachment. Participants completed an entry survey identical to the one described later in this chapter for the main experiment (see Section 6.2.2.2), with an additional question to determine the device participants intended to test *Energy Explorer* on. An exit survey (see Section 6.2.2.5) was not given as part of the pilot study.

Participants were told to test the game thoroughly, and to play the game multiple times. As we will see later in this chapter (see Section 6.2.2.3), this instruction differed to the main experiment, where participants were simply invited to play the game as much or as little as they liked.

While the main experiment featured the same build of the game for the entire experiment period to ensure identical functionality for all participants (since participant starting dates were staggered), the pilot phase was more relaxed, and 3 software updates were issued during the experiment period. These updates addressed software issues identified by the participants. Participants were emailed to notify them of updates to the game. Participants were told to play new builds of the game when they were distributed.

The pilot phase was conducted from the 1st February to 29th April 2016.

### 6.1.2 Participants

The pilot phase had 6 participants (83.3% male). The average age of participants was 40.00 (*SD* = 4.55). All participants stated that they had played a video game before, and all participants stated that they had played a mobile video game before. Participants were asked to rate their familiarity with video games and mobile video games on a scale of 0–10, and the average response was 7.50 (*SD* = 1.38) for normal video games and lower for mobile video games (*M* = 6.33; *SD* = 1.46).

The testing hardware of the participants was predominantly Android phones, with only one participant using an iOS device. No two participants had the same model of phone. The following devices were tested:

- Samsung Note 4;
- Samsung Galaxy S3;
- Samsung Galaxy S4;
- Nexus 4;
- Nexus 5; and
- iPhone 5S.

### 6.1.3 Game Usage

The average game "level" that players reached was 9.0 (*SD* = 2.74). Players on average completed 9.0 in-game checklist items (*SD* = 3.16). Participants took on average 610.5 steps in the game (*SD* = 530.3). The accuracy of these figures for game actions however were impacted by errors in the software that prevented some usage data being collected, as is described in the following sub-section.

### 6.1.4 Resulting Changes

Four participants interacted with the bug report and feedback features. A total of 11 bug reports, and 3 feedback reports were received. Reports from players focussed on the following topics:

- *loading time* of the app;
- *interface* problems;
- *unfinishable quests*;
- *quests* being completed despite requirements not being met;
- *specific areas* of the game world not loading; and
- a number of instances where the game would not *load* at all.

Feedback was given suggesting improving the smart meter data display, as well as a request to improve the usability of the quest system.

Participants in the pilot experiment used a wide range of hardware. This revealed a number of limitations of the developed game in terms of compatibility with older devices, and revealed a higher than expected number of devices with limited capabilities. On some hardware, the game operated at a low frame-rate, and the loading time for the game was longer than 60 seconds. In one case, a participant indicated that the game did not load at all (Samsung Galaxy S3 user). This indicated to the research team a need to optimize the software to reduce loading time and improve framerate. Adjustments to the game were made to reduce loading time by lowering the resolution of the textures used (thereby reducing file size), and profiling the game code using the Unity Editor to identify sections of code that could be optimized. Frame rate was improved by removing the procedural generation code from the run-time of the game. Instead, procedural generation of areas of the game was pre-computed during development, and 10,000 pre-generated levels were stored in the game's memory and chosen at random upon request. These levels were not loaded on start-up, so load time was not affected. The removal of the generation process had a large impact on CPU usage, and since this generation was originally completed while the player was moving around in the game world, overall framerate was improved.

One feedback response concerned the quest dialog system. The participant suggested that the game tell the player the quest they were working on when they last played. Adding an additional screen to the daily login screen with information on the last quest was considered, however this would have increased the login screen process to a point considered unacceptable (4 screens). Instead, the quest system was improved to track the most recent quest across play sessions (information which was visible by clicking on the "Quests" button). Originally, the "current" quest was only remembered within a play session, and upon starting a new session would be blank until the player completed a quest action. The modification allowed this current quest to be stored as part of the player's save game.

An issue was identified where the "boundary" zones (the empty areas of the game world that border the main game zones) were not loading correctly on subsequent play sessions of the game. In the case where this was reported, the boundary zone appeared black (the background colour of the app, indicating that a zone is loading), and could not be traversed by the player avatar, leaving the player in a situation where they were unable to leave the zone they were in. This issue was debugged in the code, and resolved during the pilot phase, and the player was able to continue after a software update was distributed. The same participant found an issue where a quest was able to be completed, despite them not completing the quest requirements. Again, this was fixed during the experiment.

One feedback report indicated that the smart meter feedback display needed a legend on the chart indicating which curve represented the current day, and which curve represented the previous day.

Aside from the feedback and bug reports provided by participants, an additional issue with the software was identified. The game metric recording functionality was not operating consistently. Some actions (such as quest completion, and zone entering) were not being recorded (determined by the fact that some actions were recorded that indicated other actions *must* have also happened), and for some participants metrics were not recorded at all. This issue was again fixed for the main trial, however, as stated earlier, it impacted the usage results reported for the pilot.

### 6.1.5 Summary of Pilot Study

The pilot phase was intended to obtain feedback from subject matter experts on the design and implementation of *Energy Explorer*. Six participants provided 11 bug reports and 3 feedback reports. Participants played the game multiple times over a two-month period, and tested three builds of the game which were created in response to bug reports and feedback. A wide range of mobile hardware was tested, and revealed issues with the compatibility of the game with older hardware.

The reports alerted the author to issues with loading time of the game, as well as bugs where areas of the game-world would not load, and instances of quests being unfinishable. Feedback included improvements to the smart meter feedback screen, as well as usability improvements for the quest system.

As a result, the game code and its assets were optimized, and the procedural generation of zones was removed from the runtime of the app, and instead zones were pre-computed ahead of time and stored on the devices to minimise CPU usage. Finally, it was identified that the game metrics were in some cases not being recorded—an issue that was resolved before the main experiment was conducted.

After implementing the required changes from the pilot phase of the project, the main experiment phase could begin. The following section describes the deployment of the main experiment.

## 6.2 Main Experiment

After iterating on the design of *Energy Explorer*, evaluation of the game using real-world participants was conducted to determine the effectiveness of the game in terms of reducing energy consumption, and to address the part of the research question which discusses the challenges involved in deploying the game. The experimental process for doing this has already been introduced in Chapter 3 in broad terms, with this section providing further specific implementation and deployment detail.

The following sections describe first the target participant pool, the number of participants who accepted the invitation to play the game, and the characteristics of the participants in comparison to the source population in terms of their energy saving habits. After this, the components of the experiment are presented in the order in which participants encountered them. The process of inviting participants is described, as well as the website used for registering participants. The design and contents of the entry survey that participants then filled in is described, followed by details on how the game was installed on participant devices. The details of the game metric recording are then described. The exit survey development process is described, and the resultant questions used in the survey are then presented. The results of the main experiment are presented and discussed in Chapters 7 and 8 respectively.

### 6.2.1 Participants

This section gives a detailed description of the source of participants for this project, as well as details on the number and characteristics of the participants who accepted the invitation to play the game.

#### *6.2.1.1 Source (Residential Building Energy Efficiency Survey)*

Energy consumption data was a vital data requirement for this project, and Section 3.2 described a number of sources for this data. Section 3.2 also discussed how using the CSIRO's Residential Building Energy Efficiency Survey (RBEES) participant pool was determined to be the most effective way of collecting and integrating energy consumption data. RBEES was used as the participant pool instead of other online services, or distributing an open-invitation, since there are no third-party mechanisms in place within Australia to access residential smart meter data. Systems such as *WattDepot* (Brewer & Johnson 2010)[75] are not available in Australia.

This section describes the details of the RBEES project. Full details can be found in Ambrose et al. (2013).

In 2012, the RBEES project was commissioned by the Australian Government's Department of Climate Change and Energy Efficiency to explore the differences in energy efficiency between 5-star energy rated homes and to 4- and 3.5-star homes. The CSIRO recruited 414 volunteer households in Melbourne, Brisbane, and Adelaide. Of these homes, metering equipment was installed in 209 households to measure energy usage by various heating and cooling appliances. Detailed information regarding the households was collected, including heating appliance type (e.g. reverse cycle air-conditioning vs. evaporative cooling), temperature inside and outside the house (including dew point data from local weather stations), and energy bills.

Selection of houses for the RBEES study was restricted to homes built since the BCA rating system was first introduced in 2003 and the homes had to have been subject to these procedures to be of value to the study's aims. Energy consumption measurements were made every 30 minutes.

[75] http://wattdepot.org/

The households within the RBEES project were of varied occupant types, including families with preschool children (19%), families with school children (30%), families with adult children (9%), working couples (21%), retired couples (13%), working singles (6%), and retired singles (2%).

#### *6.2.1.2 Sample Size*

This section describes the number of participants who participated in the various chronological components of the project, and reports the effective response rate at each one of the stages where participant attrition was expected. As Figure 59 shows, there are a number of points throughout the experimental design where it was possible for participants to cease participation in the project. More details on each stage of the project is provided later in Section 6.2.2.

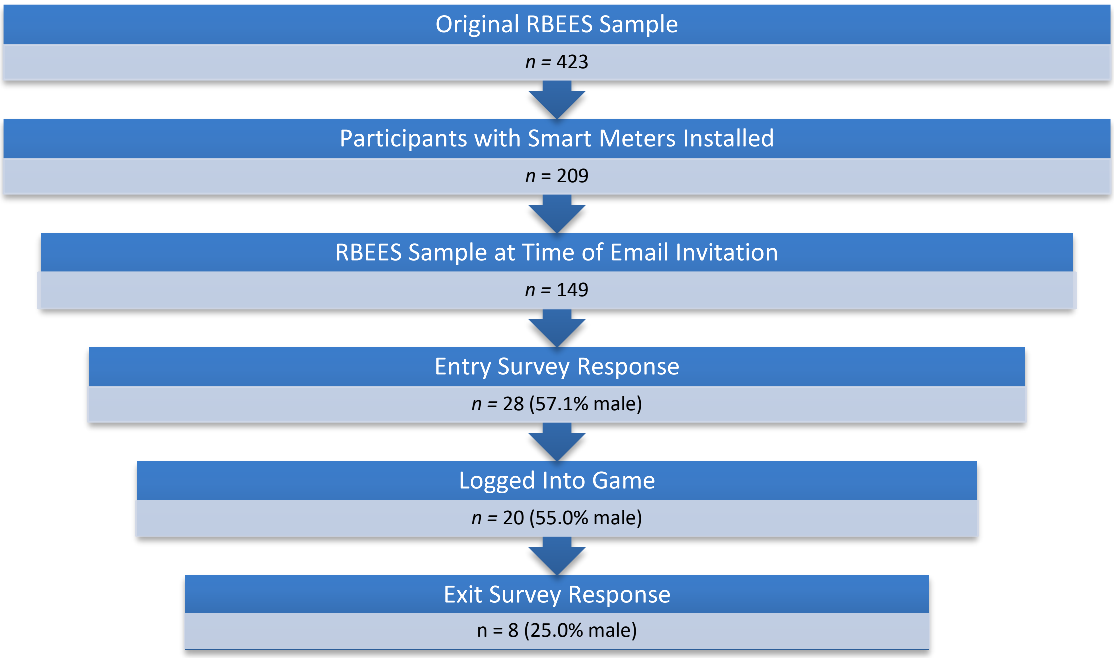



**Figure 59. Representation of participant attrition at various stages where participants had the opportunity to cease to participant in the project.**

The RBEES project had a reported sample size of $n$ = 423[76]. The data set used for the sending of invitation emails (included in Appendix N) to RBEES participants was $n$ = 149 (35.2%of the original sample), the result of participants ceasing their involvement with the RBEES project itself. The response rate of participants to the invitation email was where the largest reduction

[76] The Ambrose et al. (2013) study states that information was collected for 414 participants. An additional 9 users were present in the dataset at time of analysis (hence $n$ = 423), and were likely added after publication of the study.

in the sample size occurred. This number was calculated as the number of people who completed the entry survey (described in Section 6.2.2.2), $n = 28$ (18.8% response rate; 57.1% male[77]).

Upon completing the entry survey, participants were asked to download the *Energy Explorer* game to their personal mobile device, and log into the game. Using the game metrics data, it was determined that $n = 20$ (77.4% of entry survey respondents; 55.0% male) users logged into the game.

The final point of attrition was the response rate of the exit survey, $n = 8$ (40.0% of those who logged into the game; 25.0% male). It should be noted that at this point, the low number of respondents makes it difficult to draw any significant conclusions from the exit survey data or any other data derived by cross-referencing with this data. This limitation is discussed further in section 8.2.5.17.6.

#### 6.2.1.3 Characteristics

The locations of participants were evenly spread across the three possible Australian states, Queensland ($n = 7$; 35.0%), South Australia ($n = 5$; 25.0%), and Victoria ($n = 8$; 40.0%). This indicates that a good representation of different areas of Australia (with varying weather conditions) was sampled.

A core component of the original RBEES study was to gather information about the energy usage behaviours of participants, as well as the various attributes of the participants' homes.

Through self-reporting, RBEES participants typically identified with being an energy conserving household (Figure 60), and the majority of participants were at least "fairly mindful" of their energy usage (Figure 61). 15% of participants who played the game stated that they were "extremely mindful" of their energy consumption, and 40% and 45% of participants who played the game reported to be "very mindful" and "fairly mindful" respectively. Despite this, 57% of the participants identified as medium energy users (Figure 62). 95% of participants who played the game stated that they took steps to limit their household use of energy (main RBEES sample 89.1%).

[77] Gender was reported as part of the entry survey, completed by the head of the household (and primary user of the mobile game—i.e. the mobile game was installed on their personal mobile device)

Tests for differences in characteristics between those who chose to play the game and those who did not are explained in the next section. Participants who chose to play responded similarly to the RBEES group as whole.

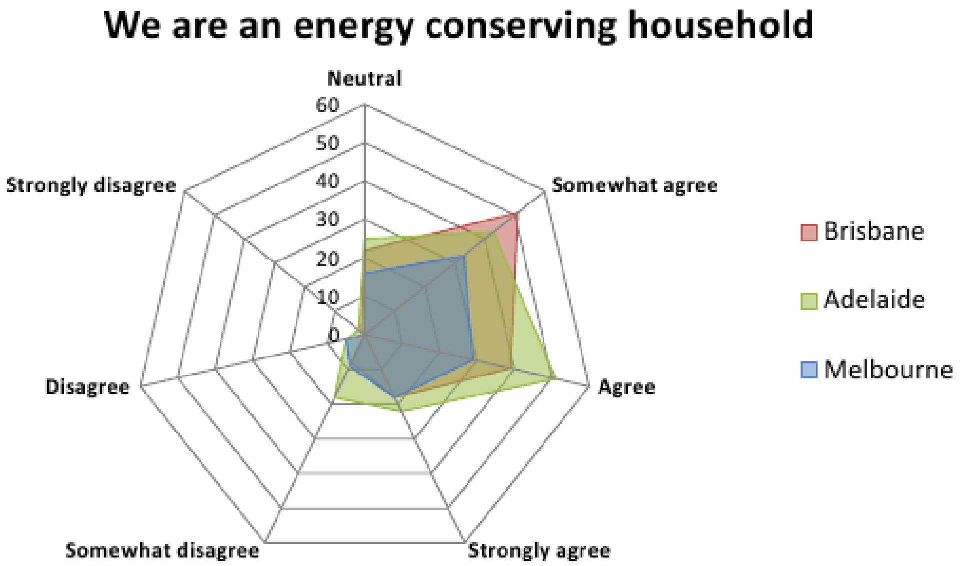
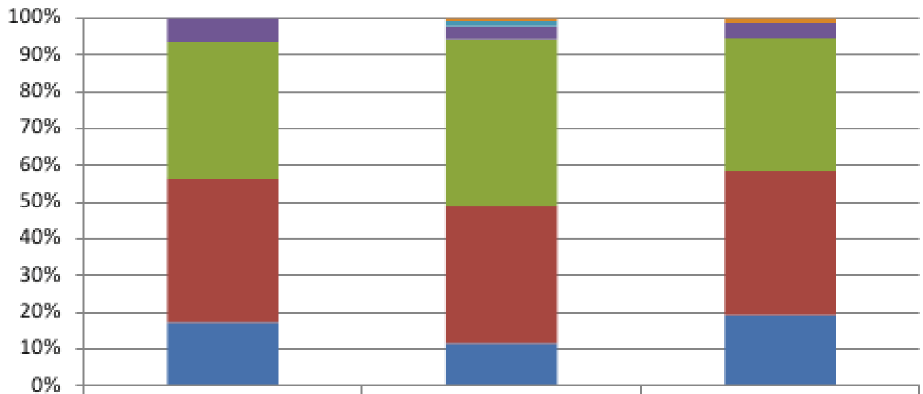



**Figure 60. Original RBEES participants' self-reported energy usage level, showing 57% identifying as medium energy users (from Ambrose et al. (2013)).**




| | Melbourne | Brisbane | Adelaide |
|---|---|---|---|
| Not sure | 0 | 1 | 2 |
| Not mindful at all | 0 | 2 | 0 |
| Not very mindful | 7 | 5 | 7 |
| Fairly mindful | 41 | 63 | 60 |
| Very mindful | 43 | 52 | 65 |
| Extremely mindful | 19 | 16 | 32 |

**Figure 61. Original RBEES participants' mindfulness of their energy usage, showing that the majority are at least fairly mindful of their usage (from Ambrose et al. (2013)).**

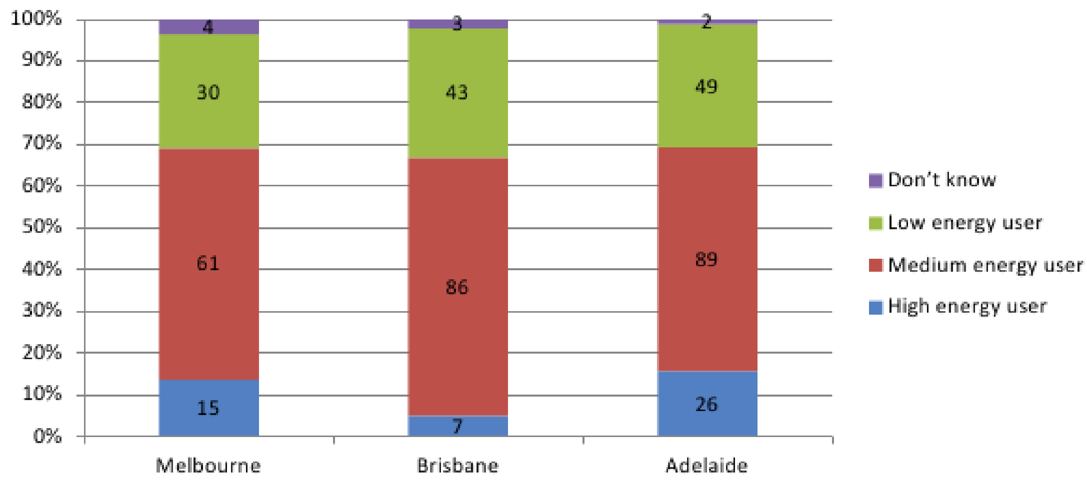



**Figure 62. Original RBEES participants' self-reported energy usage level, showing 57% identifying as medium energy users (from Ambrose et al. (2013)).**

The RBEES participants in general are energy conscious, and many stated that they would take energy-saving measures (curtailment behaviours; 61.5%), and install energy efficient appliances (effectiveness behaviours; 33.3%) in the 12 months following the survey. It was found that 89.1% of RBEES participants, and 95.0% of participants who played the game, stated that they take steps to limit their energy usage in their homes. This energy-conscious characteristic of participants is discussed in Section 8.2.1.

#### 6.2.1.4 *Characteristics — Differences in Answers to Original RBEES Household Survey*

The original RBEES survey was collected for a total of 423 participants. Comparison was made between the following groups:

- the 423 participants in the RBEES dataset, minus the 20 participants who played *Energy Explorer* (*n* = 398); and
- the participants who *played Energy Explorer*, excluding one user for whom valid RBEES survey data was not collected (*n* = 19).

RBEES survey questions were about the characteristics of the household and its energy usage. The reported number of adults and reported number of children in the households for both groups is summarised in Table 19. One participant who played the game did not have a response recorded for this survey question, and 5 participants from the non-game group did not have a response recorded for this question. Using the Shapiro–Wilk test for normality (Shapiro & Wilk 1965), it was found that the data for number of adults and number of children was not normally distributed. As a result, a Mann –Whitney U test (Mann & Whitney 1947) was performed to determine if there were any differences between the two groups for each question. The test showed that there was no significant difference between the two groups for the number of adults (Mann–Whitney U = 4187.0, n1 = 398 n2 =19, $p = 0.299$ two-tailed) and number of children (Mann–Whitney U = 3443.0, n1 = 398 n2 =19, $p = 0.481$ two-tailed) in the household.

| Sample | Observations | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|---|
| **Q3 Adults** | | | | | |
| Did not play | 398 | 1 | 6 | 2.171 | 0.745 |
| Played the game | 19 | 1 | 4 | 2.053 | 0.780 |
| **Q3 Children** | | | | | |
| Did not play | 398 | 0 | 6 | 0.977 | 1.094 |
| Played the game | 19 | 0 | 3 | 1.158 | 1.167 |

**Table 19. Summary of RBEES Household Survey responses to questions regarding household size.**

The lack of difference in household makeup between those who chose to play the game and those who did not is interesting as this was expected to be a contributing factor for uptake of the game. For example, households with children may be more pre-disposed to video games (given the popularity of video games among children), and therefore more likely to participate in a research project testing a video game. As household make up *did not* have an effect on uptake, this shows that a Serious Game approach may be more applicable to a wider range of users than first thought.

The other questions in the original RBEES survey were categorical in nature. For these questions, a two-proportion z-test was conducted on all possible survey responses between the *original* participants and those who *played the game*. For the majority of questions, there was no significant difference in proportions between the two groups (a full data table for this is provided in Appendix M), however there were a few minor exceptions.

Of the participants who played the game, 15.0% stated that their household spending on mains gas per year was between \$300 and \$1,000. This was significantly lower ($Z = -2.776$; $p = 0.005$) than the proportion of respondents who did not play the game who responded the same way (46.7%).

Another significant difference was that none of the participants who played the game stated that they used cold water in their washing machine, compared to 44.2% of those who did not play the game ($Z = -3.905$; $p < 0.001$).

### 6.2.2 Experiment Components

This section describes the specific components of the experiment that participants interacted with. Descriptions are presented in the order in which participants interacted with them.

#### *6.2.2.1 Email Invitation and Registration*

Ethical restrictions prevented the author from having direct access to the email addresses of the RBEES participants (participants were distinguished simply using an identifying number; RBBEES_ID). As such, an authorised researcher at the CSIRO was tasked with emailing participants the prepared invitation email. The email was worded to indicate the worth of the game to players, particularly how the game was individualised for each person from their own data. The full email and the attached information sheet is provided in Appendix N.

The email contained a link that was unique to each participant (using a HTTP GET parameter). The link would take them to a landing page (Figure 63), which was modified to include a "Sign Up" link (all other visitors without a unique link were given contact details of the author).

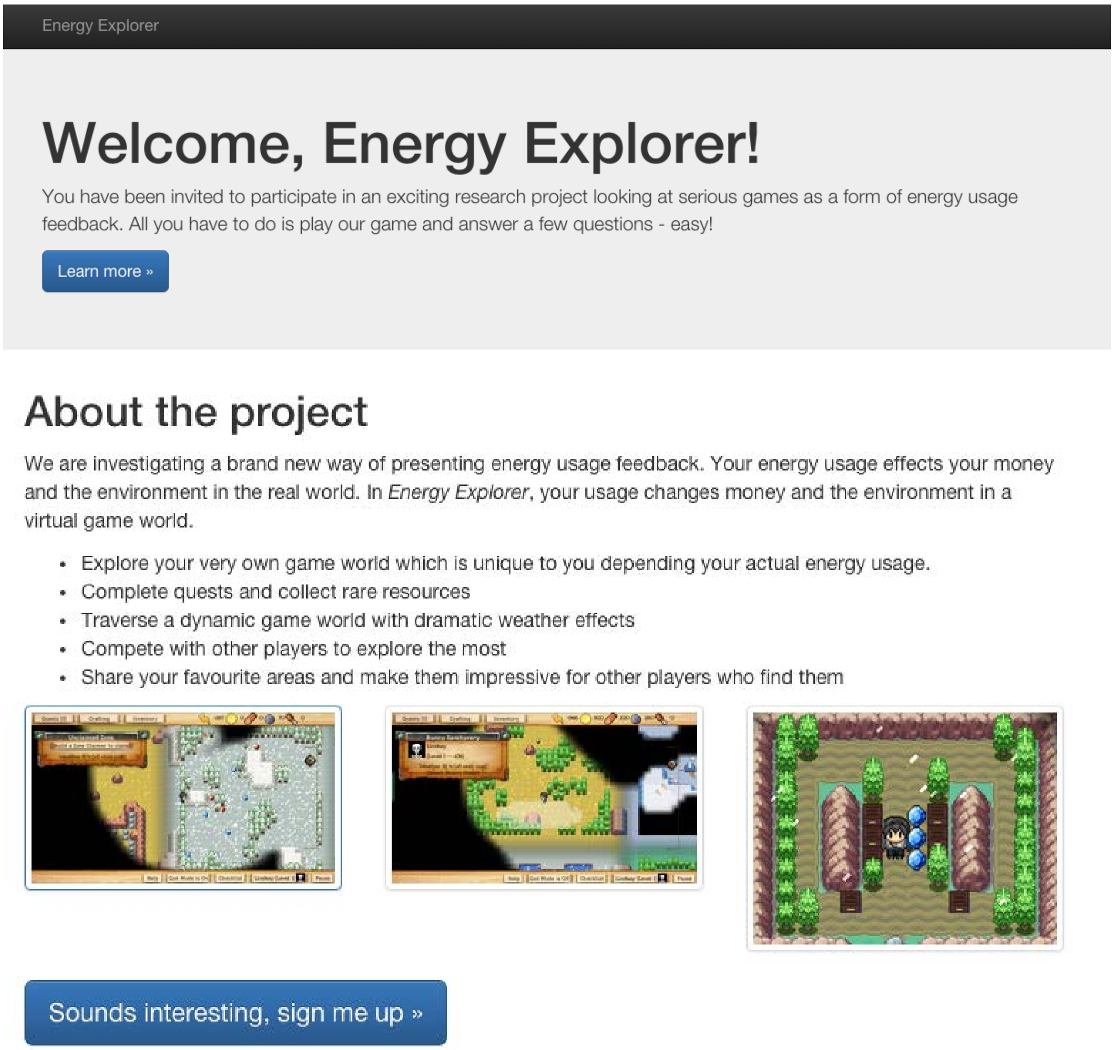



**Figure 63. Screenshot of the website that participants are shown when they accept the email invitation.**

Upon clicking the "Sign Up" button, participants needed to register an account (using a web form, shown in Appendix N), which was linked to the RBEES_ID (see Section 5.3.3) from their unique link in the email. Registration involved entering in a username (participants were asked to make this different to their real name, to prevent identification), and a password. This username and password was used to log into the client game application (see Section 6.2.2.3). Users also had to view an information sheet and consent form (both provided in Appendix N).

Once the registration process was complete, participants were asked to fill in a short entry survey, described in the next section.

#### 6.2.2.2 Entry Survey

An entry survey was developed in order to gather demographic information, as well as to estimate each participant's familiarity with games. Table 20 lists the questions which were asked.

Participant age and gender were collected. The player's location was not collected, as this information was already provided as part of the RBEES dataset.

Familiarity information was collected since the adoption of gamified experiences (and Serious Games) is dependent on previous game experience and attitude towards games (Landers & Callan 2012; Landers & Armstrong 2017). Participants were asked if they had played a video game before, and whether they had played a mobile video game before (both questions were yes/no responses). Participants were then asked to rate their familiarity with video games on a scale of 0 to 10 (where 0 is not familiar at all, and 10 represented very familiar). This question was then repeated for familiarity with mobile video games.

| Entry Survey Question | Response Type |
|---|---|
| 1. Have you played a video game before? | Yes / No |
| 2. Have you played a mobile video game before? | Yes / No |
| 3. How familiar are you with video games? | 0–10 |
| 4. How familiar are you with mobile video games? | 0–10 |
| 5. What is your age? | Numeric field |
| 6. What is your gender? | Male / Female |

**Table 20. The entry survey questions and their associated data types for the *Energy Explorer* trial.**

The survey was facilitated by the *Typeform*[78] website plugin. The survey was completed within the *Energy Explorer* website, however the responses to the survey were stored temporarily on the Typeform servers. At the conclusion of the data collection phase, this data was transferred to internal servers for analysis.

At the conclusion of the survey, participants were redirected to a download instructions page, described in the next section. The results of the entry survey are presented in Section 7.1.

#### 6.2.2.3 Game Download and Login

Participants were given instructions on how to download and install *Energy Explorer* on their mobile device. Since the game was only available to invited users, distribution was not possible via the Apple App Store and Google Play Store. Instead a manual process was required. The process was different for Android and iOS.

[78] https://www typeform.com

To install the game on an Android device, users were instructed to change the security settings on their device to allow applications to be installed from sources other than the Google Play Store. After completing this, users simply downloaded an Application Package Kit (APK) file directly from the *Energy Explorer* website to their mobile device. After downloading this file, the participant had to open the file on the device, which began the installation process. Once installation was complete, the participant was able to open the game from the menu screen on their device.

For iOS, distribution was delivered through the *TestFlight*[79] system. Traditionally using *TestFlight*, the developer of an App manually invites users to use the App, however for *Energy Explorer* this process was automated, since participants were able to sign up to the project at any time. Manually sending the invitation would cause a delay between registration and playing the game (which would not have been present for those with Android devices). Using the *Fastlane Pilot*[80] API, the *Energy Explorer* website was able to automatically send a *TestFlight* invitation to the participant from the download instructions page during the registration process. The participant had to enter the Apple account email address associated with their iOS device in to the *Energy Explorer* website. Upon entering their email address, participants received an automated email invitation from Apple, indicating that they had been invited to play *Energy Explorer*, and contained instructions on how to accept the invitation. Participants were instructed by Apple to download the *TestFlight* App from the AppStore. Inside *TestFlight*, participants had to enter the invitation code from the email to activate their access to *Energy Explorer*. Upon entering the code, the game was installed on their device. Users could then open the game via the menu screen on their device.

Once installed, the implementation of *Energy Explorer* is equivalent across both Android and iOS devices. The first time that players opened the game, they were presented with a login screen (Figure 64). On this screen, participants were required to enter the username and password they used when registering for the project. This was done for two reasons: to ensure that if an unauthorized person obtained a copy of the game they would not be able to access the game content (and see the usage data of other users), and to allow the Web API to determine which user to request energy usage and game progress data for. Subsequent loads of the game do not show the login screen, however authorization is still requested by the game (if an active internet connection is detected) in case the user's account is disabled (this allowed

[79] https://developer.apple.com/testflight/

[80] https://github.com/fastlane/fastlane/tree/master/pilot

for the unlikely circumstance of the participant's phone being stolen, where their *Energy Explorer* password could be changed to prevent access).


**Figure 64. The *Energy Explorer* login screen.**

#### *6.2.2.4 Playing the Game*

After entering the correct username and password, the player is able to create their avatar (see Section 5.2.4). Once the player has finished customizing their player avatar, the main game world loads. On first load, the player starts in the "Introduction" zone, and the first quest "Welcome to Energy Explorer" is automatically triggered. This quest introduces players to the controls of the game, as well as beginning the narrative of the game. A full transcript of the "Welcome to Energy Explorer" quest is provided in Appendix J.

Participants were asked to play the game "as much or as little as [they] like[d]". This choice was provided instead of forcing players to play the game for a requisite amount of time in order to determine the natural appeal of the game when in competition with the other apps and games the player had available to them on their personal device. The information sheet (this was attached to the email invitation, and made accessible on the *Energy Explorer* website—shown in full in Appendix N) gave the following instructions for play:

> *"We ask that you download the appropriate version of the game (iPhone or Android), log in to the game and play as much or as little as you like, whenever you like. This is a field test, and as such you can play the game on your phone at any time of day within the two-month period <DATE>. You can use the application anywhere you have an active internet connection (WiFi, 3G, 4G, etc), as well as offline (the game experience will not be as complete, however).*

*The game has a number of exciting features, and we encourage you to explore the game as much as you like. Some features are only available after you have progressed a certain amount in the game.*

*We ask that you connect the game to the internet at least once, and should you choose to stop playing the game, you connect the game to the internet one last time, to allow for any final data to be transferred."*

As described for the pilot experiment in Section 6.1.3, player actions were recorded and sent to the *Energy Explorer* server for later analysis. Metrics were recorded for 25 different in-game actions, specifically when they logged into the game, when they found new areas in the game, when they used certain parts of the user interface, when they received certain rewards from the daily login screen, when notifications were received, and when they completed quests. A full list of the recorded metrics is provided in Appendix E. Each action was logged with a timestamp. Game analytics have been highlighted in the literature as important to exploring and quantifying the game experience (Nacke et al. 2009; Xu et al. 2014). Analytics recorded mirrored the chosen game elements to measure their uptake by participants, and to determine if those who used particular elements more than others had a higher conservation effect. This analysis is presented in Section 7.2.

Participant energy consumption was recorded before, during, and after being given access to the game. Analysis was performed on this data to test for a conservation effect, as described in Section 3.3.5 and presented in Section 7.4.

#### 6.2.2.5 Exit Survey

Players were given access to the *Energy Explorer* game for a two-month period, and following this were invited to complete an exit survey. Similar to the entry survey, delivery was made using the *Typeform* software hosted on the *Energy Explorer* website (shown in Appendix N). Again, participants were asked to enter their username to allow for data linking of the *Typeform* data. While no specific steps were taken to ensure that the person who completed the survey was the person playing the game, the notification to complete the survey was emailed to the same address as the original invitation to participate. Assuming this email address was monitored by a single person and not a shared account, the person who accepted the original invitation, completed the entry survey, and played the game, was likely the same person who opened the exit survey email and completed it.

The exit survey consisted of two components: household information and game experience questions. Household information was recorded to determine some potentially determining factors of energy usage. Participants were asked the following questions about their household:

- How many people reside in your household?
- How many bedrooms are in your household?
- Do you own an Air Conditioner?

These questions helped determine the size of the household in terms of number of people, and also the physical size of the dwelling.

The remainder of the questions were about the specific game elements present in the game, and how the players perceived them. These questions were statements to which participants were required to respond on a standard 5-point Likert scale of *Strongly Disagree, Disagree, Neither Agree or Disagree, Agree,* and *Strongly Disagree.* Statements were developed for each game element in two ways. The first used the game element classification framework by Octalysis by (Chou 2016) as it provided easy-to-understand questions to the participant about the intention of each element. For example, the game element of the *player avatar* was linked to the Octalysis category *ownership*. The resulting statement from this linkage was:

*I felt like I owned my game avatar in Energy Explorer.*

The second exit question type focussed on the linkage of game elements to BCTs. For example, the *social system* game element facilitated the *social comparison* BCT. The resulting statement for this element was:

*The social system in Energy Explorer allowed me to compare my behaviour to others.*

Note that alternative approaches to assessing player experience, such as the Game Experience Questionnaire (IJsselsteijn et al. 2008), focus primarily on the player's reception to the game as a whole, which insufficiently explores the effectiveness of the selected game elements in delivering value.

Appendix H shows the full list of questions asked in the exit survey.

### 6.2.3 Summary of Main Experiment

At the conclusion of the pilot phase, improvements were made to the design of the *Energy Explorer* game, and the main experiment commenced. The participants were sourced from the CSIRO's Residential Building Energy Efficiency Survey study, providing a participant pool with relevant smart meter infrastructure. The size of the sample at each stage of the experiment was described, and the characteristics of the users was explored. A bias towards people who are already conserving energy was identified in the RBEES sample whole. No significant differences in characteristics were observed between those who chose to play the game and those who did not, indicating that the sample was representative of the overall RBEES sample. Similarly, an even spread of Australian states was observed among the participants who chose to play the game.

The components of the experiment were detailed in the order in which participants interacted with them.

## 6.3 Chapter Summary

Two experiments were deployed during the course of this project: a pilot, and the main experiment. This chapter has presented the design of both, as well as the results of the pilot phase.

The pilot phase was conducted using subject matter experts in the area of energy conservation to receive feedback on the design of the game, and to find bugs specific to different mobile devices. Feedback messages and bug reports were collected from the experts, and a number of changes were made to the *Energy Explorer* game. In particular, the game was optimised such that it could run at an acceptable frame rate on older devices, and loading times were reduced. This was accomplished primarily by pre-generating the randomly generated zones of the game world at build-time and by including a large number of levels for the game to select from (rather than generating levels while the player was interacting with the game). Additionally, issues identified with the collection of game analytics were identified, and these were fixed before the main trial.

The design of the main experiment was described, as well as the characteristics and sample size of the participants who played the game. Sample sizes were reported for response to the entry survey ($n$ = 28), playing the game ($n$ = 20), and responding to the exit survey ($n$ = 8). The different components of the experiment were described in the order in which participants would interact with them. The experiment process began with an email invitation, followed by a registration where participants created a non-identifiable username and password, and reviewed an information and consent form. A short entry survey was presented to determine demographic information and familiarity level with video games. Participants were then given instructions on how to install *Energy Explorer* on their Android or iOS device. Participants were invited to play the game as little or as much as they liked in order to determine the natural appeal of the game. The process of launching the game was described in this chapter, as were the game metrics which were recorded as players played the game.

Finally, after the two-month period had concluded, participants were invited to complete an exit survey. The process of developing the questions for this survey was presented, which used a combination of the Octalysis framework and the novel BCTs from Section 4.3.

This chapter has described the deployment of the intervention. The next chapter presents the results of this deployment.

# 7 Results

To test the effectiveness of the designed Serious Game *Energy Explorer*, the game was distributed to participants to test in a real-world scenario, as described in the previous chapter. Multiple measurements were recorded, including an entry survey, exit survey, game usage, and energy consumption. The reception to the game, and its effectiveness for conservation help inform the main research question of this work. This chapter presents the results of the main experiment for this project. Figure 65 shows how this chapter fits within the overarching methodology of the project.

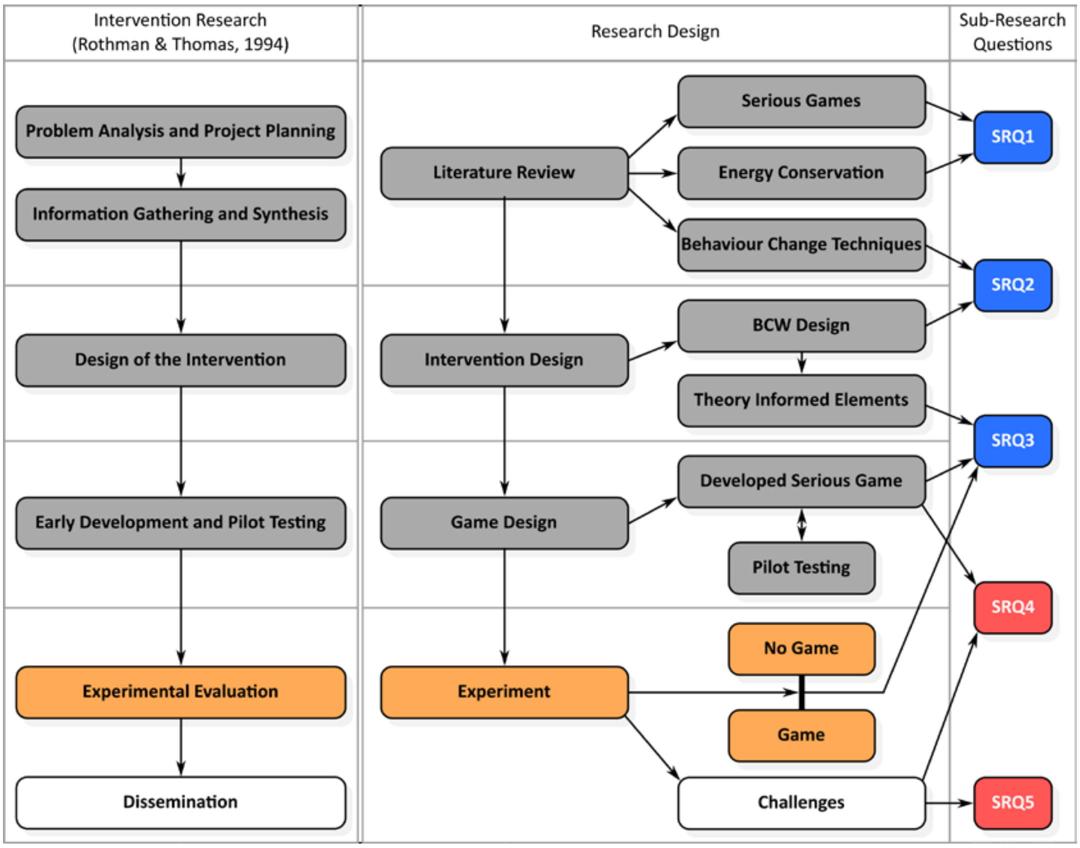



**Figure 65. The project methodology diagram, showing the components covered in this chapter: the results of the main experiment.**

The chapter begins by describing the results of the entry survey. Usage of the game as recorded by the game metrics is then presented, followed by the answers to the exit survey. Analysis of participant energy consumption change while using the app is then described. Relationships between the recorded measures are presented, revealing factors that may have influenced energy consumption. The chapter concludes with analysis of three examples within the study, representing high-, low-, and median-usage of the game as determined by the number of game actions recorded.

## 7.1 Entry Survey

This section presents the results of the entry survey, first in terms of the descriptive statistics that indicate characteristics of participants beyond what was already known from Section 6.2.1, and then in terms of the relationships between the questions. Note that relationships between the data for this survey and the other recorded measures such as energy consumption are described later in this chapter in Section 7.5.

### 7.1.1 Descriptive Statistics

Twenty-eight responses were obtained from the entry survey (57.1% male), which was an 18.8% response rate from the people who were sent the invitation ($n$ = 149). However, of the 28 who completed the survey, only 20 (71.4% of sample; 55.0% male) were registered as having played the game (note this is different to *downloading* the game). The results of this section refer to the entry survey responses of the 20 participants who played the game.

The median age of participants was 44.5 (SD = 9.492) and the variable was not normally distributed (Shapiro–Wilk test; p = 0.029). The average age of participants in the study was 48.1 years (SD = 9.492). Ages of participants varied between 35 years for the youngest, and 65 years for the oldest.

The entry survey showed that 85.0% of participants reported that they had played a video game before, and 70.0% of participants stated that they had played a mobile video game before. Additionally, 82.4% of the participants who had stated that they had played a video game before had played a mobile video game before.

The questions which asked participants about their familiarity with video games on a scale of 0 to 10 (inclusive) were normally distributed (Shapiro–Wilk test; $p$ = 0.132[81] for familiarity with video games; $p$ = 0.087 for familiarity with mobile video games). The average familiarity level with video games was 6.0 ($SD$ = 3.146), and the average reported familiarity level with mobile video games was 5.6 ($SD$ = 9.492). Minimum responses for both questions were 0 ($n$ = 1), and the most familiar was reported to be 10 ($n$ = 4).

A summary of the descriptive statistics is provided in Table 21.

[81] Note that a high p value indicates that the null hypothesis that the data came from a normally distributed population cannot be rejected.

| | Min | Max | Median | Mean | SD |
|---|---|---|---|---|---|
| **How familiar are you with video games (0–10)?** | 0.0 | 10.0 | 6.5 | 6.0 | 3.146 |
| **How familiar are you with mobile video games (0–10)?** | 0.0 | 10.0 | 6.0 | 5.7 | 3.281 |
| **Age (years)** | 35.0 | 65.0 | 44.5 | 48.1 | 9.492 |
| **Time taken to complete survey (minutes)** | 0.0 | 2.0 | 1.0 | 1.1 | 0.447 |

**Table 21. Summary of Entry Survey responses.**

#### 7.1.2 Relationship between Questions

The median age of participants who had played a video game before was 44 ($SD = 8.076$) which is significantly lower (Mann–Whitney $U = 3.0$, $n_1 = 17$, $n_2 = 3$, $p = 0.020$ two-tailed) than the median age of participants who had never played a video game before ($M = 61$ ($SD = 3.055$).

Participants who stated that they had played a video game before rated their familiarity with video games on average 6.94 out of 10 ($SD = 2.331$), which was significantly higher (Students $t(18) = 4.542$, $p < 0.001$) than the average familiarity of 0.667 ($SD = 0.557$) of the participants who had never played a video game before. Similarly, participants who stated that they had played a video game before had significantly higher reported familiarity with mobile video games ($M = 6.529$, $SD = 2.695$) than those who had never played a video game before ($M = 0.667$, $SD = 0.557$, $t(18) = 3.674$, $p = 0.002$).

The median age of participants who had played a mobile video game before was 44.0 ($SD = 7.780$), which was lower than the median age of participants who had never played a mobile video game before (58.0; $SD = 11.873$). This difference, however, was not found to be significant at the 0.05 level lower (Mann–Whitney $U = 24.0$, $n_1 = 13$, $n_2 = 6$, $p = 0.202$ two-tailed).

The mean reported familiarity with video games of participants who had played a mobile video game before was 7.5 out of 10 ($SD = 1.990$), which was significantly higher than the reported familiarity of participants who had never played a video game before ($M = 2.5$, $SD = 2.510$, $t(18) = 4.772$, $p < 0.001$). A similar significant difference was found between the mean reported familiarity with mobile video games between participants who had played a mobile video game before ($M = 7.214$, $SD = 2.119$) and those who had not ($M = 2.0$, $SD = 2.530$, $t(18) = 4.770$, $p < 0.001$).

A Pearson product-moment correlation coefficient was computed to assess the relationship between participant responses to the familiarity questions. The two questions which asked participants to rate their familiarity with video games and mobile games were very strongly positively correlated ($r = 0.964$, $n = 20$, $p < 0.001$). The higher the reported familiarity with video games, the higher the reported familiarity with mobile video games.

There was also a relationship between the familiarity variables and age. There was a strong negative correlation ($r = -0.724$, $n = 20$, $p < 0.001$) between age and familiarity with video games, and a strong negative correlation ($r = -0.648$, $n = 20$, $p = 0.002$) between age and familiarity with mobile video games. The higher the participant's age, the lower the familiarity with video games was reported to be (Figure 66), and this was found for both standard video games and mobile video games. This is discussed further in Section 8.2.1.2.

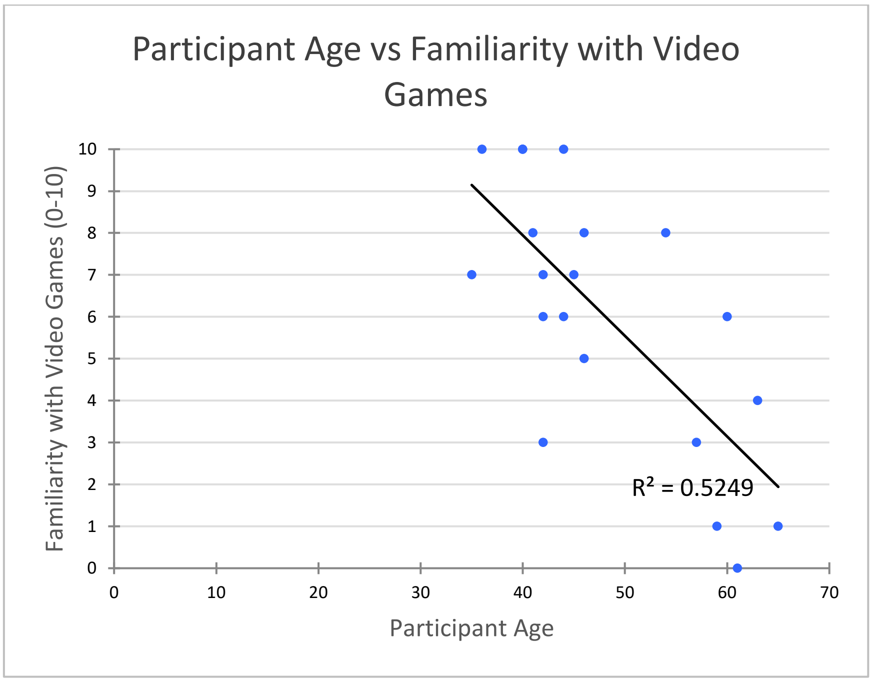



**Figure 66. Reported familiarity with video games plotted against participant age, showing that as age gets higher, familiarity with video games reduces.**

There was no significant difference between the median age of male (44.0, *SD*) and female (46.0, SD = 11.469) participants (Mann–Whitney $U = 38.0$, $n_1 = 11$, $n_2 = 9$, $p = 0.402$ two-tailed). Gender also was not a factor in reported familiarity with video games ($M_{male} = 6.545$, $SD_{male} = 2.734$, $M_{female} = 5.333$, $SD_{female} = 3.640$, $t(18) = 0.851$, $p = 0.406$), or for reported familiarity with mobile video games ($M_{male} = 5.909$, $SD_{male} = 2.625$, $M_{female} = 5.333$, $SD_{female} = 4.093$, $t(18) = 0.382$, $p = 0.707$).

### 7.1.3 Summary of Entry Survey Results

In general, the participants were familiar with both video games and mobile video games. Participants who had never played a video game rated their familiarity with video games significantly lower than those who had played video games before. These results were also seen for the same questions referring to mobile video games. While having a high familiarity with video games among participants may be good since they are more likely to understand how to play the game, it may also have been detrimental since the participants may have higher expectations of the quality of games given the games they have played in the past (discussed further in Section 8.2.1.4).

Participants were aged 35 to 65 ($M = 48.1$, $SD = 9.492$). The mean age (48.1) was overall higher than the average age of gamers in Australia which is 33 (Entertainment Software Association 2016; IGEA 2016). This was expected since the RBEES participant group were homeowners, however the increased age of participants may have been detrimental in terms of openness to playing the game and ability to play it, and this is discussed in Sections 8.2.1.2 and 8.2.1.3. Participant gender had no significant impact on any of the entry survey questions.

Participant age was strongly correlated with familiarity with video games, showing that the older a participant was, the less familiar they tended to rate themselves with video games, which again may have impacted their ability or willingness to play the game.

## 7.2 Game Metrics

Metrics were recorded for 25 different in-game actions, as described in Appendix F. Each participant had a total action count derived, as well as a variable representing the total types of actions (calculated as the total unique action types taken, maximum 25). In addition, the "login" metric was used to determine play sessions. Using play session information, data for session count, total play time, average session length, and average actions per session were determined in order to provide an indication of overall game usage, and facilitate the selection of example user analysis presented later in this chapter in Section 7.6.

A full summary of the descriptive statistics, per-player usage, and correlation of game metrics is provided in Appendix G. Usage of game features by specific example users is provided later in this chapter in Section 7.6. As with the previous section, descriptive statistics are first presented, followed by a description of the relationship between the variables.

### 7.2.1 Descriptive Statistics

Participants completed a total of 88 sessions, an average of 4.4 per player ($SD = 3.2$). One player completed 15 individual sessions (this user is examined in detail in Section 7.6.1). The total time playing the game for each user was on average 23.4 minutes (1402.7 seconds, $SD = 2077.1$ seconds). The average session length for each player was on average 4.4 minutes (266.4 seconds, $SD = 172.3$ seconds). This indicated that players played the game on multiple occasions for a suitable amount of time, however the total number of times they played was lower than expected. Descriptive statistics are presented in Table 22.

| | Min | Max | Mean | Standard Deviation |
|---|---|---|---|---|
| **Total Action Count** | 16.0 | 364.0 | 83.3 | 89.0 |
| **Total Types of Actions** | 7.0 | 21.0 | 13.6 | 4.4 |
| **Session Count** | 2.0 | 15.0 | 4.4 | 3.2 |
| **Total Session Length (seconds)** | 43.0 | 9457.0 | 1402.7 | 2077.1 |
| **Average Session Length (seconds)** | 21.5 | 630.5 | 266.4 | 172.3 |
| **Average Actions Per Session** | 3.5 | 39.7 | 16.3 | 11.2 |

**Table 22. Summary statistics of the session data.**

In total, 1,666 game actions were recorded (on average 83.3 actions per user, $SD$ = 89.0), with the distribution across actions summarised in Figure 67. A total of 152 login actions were recorded (per player $M$ = 7.6, $SD$ = 5.8), however this is not necessarily representative of actual gaming sessions (discussed later in this section), as failure to complete the loading process and begin actual play does not constitute a session, and may result in multiple login attempts before the game loaded. The most frequently completed action was “chopped down a tree”, which occurred 303 times.

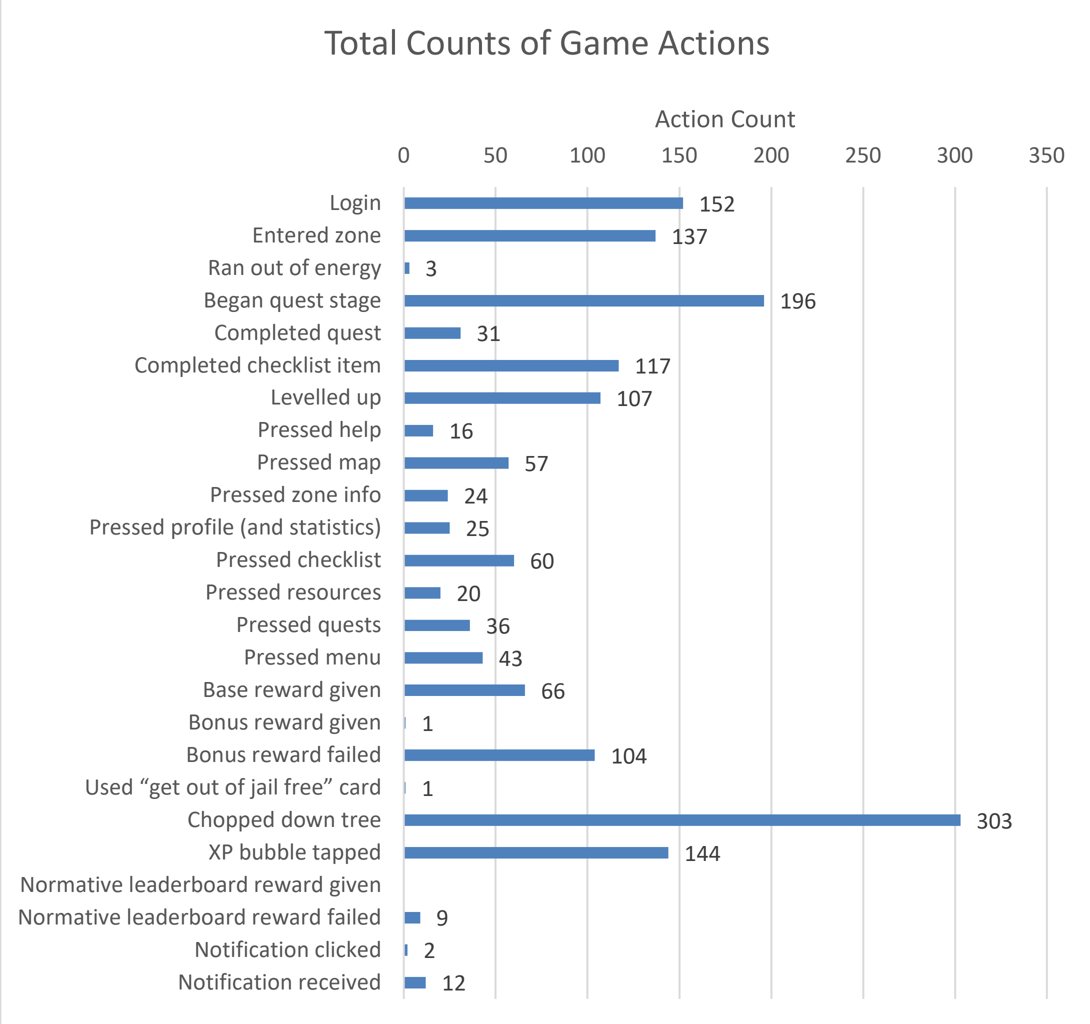



**Figure 67. Summary of recorded game metrics; a per-player breakdown of these statistics is provided in Appendix D.**

Players completed 31 quests ($M = 1.6$, $SD = 2.3$). Although the difference between "begin quest stage" and "complete quest" actions on the surface may indicate that many quests were started and not finished, it should be noted that quests were made up of *multiple* stages which must be completed before the quest is completed, which inflates the "begin quest stage" action. This along with the counts for checklist items ($M = 5.9$, $SD = 6.6$) and levelling up ($M = 5.4$, $SD = 7.1$) indicated that players played the game to the extent that they witnessed most features of the game.

Of the various interface items, the checklist screen was used the most ($M = 3.0$, $SD = 4.0$), followed by the map screen ($M = 2.9$, $SD = 4.0$).

The "base reward" was only awarded when participants launched the game more than one hour after the last time they launched the game, and as a result it is much lower than the number of logins. Participants generally failed to improve upon their usage, and thus did not receive any bonus rewards except for one instance (the reward was failed 104 times, and given once). This action was recorded for each resource that players could receive a bonus for, and so this action was recorded multiple times per session. The normative leaderboard reward was only recorded as failed. It is suspected that a software error prevented the recording of successful normative leaderboard rewards, as some users would *have* to have performed better than others in the trial.

The notification system sent 12 notifications, however only 2 of these were clicked by players.

### 7.2.2 Relationship Between Variables

Most game metrics were strongly correlated with other game actions, which was expected since most game actions were complimentary with each other (e.g. chopping down trees yielded XP resource, which resulted in levelling up). Whilst Appendix G provides a full correlation table of game actions, this section summarises correlations of interest found.

Logging in was strongly positively correlated to levelling up ($r = 0.622$, $n = 20$, $p < 0.05$). The more worlds someone visited (i.e. the more they explored), the more quests they completed ($r = 0.519$, $n = 20$, $p < 0.05$), the more overall actions were recorded for them ($r = 0.942$, $n = 20$, $p < 0.05$), and the longer their average session time was ($r = 0.721$, $n = 20$, $p < 0.05$).

As checklists and quests were tightly linked, quest completion was strongly positively correlated with checklist item completion ($r = 0.944$, $n = 20$, $p < 0.05$). People who completed checklist items were also more likely to tap XP bubbles ($r = 0.913$, $n = 20$, $p < 0.05$).

Players tended to level up the most using the XP bubble feature, as one of the strongest correlations was between levelling up and tapping XP bubbles ($r = 0.983$, $n = 20$, $p < 0.05$). Tapping XP bubbles was also strongly positively correlated with the number of sessions ($r = 0.895$, $n = 20$, $p < 0.05$), and session length ($r = 0.957$, $n = 20$, $p < 0.05$).

### 7.2.3 Summary of Game Metrics Results

Users recorded on average 83.3 actions each, and on average played 4.4 sessions totalling an average of 23.4 minutes. Participants witnessed most features of the game, however, they did not play the game as much as hoped for. Players used the checklist screen the most out of the user interface elements, and completed a large number of checklist items. Most bonus rewards were not awarded, indicating that players did not improve on their energy usage. A software fault was suspected for recording of normative leaderboard rewards, as no rewards were recorded.

Most metrics strongly positively correlated with each other, given the complimentary nature of each of the game actions. Players who logged in more were more likely to level up and complete quests, and checklist items and quests were shown to be strongly correlated with each other.

It should be noted that given the overall under-use of the system by participants, analysis of the effectiveness of the game to implement Behaviour Change Techniques (as recorded by game metrics) was not possible. Metrics showed a lack of interaction with BCT-supporting game elements, and so it would have been difficult to draw any rigorous conclusions from this data. This lack of interaction with BCTs is mirrored by participant responses to the BCT-related exit survey questions, described in the next section.

## 7.3 Exit Survey

The exit survey consisted of two main components: 2 questions regarding household occupancy ($\alpha = 0.921$), a question confirming the existence of an air conditioner in the household, and 38 questions about the participant's experience playing the game ($\alpha = 0.986$). The following two sub-sections look at each of these components in detail. Again, it should be noted that due to the low number of respondents ($n = 8$) to this component, it is difficult to draw any solid conclusions from this data.

### 7.3.1 Household Questions

The mean number of people in participant households was 3.3 ($SD = 0.886$), and the mean number of bedrooms in participant homes was 4.0 ($SD = 0.756$). Summary statistics are provided in Table 23. Seventy-five percent ($n = 6$) of participants reported that their house had an air conditioner.

| | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|
| **Number of people in the household** | 2.0 | 4.0 | 3.3 | 0.8 |
| **Number of bedrooms in the home** | 3.0 | 5.0 | 4.0 | 0.7 |

**Table 23. Summary of exit survey questions regarding household type.**

There was a strong positive correlation ($r = 0.853$, $n = 8$, $p = 0.007$) between the reported number of people in a participant's household, and the reported number of bedrooms in participant's home. The higher the number of people in the home, the more bedrooms there were in the home. There was no significant difference in the number of people or number of bedrooms in the household between those households which had an air conditioner, and those that did not ($p > 0.05$).

The number of people in house and the number of bedrooms had no correlation ($p > 0.05$) to any of the other questions on the exit survey, while the presence of an air conditioner had no relationship on the other survey questions.

### 7.3.2 Game Experience

The average of the average responses for questions 4 to 41 was 1.9 ($SD = 0.8$, the possible responses to these questions were 1 to 5 inclusive). A full set of summary statistics is provided in Appendix H. Figure 68 shows the distribution of responses for each question.

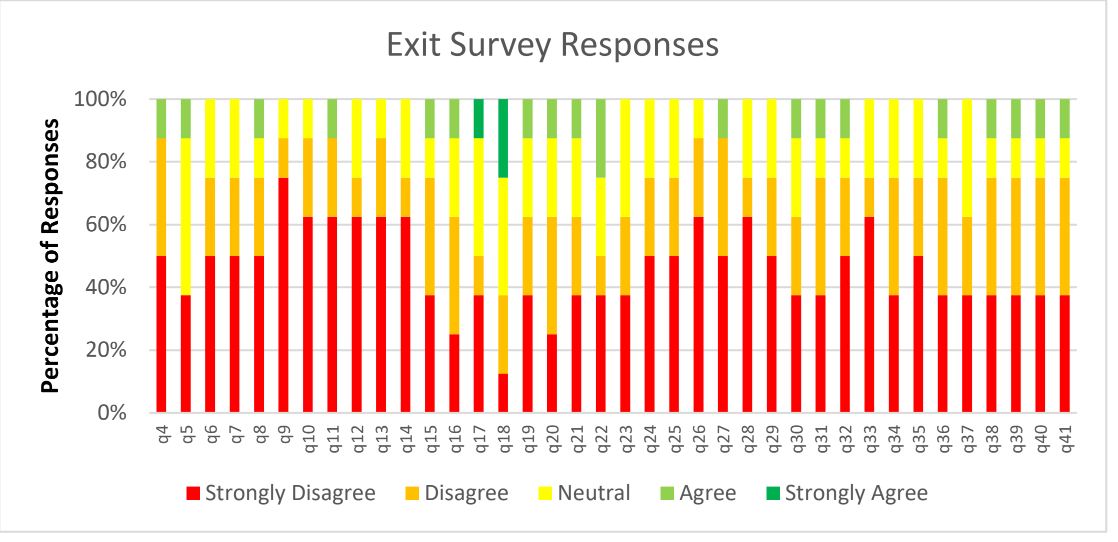



**Figure 68. Distribution of responses to the exit survey, showing that the majority of questions were responded to with "disagree" or "strongly disagree". Question numbers refer to those listed in Appendix H.**

Two statements had responses of "strongly agree": "the Energy resource in Energy Explorer was scarce" and "the treasure chest rewards in the game were unpredictable". These questions related to the Octalysis framework (Chou 2016) elements of scarcity and unpredictability, and not necessarily to the BCTs. The statement that obtained two "agree" responses was "In-game energy being linked to my real-world energy usage provided me with feedback on my behaviour". Most of the positive responses came from a single user (UserID = 11), who averaged a score of 3.5 ($SD = 0.5$). Figure 69 summarises the proportion of responses for each of the Likert levels.

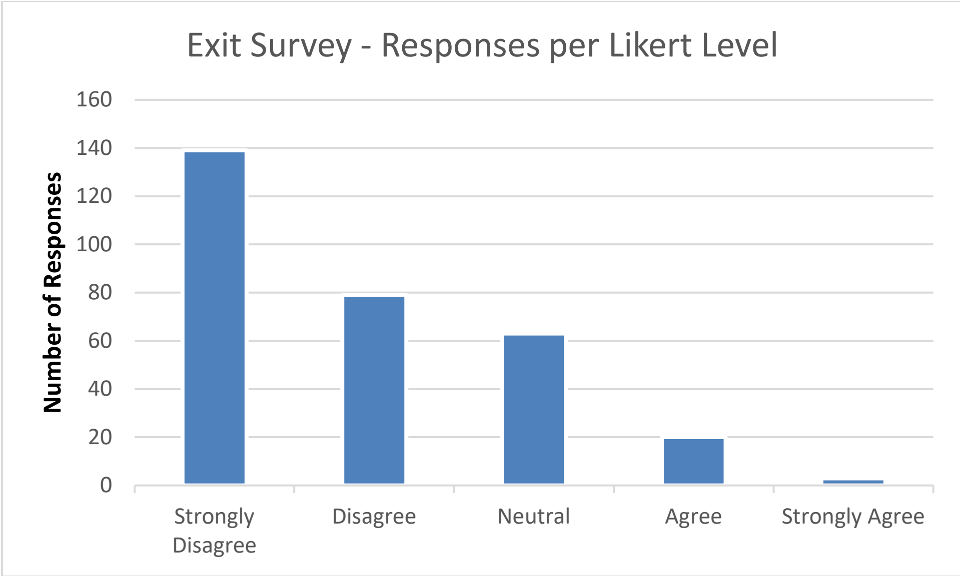



**Figure 69. Distribution of responses into the 5 possible Likert responses.**

The descriptive statistics show that participants generally disagreed with the statements that the chosen game elements facilitated the BCTs. This does not necessarily mean that the game elements *did not* facilitate the BCTs, but rather that participants did not fully witness the game elements in the game enough, and chose to enter "strongly disagree" as a default option. It should be noted that the survey only showed "strongly agree" and "strongly disagree", while the "neutral" option was not labelled. It is possible that participants indicated "strongly disagree" when attempting to indicate "neutral".

Almost all the game experience questions had strong positive correlations ($p < 0.05$) indicating that participants provided similar answers across all questions (i.e. high responses on one question was a predictor for high responses on another question). Appendix H shows a correlation matrix of these questions. There were no negative correlations in the dataset.

### 7.3.3 Summary of Exit Survey Results

An even spread of household sizes in terms of people and number of bedrooms was present in the sample. Generally, participants responded negatively to the exit survey questions, indicating that they felt that the game elements did not facilitate the chosen BCTs within this implementation. Despite this, the energy consumption results (presented in the next section) appear more promising.

## 7.4 Energy Consumption

Energy consumption data was collected by the CSIRO for all participants and analysis was performed on data recorded since January 1st, 2015. As described in the methodology chapter in Section 3.3.5, weather data was collected by the Bureau of Meteorology (BoM) for 15 weather stations, each relevant to one or more participants based upon participant post-code data collected by the CSIRO. For each station for each day (the comparison day), all other days were given a similarity value[82] to the comparison day and ranked in order from most-similar to least-similar. For participants in the experiment group[83], energy consumption on the $x$ days after participants were exposed to the mobile video game was compared to the energy consumption on the 20 most similar days[84] for that given day $x$. The calculation of *conservation effect* was previously described in Section 3.3.5.

First, a Shapiro–Wilk test for normality test was conducted, and in all cases conservation effect data was found to be not following a normal n ($p < 0.0001$), thus a non-parametric two-tailed Mann–Whitney (Mann & Whitney 1947) test was performed.

Given the small amount of time each participant interacted with the game, analysis of conservation effect pre- and post- was conducted for a shorter period of time than originally planned.

Change was calculated for each user, and a Mann–Whitney U test was performed to compare change between the control and treatment groups. Table 24 summarises these tests.

[82] Similarity value was calculated based upon apparent temperature and determined using the Euclidian distance formula as described in section 3.3.5

[83] The experiment group excluded participants who completed the entry survey but failed to play the game ($n$ = 20)

[84] Given each day was compared to 1,973 other days, 20 represents the top 1% of similar days.

| Comparison period (*d*) | Change in Conservation Effect over *x* days (kWh, lower is better, mean is for the entire period *d*) | | *p*-value | *U*-value |
|---|---|---|---|---|
| | $M_{control}$ ($SD_{control}$) | $M_{treatment}$ ($SD_{treatment}$) | | |
| 1 | −0.015 (0.085) | −0.011 (0.076) | 0.901 | 1194 |
| 2 | −0.017 (0.158) | −0.039 (0.124) | 0.404 | 1361 |
| 3 | −0.033 (0.232) | −0.032 (0.132) | 0.938 | 1202 |
| 4 | 0.004 (0.300) | −0.045 (0.200) | 0.516 | 1329 |
| 5 | 0.066 (0.343) | −0.024 (0.213) | 0.314 | 1391 |
| 6 | 0.087 (0.400) | −0.003 (0.227) | 0.271 | 1407 |
| 7 | 0.111 (0.456) | 0.040 (0.227) | 0.451 | 1347 |
| 8 | 0.148 (0.500) | 0.024 (0.257) | 0.150 | 1466 |
| 9 | 0.163 (0.525) | 0.003 (0.268) | 0.084 | 1516 |
| 10 | 0.126 (0.583) | 0.016 (0.273) | 0.295 | 1398 |
| 11 | 0.137 (0.644) | 0.017 (0.331) | 0.289 | 1400 |
| 12 | 0.159 (0.728) | 0.003 (0.378) | 0.224 | 1427 |
| 13 | 0.192 (0.771) | −0.020 (0.477) | 0.096 | 1505 |
| 14 | 0.234 (0.799) | −0.043 (0.578) | **0.043** | 1567 |

**Table 24. Summary of Mann–Whitney U tests for change in conservation effect before and after d number of days before and after being given access to the game ($n1 = 128$, $n2 = 19$[85]).**

The mean change in conservation effect over 14 days ($d = 14$) for participants in the treatment group was –0.043kWh ($SD = 0.578$), which was significantly lower ($U = 1567$, $n1 = 128$, $n2 = 19$, $p = 0.043$) than the mean change in conservation effect for participants in the control group ($M = 0.234$, $SD = 0.799$). Negative values for change in conservation effect indicate a reduction in energy, thus when comparing over a 14-day period, participants who played *Energy Explorer* had a better conservation effect than those in the control group. It should be noted however that the change in consumption was small. Figure 70 shows how as *d* increased, change in conservation effect increased for the control group (strongly positively correlated, ($r = 0.951$, $p < 0.05$), whereas this statistic remained steady for those who played the game ($r = 0.257$, $p < 0.05$).

[85] One user who played the game did not have valid energy data due to a fault with smart meter collection

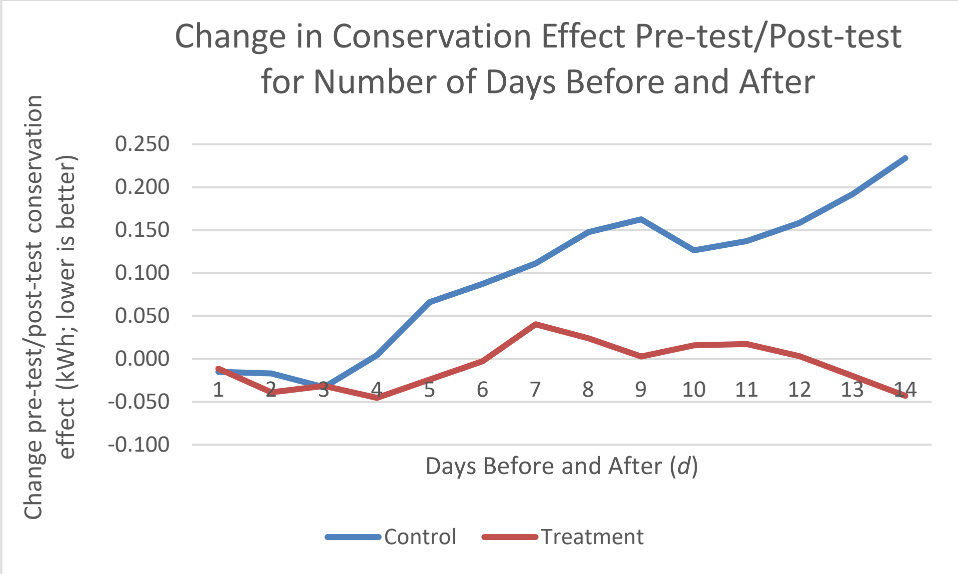



**Figure 70. Difference in sums of *d* number of days before and after being given access to the game.**

Looking at the conservation effect for the day that participants were given access to the game ($x = 1$), the average conservation effect for the treatment group was -0.005kWH ($SD = 0.058$), and 0.003kWh for the control group ($SD = 0.102$), however this difference was not found to be significant ($U = 1277.5$, $n1 = 128$, $n2 = 19$, $p > 0.05$).

## 7.5 Relationships between Measures

The previous sections have described each of the recorded measures in isolation. This section now considers relationships between these measures. Each sub-section describes a different combination of measures.

Where the exit survey is examined $n = 8$, for all other comparisons $n = 20$ (i.e. the number of people who played the game), with the exception of comparison to energy conservation where $n = 19$ given that one participant had unusable energy data due to a fault in the smart meter collection process. It is important to note that correlations reported for $n = 8$ should be considered with caution due to the small sample size.

### 7.5.1 Entry Survey and Game Metrics

The more familiar participants were with video games, the more zones they visited ($r = 0.470$, $n = 20$, $p < 0.05$), the more quests they completed ($r = 0.463$, $p < 0.05$), and the more checklist items they completed ($r = 0.517$, $p < 0.05$). Similar correlation was found for familiarity with mobile video games, with additional strong positive correlations to level-ups ($r = 0.511$, $p < 0.05$), visiting the profile and statistics screen ($r = 0.548$, $p < 0.05$), and number of sessions

($r = 0.494$, $p < 0.05$). Familiarity with video games resulted in more interaction with elements common to games like levelling-up.

Age did not correlate with any of the game metrics, which was unexpected since it was anticipated to be a factor in how much the participants would interact with the game. Gender, however, did impact game usage. Females overall had more play time (Mann–Whitney $U = 24.5$, $n_1 = 11$, $n_2 = 10$, $p = 0.035$ two-tailed), and longer average session lengths (Mann–Whitney $U = 24.5$, $n_1 = 11$, $n_2 = 10$, $p = 0.035$ two-tailed). Females also pressed the help button more (Mann–Whitney $U = 28.5$, $n_1 = 11$, $n_2 = 10$, $p = 0.040$ two-tailed), pressed the map button more (Mann–Whitney $U = 25.5$, $n_1 = 11$, $n_2 = 10$, $p = 0.036$ two-tailed), and completed a wider range of game action types (Mann–Whitney $U = 20.5$, $n_1 = 11$, $n_2 = 10$, $p = 0.016$ two-tailed).

### 7.5.2 Exit Survey and Game Metrics

The household questions on the exit survey did not correlate with any of the game metrics. There was a high correlation between most exit survey questions and the get out of jail free card action, however this was likely skewed by the fact that there was only one instance of the get out of jail free card action. This action was recorded by user 11, who as stated previously was the only user to give positive scores on the exit survey.

### 7.5.3 Exit Survey and Entry Survey

The only question in the exit survey to correlate to the entry survey was question 17, "The energy resource in Energy Explorer was scarce". Question 17 was strongly negatively correlated to familiarity with video games ($r = -0.735$, $p < 0.05$), and familiarity with mobile video games ($r = -0.708$, $p < 0.05$). This may have been the result of competent video game players being able to use their energy resource more effectively.

Additionally, age strongly positively correlated to question 17 ($r = 0.793$, $p < 0.05$), which may indicate a level of frustration with running out of in-game energy amongst older users, who may have "wasted" their energy learning how to control their character.

### 7.5.4 Entry Survey and RBEES Household Survey

There was no significant relationship between the entry survey and the original RBEES household survey.

### 7.5.5 Exit Survey and RBEES Household Survey

The number of adults in the household as recorded by the RBBES household survey strongly positively correlated with a number of the BCT-informed exit survey questions, specifically the *social system* ($r = 0.754$), feeling like a *role model* ($r = 0.802$), *in-game improvement linked to* *energy behaviour* ($r = 0.754$), *social reward* ($r = 0.802$), *quests incentive* ($r = 0.721$), and *social reward incentive* ($r = 0.754$). Similarly, the number of children in the household positively correlated with the *social system* ($r = 0.754$), *in-game improvement linked to energy behaviour* ($r = 0.754$), and *social reward incentive* ($r = 0.754$). Having more people in the home appears to relate to more positive feelings toward the social aspects of *Energy Explorer*.

Reported computer usage according to the RBEES household survey was strongly negatively correlated with more positive exit survey responses (summarized by averaging participant responses for question 4 to 41, $r = -0.864$, $p < 0.05$). Players who used their computers less seemed to respond more positively to the *Energy Explorer* game elements.

Self-reported observation of energy usage increase for the 12 months prior to completing the RBEES survey in 2012 strongly positively correlated with positive responses to "I wanted to avoid missing out on bonus energy given for improving my energy behaviour" ($r = 0.745$). People who felt their energy usage was increasing tended to want to avoid missing out on bonus energy in the game.

Participants with more bedrooms in their home stated in the RBEES survey that they felt their household energy usage was "high" ($r = 0.791$). Larger households stated a higher level of mindfulness of energy usage than smaller households ($r = 0.724$).

Households that stated that they were an "energy conserving household" in the RBEES survey had a higher number of people in their home ($r = 0.856$), had larger homes ($r = 0.856$), were more influenced by social features in the game (question 9, $r = 0.788$; question 10, $r = 0.730$, question 13, $r = 0.730$; question 26, $r = 0.730$), and responded more positively to the player avatar in *Energy Explorer* (question 11, $r = 0.748$). Social features appeared to be of more interest to participants already conserving energy.

#### 7.5.6 RBBES Household Survey and Game Metrics

The number of children in the household strongly positively correlated to the number of quests completed ($r = 0.860$), the number of checklist items completed ($r = 0.775$), and the total number of actions recorded for a participant ($r = 0.723$). Amount spent on electricity per year was strongly positively correlated to the number of quests completed ($r = 0.905$), the number of checklist items completed ($r = 0.751$), and XP bubbles tapped ($r = 0.707$). Larger households in terms of children and energy spend appeared to interact with the quest and checklist features more than smaller ones.

### 7.5.7 Energy Consumption and Other Measures

Conservation effect (described previously in this chapter as average difference in consumption compared to the 20 most similar days using apparent temperature as a metric) was considered for pre-test/post-test periods 1 to 14 days after participants were given access to *Energy Explorer*. Entry survey, exit survey, and game metric data was analysed for correlation with these data points for each user using a Pearson product-moment correlation coefficient. Negative correlations indicate that an improvement in energy consumption was found. The following sub-sections present this information.

#### *7.5.7.1 Energy Consumption and Entry Survey*

When comparing a pre-test/post-test period of 8 days ($d = 8$), female participants had a mean conservation effect of −0.076kWh ($SD = 0.306$) compared to males who had a conservation effect of 0.114 ($SD = 0.175$). Using a Mann–Whitney U test, this difference was found to be significant ($U = 18$, $n1 = 9$, $n2 = 10$, $p = 0.030$, Figure 71). No other entry survey questions correlated with pre-test/post-test data.

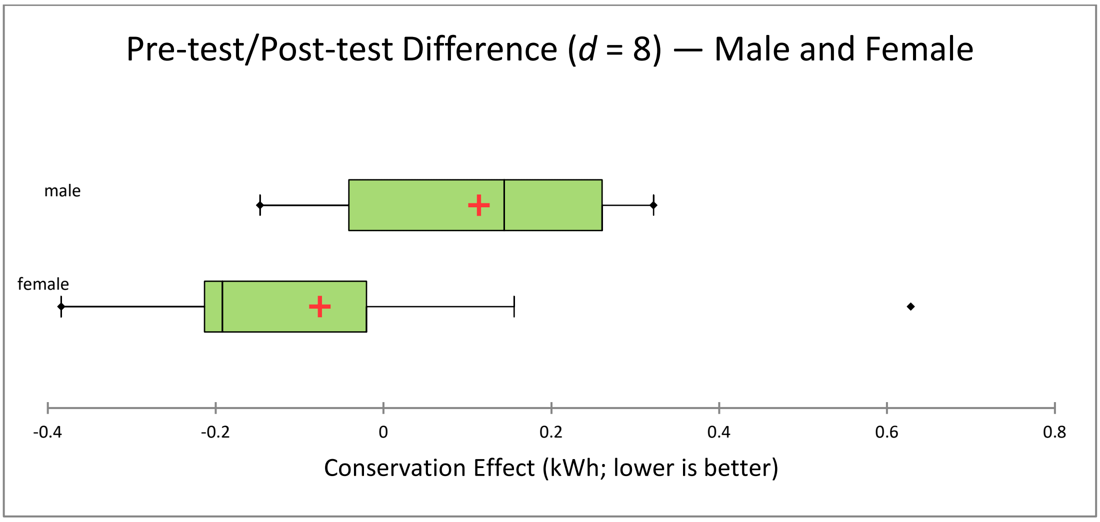



**Figure 71. Box plot of change between average conservation effect for the 8 days before playing the game, and average conservation effect for the 8 days after playing the game for males and females, showing that females used significantly less energy than males (within those who played the game).**

Gender was also discovered to be a determining factor for conservation effect on the first day participants were given access to the game. Female participants on the first day of playing *Energy Explorer* had a conservation effect of −0.027kWh (a decrease in consumption; $SD = 0.041$) for that day, compared to males who had an increase of 0.033kWh ($SD = 0.057$), which was found to be significantly different ($U = 18.0$, $n1 = 9$, $n2 = 10$, $p = 0.030$, Figure 72).

Significance found on the first day may be an indicator of participant *intent* to conserve energy to progress in the game.

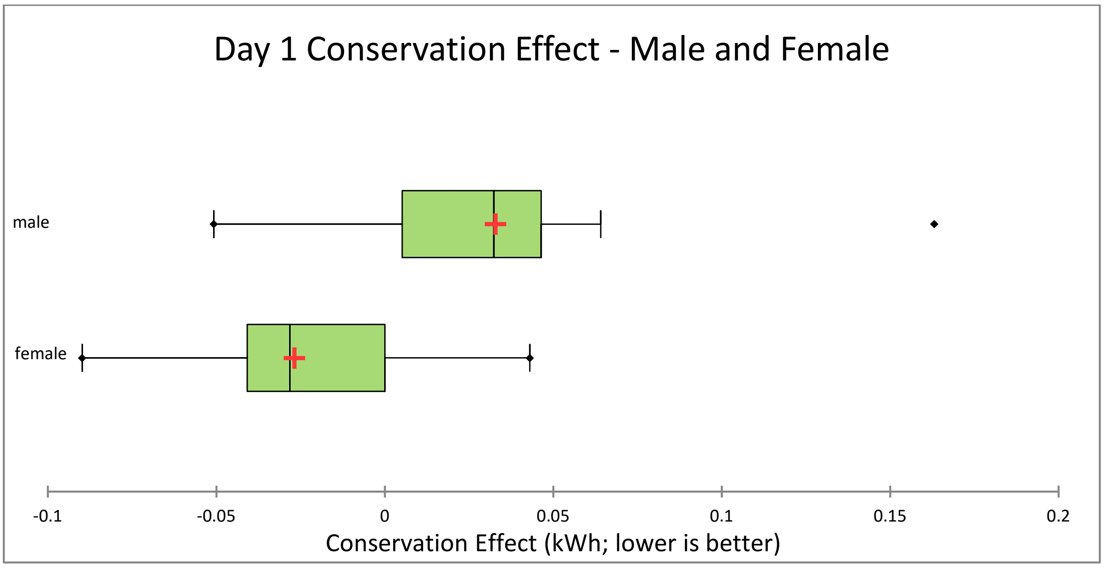



**Figure 72. Box plot of day 1 conservation effect between male and female participants, showing females used significantly less energy than males (within those who played the game).**

#### *7.5.7.2 Energy Consumption and Exit Survey*

Change in conservation effect between the 2 days before and after being given access to the game ($d = 2$) was strongly negatively correlated with the exit survey question "I wanted to avoid missing out on bonus energy given for improving my energy behaviour" ($r = -729$). The more that participants wanted to avoid missing out on the bonus reward the more they reduced their energy usage in the short term.

Change in conservation effect when $d = 3$ was strongly negatively correlated with exit survey questions on accomplishment (question 5, $r = -0.751$; question 7, $r = -0.715$; question 15; $r = -0.742$), meaning of actions (question 6, $r = -0.715$), avoidance (question 21, $r = -0.738$), and feedback (question 22, $r = -0.785$; question 23, $r = -0.775$). Similar correlation was found for $d = 4$ for accomplishment (question 5, $r = -0.784$; question 7, $r = -0.789$), meaning of actions (question 6, $r = -0.789$), avoidance (question 21, $r = -0.744$), and feedback (question 22, $r = -0.799$; question 23, $r = -0.791$).

Question 22 on in-game energy being used for feedback correlated not only for $d = 3$ and $d = 4$, but also for $d = 5$ ($r = -0.763$), and $d = 13$ ($r = -0.709$). Similarly, positive responses to question 24 on in-game experience points being used for feedback correlated strongly for $d = 6$ ($r = -0.717$), and $d = 12$ ($r = -0.723$). This indicates that people with more positive responses to feedback through game resources improved their energy usage. Note that in this case "positive" is a relative term, and the correlation may be referring to a difference between "disagree" and "strongly disagree."

No additional significance between conservation effect values of $d$ and other measures were found beyond what has been presented in this section.

#### *7.5.7.3 Energy Consumption and Game Metrics*

Conservation effect on the first day participants were given access to the game was strongly positively correlated with a small number of recorded game metrics. A strong negative correlation was found between day one conservation effect and the number of times a player levelled-up ($r = -0.475$), viewed the profile and statistics screen ($r = -0.624$), the variety of actions recorded ($r = -0.661$), average session length ($r = -0.608$), and average number of actions per session ($r = -0.542$). Players who played longer sessions had a higher conservation effect, although as we have seen in Section 7.4 conservation effect across all participants appears to be of a small magnitude.

Participant reduction in energy between the day before first playing *Energy Explorer*, and the first day playing the game was strongly negatively correlated with session count ($r = -0.475$), total time played ($r = -0.585$), pressing the checklist button ($r = -0.513$), pressing the resources button ($r = -0.601$), and running out of energy in the game ($r = -0.508$). This is interesting, as running out of energy can indicate that the user played the game a considerable amount, and a reduction in usage on the first day playing the game may be attributed to playing the game.

### 7.5.8 Summary of Relationships between Measures

Having more people in the home appeared to be related to having more positive feelings toward the social aspects of *Energy Explorer*. Players who used their computers less seemed to respond more positively to the *Energy Explorer* game elements. Social features appeared to be of more interest to participants already conserving energy, which is discussed further in Section 8.2.1.1.

Larger households in terms of children and energy spend appeared to interact with the quest and checklist features more than smaller ones.

Female participants on the first day of playing *Energy Explorer* had a better conservation effect than males. Significance found on the first day may be an indicator of participant *intent* to conserve energy to progress in the game.

The more that participants wanted to avoid missing out on the bonus reward the more they reduced their energy usage in the short term.

Short term change in conservation effect pre-test/post-test was related to accomplishment, avoiding punishment, meaning of actions, and feedback ($d = 3$, $d = 4$). People with positive responses to feedback through game resources improved their energy usage while playing the game a small amount.

Players who ran out of energy had a reduction in usage on the first day playing the game, which is interesting as these players may have witnessed more of the game features and content (as indicated by them running out of energy).

Again, it should be noted that relationships between variables should be considered with caution, given the small sample size.

## 7.6 Example Users

Given the small number of participants who opted to both play the game and complete the exit survey, additional analysis for particular cases was performed, to gain a clearer picture of the use of the the game by participants. Individual participants were selected for further analysis based upon a quantitative measure of how much they interacted with the game: the sum of the number of actions they completed in the game. Selection was limited only to participants who completed the exit survey ($n = 8$). Three cases were selected for further analysis:

- a *high-usage* case, determined by the user with the highest sum of actions, to investigate the impact of the game on a user who used the game a lot, and possibly enjoyed using the game;
- a *low-usage* case, determined by the user with the lowest sum of actions, to investigate an instance of a participant who did not interact with the game very much; and
- a *median-usage* case, determined by the user whose sum of actions was closest to the median of the sample ($n = 8$), to investigate how the game impacted a participant who neither used the game a lot, nor barely used the game.

The following three sub-sections explore each of these cases in detail. Within each section, a description of the participant household is given, the game usage (metrics) information is examined, the change in energy consumption is presented, and responses to the exit survey investigated.

### 7.6.1 High-Usage Example User

To investigate the impact of the game on a user who interacted with the game frequently, the participant with the highest action count was selected. The user with the highest action count was user ID 16 with an action count of 334[86] (for reference, the user with the second-highest action count was user ID 20 with 184). When considering users who did not complete the exit survey (therefore making investigation on those participants more difficult), the highest action count was still user ID 16, however the second-highest was user ID 41 (count = 236). The exclusion of participants who did not complete the exit survey therefore did not have an impact on selection for this use case.

#### *7.6.1.1 User Identity*

User 16 was registered by a 46-year-old female, on the 30th May 2016. The user's age was around the central values of the sample of users who played the game ($M = 48.1$, $SD = 9.492$). The date of registration was the first day that invitations were sent out, meaning that they responded quickly to the invitation to play the game. They were the 8th participant to complete the entry survey.

Like most participants, the high-usage case user responded to the entry survey with answers that suggested that they were familiar with video games and mobile video games. Their self-reported rating of their familiarity with video games was 8 out of 10, and they rated themselves as even more familiar with mobile video games, rating themselves the maximum score of 10. These familiarity ratings were well above the average self-reported ratings of familiarity with video games in general ($M = 6.0$, $SD = 3.146$) and familiarity with mobile video games ($M = 5.6$, $SD = 9.492$).

According to the user's exit survey responses, this participant lived in a larger house with a large number of occupants. The specific numbers are omitted here to maintain the anonymity of the participant; however the numbers were well above the average reported by participants (mean people in household = 3.3, $SD = 0.886$; mean rooms = 3.0, $SD = 0.756$), and were in fact the maximum values (only one other user also reported these same maximum values, from the sample of participants who played the game). The participant also indicated that they owned an air conditioner.

[86] For this stage of the analysis, some metrics were filtered out that were used to facilitate save game functionality. As a result this user's total action count for this analysis was 334, not the maximum value 364 as stated in section 7.2.

The participant was from the Australian state of Victoria, and stated that there was nobody home during school hours. They stated that their television and air conditioner (in summer) was used a few hours a day, and that their computer and heater (in winter) was used continuously. The participant stated that they did *not* take steps to limit their household use of energy, and although when asked about specific energy saving behaviours stated they rarely or never took part in them, however, they did flag that they *always* turned off lights in rooms not being used. They cited “comfort” as the main reason they did not partake in energy saving activities, said that their energy usage increased in the 12 months prior to taking the RBEES survey. The participant stated that they intended to take additional steps to reduce their energy in the 12 months after taking the RBEES survey.

The participant suggested that they were a high energy using household, and only “fairly mindful” of their energy usage.

The user who played *Energy Explorer* the most was essentially a high-user of energy, and rarely took actions to change their behaviour.

#### *7.6.1.2 Game Metrics*

As summarised in Table 25 and visualised in Figure 73, User 16 interacted with the game across 6 different days, and skipped one day (1st June 2016). The participant played predominantly on week-days, and stopped playing the game after 7 days of being given access.

| Date | Sessions | Total Actions | Minutes game open |
|---|---|---|---|
| 30/05/2016 | 5 | 133 | 41.42 |
| 31/05/2016 | 4 | 68 | 21.05 |
| 1/06/2016 | - | - | - |
| 2/06/2016 | 2 | 52 | 42.52 |
| 3/06/2016 | 1 | 5 | 2.28 |
| 4/06/2016 | 1 | 15 | 1.38 |
| 5/06/2016 | 2 | 61 | 18.35 |
| **Sum:** | **15** | **334** | **127.00** |
| **Mean (SD):** | **2.5 (1.64)** | **55.7 (45.60)** | **21.2 (18.01)** |

**Table 25. Summary of game usage for the high usage case.**

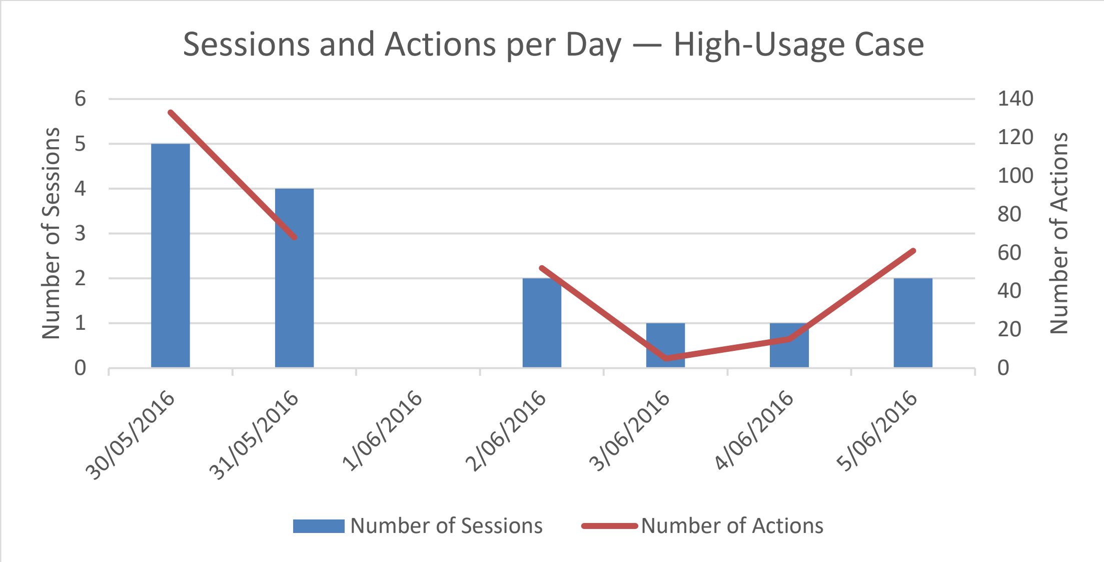



**Figure 73. Visual representation of game usage for the high-usage case.**

Over the seven-day period where the participant interacted with the game, there was a strong positive correlation between the number of sessions in a day and the number of actions the participant took in day ($r = 0.942$, $n = 7$, $p < 0.002$). There was also a strong positive correlation between the number of sessions in a day and the number of minutes the game was open in day ($r = 0.743$, $n = 7$, $p = 0.056$), and a strong positive correlation between the number of actions in a day and the number of minutes played in a day ($r = 0.829$, $n = 7$, $p = 0.021$).

Figure 74 shows the specific actions taken by user 16. Of note, they interacted with the quest and checklist components the most, completing 7 quests, more than most other users ($M = 3.1$), and completing 23 checklist items ($M = 7.3$). Indeed user 16 had the highest action count for most actions except for the number of times the map was viewed, the number of times the zone info was viewed, the number of times the profile page was viewed, the number of times a tree was chopped down, and the actions for which there was a 0 count, including the get out of jail free option, the number of times a bonus reward was given, interaction with the "above average" rewards, and interaction with notifications. It is interesting to note that the highest use case came from a user who did not receive any notifications, and did not interact with the "above average" reward system.

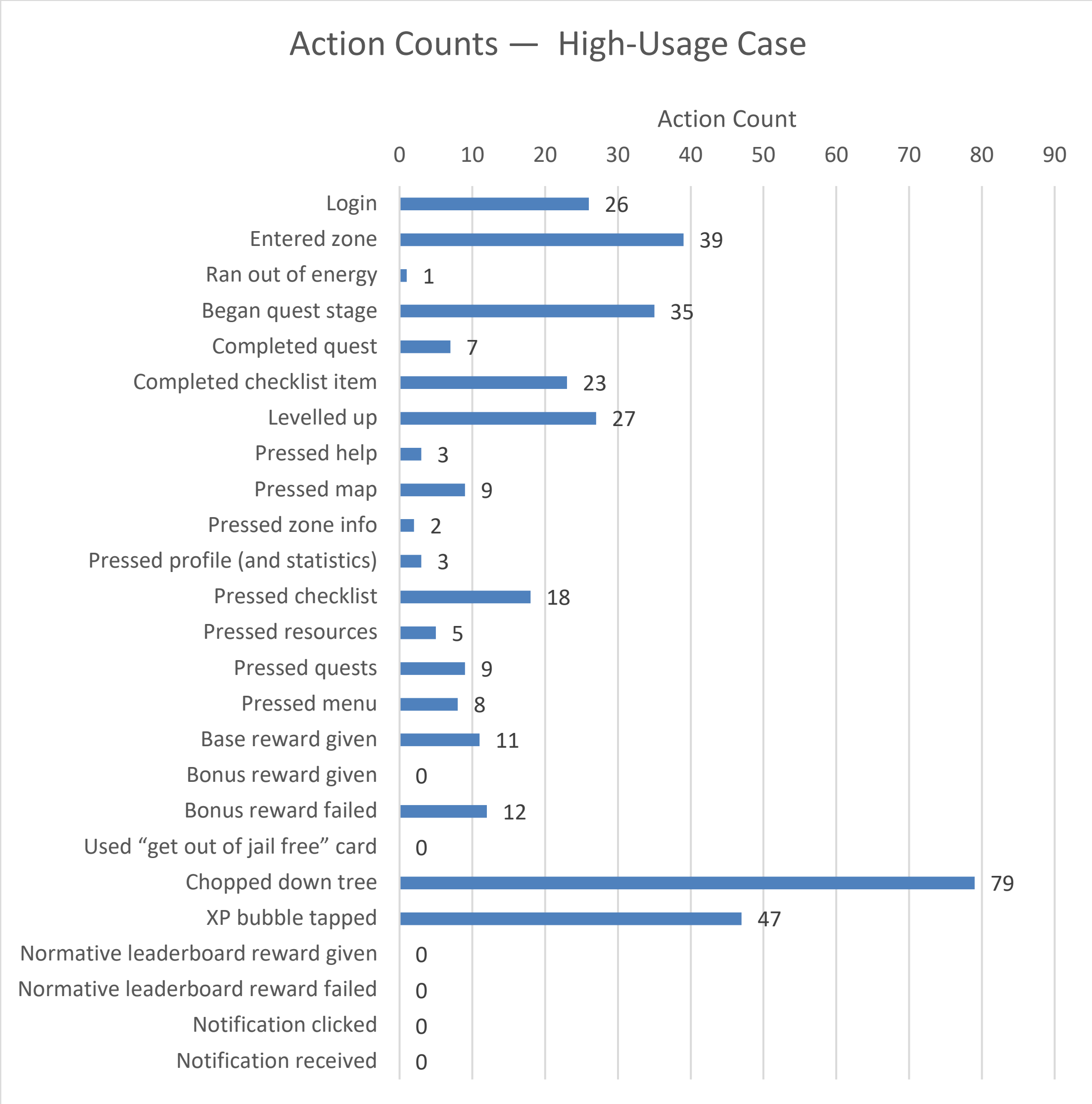



**Figure 74. Summary of game metric data for the high usage case.**

#### *7.6.1.3 Energy Consumption*

Conservation effect described in Section 3.3.5 was conducted for this user. Figure 75 shows for each day the conservation effect for that day, and plots this against the number of game-actions the player took on that day. It can be seen that on the first 5 days after being exposed to the game, the participant's usage was lower than the average of the 20 similar days, including a day where the participant used 7.5kWh less than the average.

The conservation effect for the 14 days prior to being given the game and conservation effect for the 14 days after being given the game (inclusive of the first day of having access to the game) were compared. The average conservation effect for the 14 days before playing the game was 0.78kWh (SD = 3.594), compared to −0.481kWh for the 14 days after playing the game. This difference however was not found to be significant.

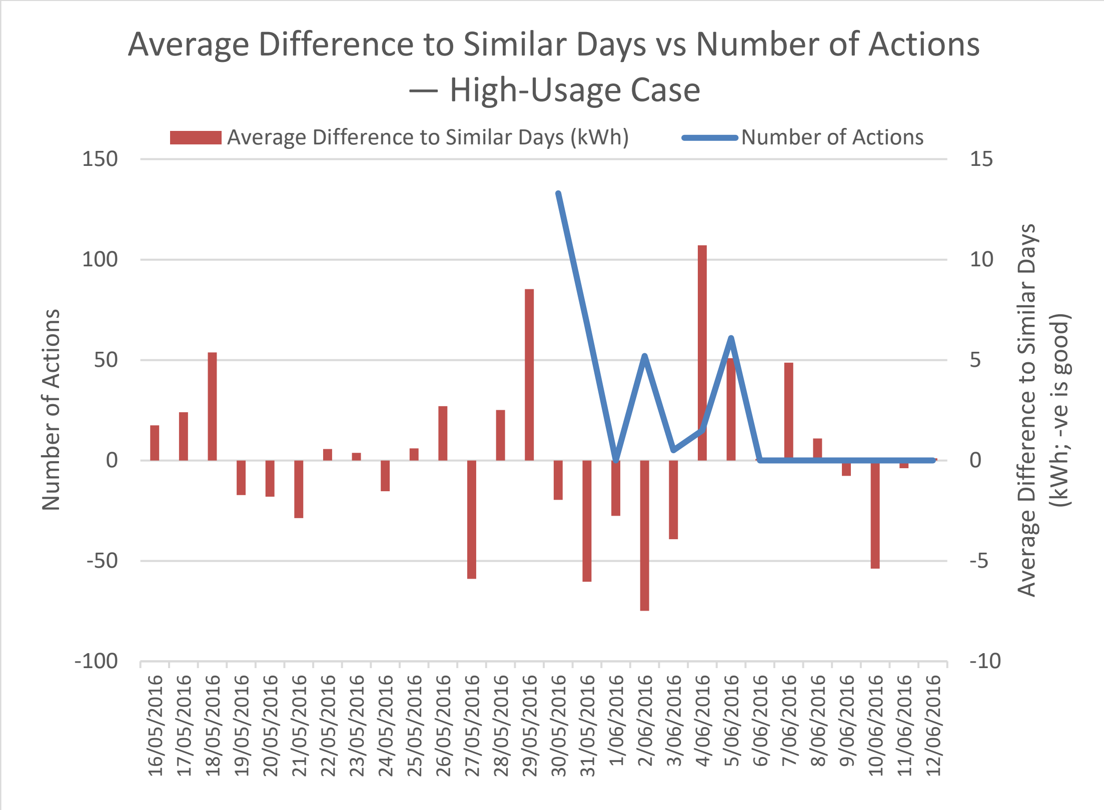



**Figure 75. Difference in energy consumption to similar days per day with game usage overlayed for the high-usage case. The first day playing the game was the 30th of May 2016, as indicated by the start of the blue line.**

#### *7.6.1.4 Game Experience*

Despite playing the game the most out of all other participants who completed the exit survey, this example user ultimately entered a response of "strongly disagree" for every exit survey item, indicating negative response to the game's behavioural characteristics. The user took 4 minutes to complete the survey.

#### *7.6.1.5 Summary of High-Usage Example User*

The high-usage example user played the game for a total of 127 minutes over 7 days. The household did not identify as energy conserving, and generally did not often partake in energy curtailment behaviours. The player responded "strongly disagree" to all exit survey questions on game experience, and did not exhibit a significant difference in conservation effect pre-test/post-test.

### 7.6.2 Low-Usage Example User

To consider the instance of a participant not interacting with the game very much, the participant with the lowest action count was selected. The user with the lowest action count was user ID 29 (count = 23; for reference the second-lowest action count was user ID 13 with a count of 30). When considering users who did not complete the exit survey (therefore making investigation on those participants more difficult), two users had a lower action count than user ID 29: users 34 (count = 16) and 42 (count = 21). Since the action counts of these excluded participants were similar to the selected participant, the exclusion of participants who did not complete the exit survey did not have a considerable impact on selection for this example user.

When exploring the specific game actions of the user ID 29, it was discovered however that the user did *not* get to experience any of the game mechanics (e.g. exploring the game world). This was indicated by a count of 0 for the game metric "entered zone", which should at least have a count of 1 for entering the tutorial zone. Their recorded 23 actions revealed a pattern of trying various interface buttons which were visible whilst the game world itself was not visible. As a result, the user who completed the exit survey with the next lowest action count was considered; user ID 13. However, this user also was discovered to have the same problem. Again, the user with the next lowest action count was considered; user ID 35. User ID 35 *was* found to have usable game metric data. Their action count was 34. When considering users who *did not* complete the exit survey (therefore making investigation on those participants more difficult) *and also did not* have the aforementioned unusable game metric data, the lowest action count was 24. Since the action counts of these excluded participants were similar to the selected participant, the exclusion of participants who did not complete the exit survey did not have a considerable impact on selection for this use case.

#### 7.6.2.1 User Identity

The low-usage example user was registered by a 41-year-old male, on the 17th June 2016. The user's age was below the central values of the sample of users who played the game ($M$ = 48.1, $SD$ = 9.492). This user was registered as part of a second phase of invites, meaning they did not respond to the initial invitation. They were the 22nd participant to complete the entry survey.

The low-usage example user had played a video game and mobile video game before, and their self-reported rating of their familiarity with video games were just above average; for regular video game familiarity they scored themselves an 8 out of 10 (sample $M$ = 6.0, $SD$ = 3.146), and rated their familiarity with mobile video games slightly lower at 7 out of 10 (sample $M$ = 5.6, $SD$ = 9.492).

This participant reported high values for house size and occupancy size, although lower than the high-usage case (again, omitted here for the purposes of anonymity). These numbers were well above the average reported by participants. Their reported number of people in the household was the maximum value. The participant also indicated that they owned an air conditioner.

This participant was from the Australian state of Queensland, and stated that nobody was home all day in their household. While the participant stated that their computer was used continuously, and the television used a few hours a day, their air conditioner was only used once a week in summer, and their heater used once a month in winter. The low-usage example user stated that they took steps to limit their household energy, and said they "often" or "always" undertook the example energy conservation activities on the RBEES survey[87], for the reasons of "economic benefits", "concern about the environment", "maintaining comfort", and "making a positive contribution". The participant said they would continue their energy conservation efforts, but not partake in any additional actions to save energy (both curtailment and effectiveness).

The participant suggested that they were a low energy using household, and "very mindful" of their energy usage.

It is interesting to see that the player who used *Energy Explorer* the least (and still completed the exit survey) was someone who was overall a low energy user who conserved energy frequently. The user may have felt they could not do any more to conserve energy.

#### *7.6.2.2 Game Metrics*

User 35 completed a total of 3 game sessions across two consecutive days (a Friday and Saturday). As shown in Table 26 and summarised by Figure 76, they completed 2 sessions on the first day, and a single session on the second day.

[87] These were "turning appliances off at the power point when not in use", "washing clothes in cold water", "shortening the length of your shower", "closing off areas that do not need to be cooled in summer/heated in winter", "using fans instead of an air conditioner", "switching off lights in rooms not being used", "only putting on washing machine or dishwasher with a full load", "shutting blinds/curtains during the day in summer to reduce heat getting into the home", "not having air conditioner so cold in the summer or the heater so hot in the winter", and "buying electrical appliances that have a high energy efficiency star rating".

| Date | Sessions | Total Actions | Minutes game open |
|---|---|---|---|
| 17/06/2016 | 2 | 23 | 4.38 |
| 18/06/2016 | 1 | 3 | 1.02 |
| **Sum:** | **3** | **26** | **5.40** |
| **Mean (SD):** | **1.5 (0.70)** | **13.0 (14.14)** | **2.70 (2.38)** |

**Table 26. Summary of game usage for the low-usage case.**

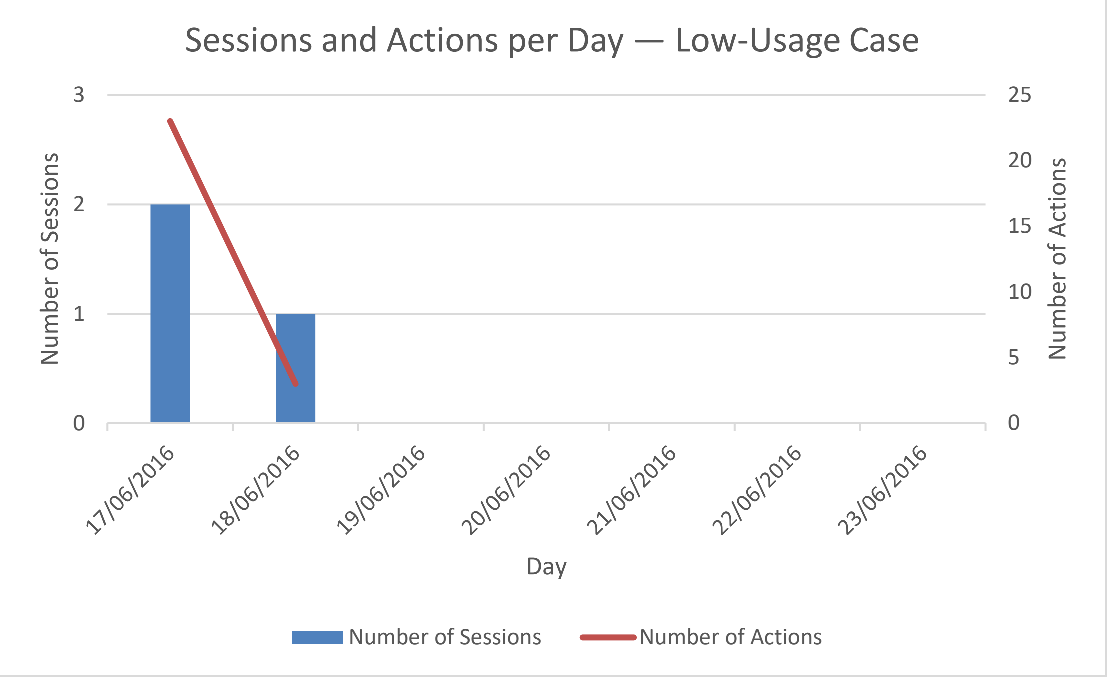



**Figure 76. Visual representation of game usage for the low-usage case.**

Figure 77 shows a breakdown of the specific game actions user 35 completed. The low-usage case experienced the bare minimum of content within the game, only completing 3 checklist items, and indeed never finishing even the opening quest to the game. The user was able to interact with trees in the game, however never (successfully) logged in enough times to interact with some of the social features of the game. It is likely that this user encountered issues with loading the game on their device, given the disproportionate number of logins to sessions.

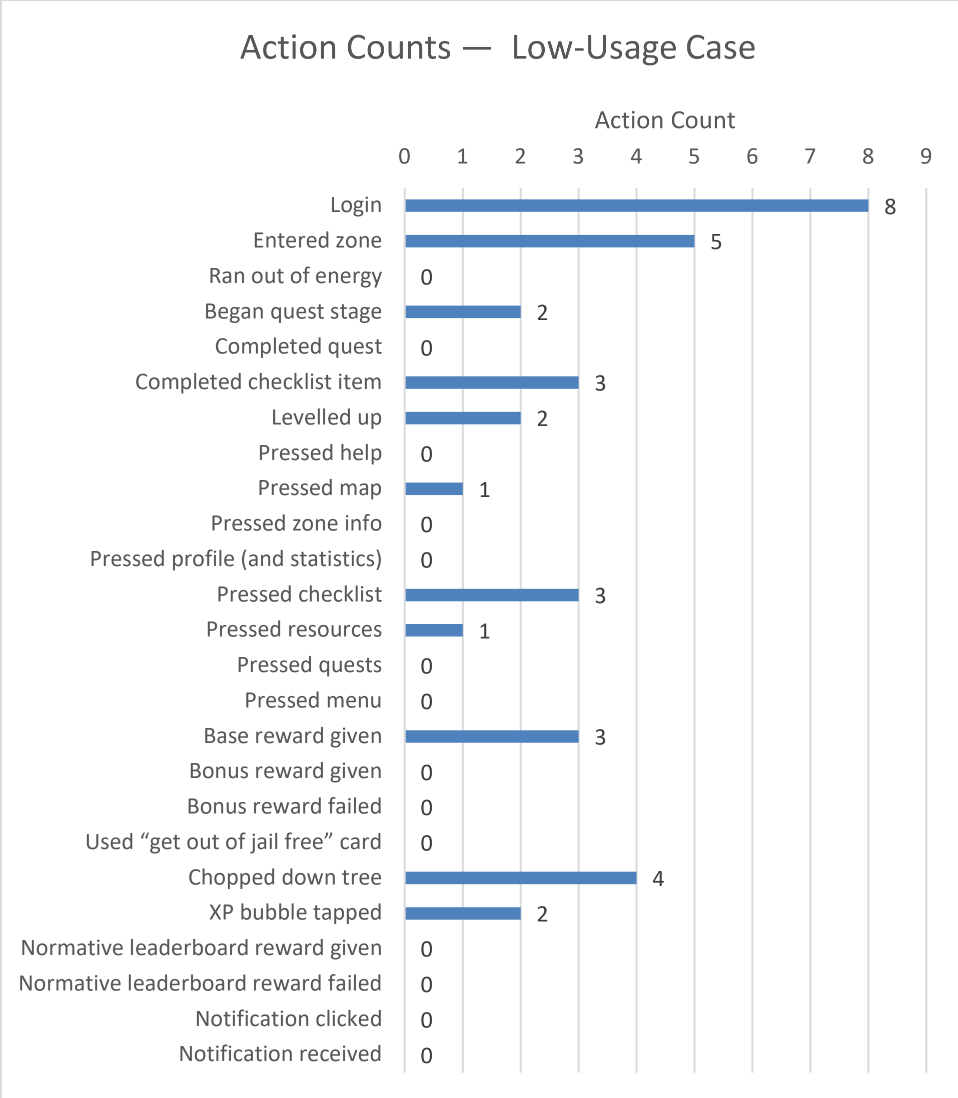



**Figure 77. Summary of game metric data for the low-usage case.**

#### *7.6.2.3 Energy Consumption*

It is clear from Figure 78 that conservation effect remained steady around the time that the user played *Energy Explorer*. However, there does appear to be a delayed reduction a few days after the game. Given how little the user interacted with the game, it is likely this reduction was caused by something other than the game.

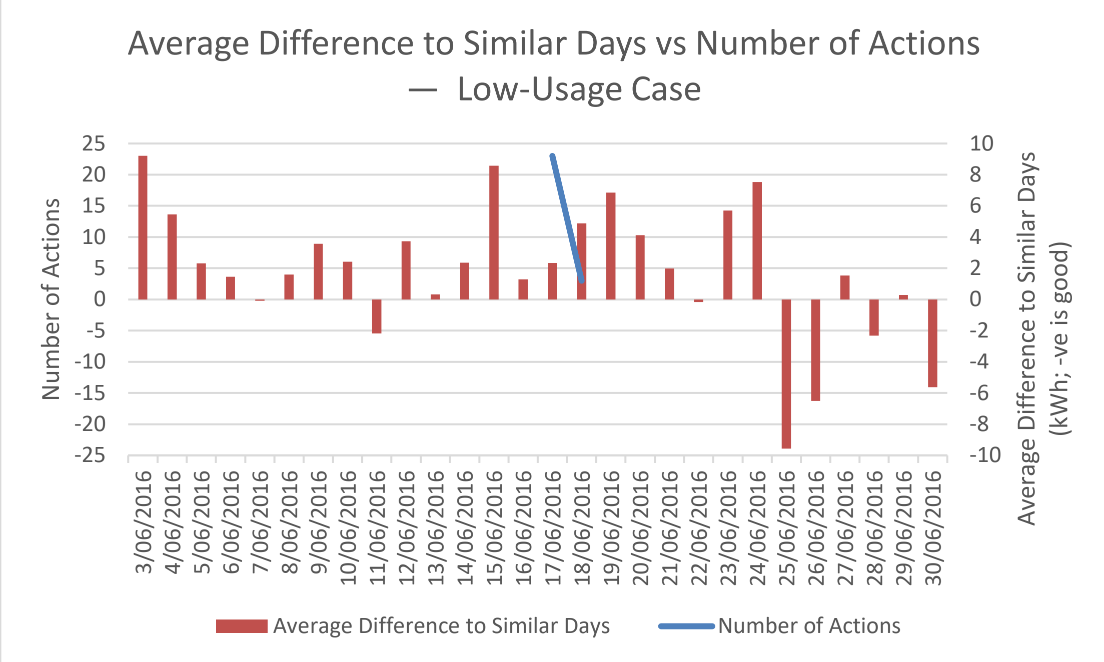



**Figure 78. Difference in energy consumption to similar days per day with game usage overlayed for the low-usage case.**

#### *7.6.2.4 Game Experience*

The low-usage example user gave more positive responses than the high-usage example, however still generally disagreed with the statements presented ($M = 2.1$, $SD = 0.56$). The participant never answered higher than "neutral" (answered 10 times). The participant gave 25 "disagree" responses, and 3 "strongly disagree" responses. The strongly disagree responses solely referred to "other players" (questions 9, 28, and 33), which makes sense as the user did not interact with the social features of the game.

#### *7.6.2.5 Summary of Low-Usage Example User*

The low-usage example user only participated in 3 game sessions, and played the game for a total of 5.4 minutes. With only 26 game actions recorded, this example user outlines the extent to which some users failed to interact with the game, and indeed no significant difference pre-test/post-test was found. The participant recorded more positive responses on the exit survey then the high-usage example, although the responses were still aligned with general disagreement with the statements in the survey.

This user considered their household very mindful of energy conservation, and one that often partakes in energy conserving actions. They stated that they were willing to continue their conservation actions, but not undertake any new ones. As a result, they may have been unwilling to participate in additional interventions. This user may have already been operating at optimal conservation capacity, and found the game provided little addition to their household. It is equally possible that game software issues were encountered by this user, which limited their ability to use the game (discussed further in Section 8.2.4).

### 7.6.3 Median-Usage Example User

The participant to investigate for the median-usage case was determined by selecting the participant whose action count was nearest to the median value for the action count variable. The median value for action count was 80.5, however since this was calculated for a population of 8, the median calculation used the mid-point between two participants (user ID 6 = 122; user ID 28 = 39). To split the tie, the participant whose action count was closest to the average value of the action count variable was used. The average action count was 115.38, thus user ID 6 was selected for the median-usage case.

#### *7.6.3.1 User Identity*

The median-usage example user was registered by a 36-year-old female, on the 30th May 2016. The age of this user was well below the average of the sample of users who played the game ($M = 48.1$, $SD = 9.492$), in fact they were the second-youngest registered user. The date of registration was the first day that invitations were sent out, meaning that they responded quickly to the invitation to play the game. They were the 2nd participant to complete the entry survey.

The user's entry survey responses were the maximum values for video game and mobile video game familiarity (i.e. 10).

The number of rooms above the average reported by participants ($M = 3.0$, $SD = 0.756$), and the number of people in the participant's household was close to the average value of the rest of the sample ($M = 3.3$, $SD = 0.886$). The participant also indicated that they owned an air conditioner.

This participant was from Queensland, and stated that someone was home all day. The participant stated that their computer was used continuously, whereas their television and air conditioner was only used a few hours a day. In winter, they used the heater once a week. They stated that they took steps to limit their household energy, and responded with "sometimes" and "often" to most of the energy conservation examples. Again, the reasons for the conservation were "economic benefits", "concern about the environment", and "making a positive contribution". The participant felt their energy consumption had decreased in the 12 months before completing the RBEES survey, and the participant said they would continue their energy conservation efforts, however only as curtailment behaviours, not effectiveness (i.e. more efficient appliances).

The participant suggested that they were a medium energy using household, and "very mindful" of their energy usage.

#### *7.6.3.2 Game Metrics*

The median case user completed 3 total sessions, on two consecutive days (Table 27). The first two sessions occurred on a Monday, and the final session was on the next day; Tuesday. As Figure 79 shows, the third session had 64.4% more actions than the first two sessions combined. Given there are only two data points, correlation statistics were not performed on this data. The user played the game for a total of 28.55 minutes.

| Date | Sessions | Total Actions | Minutes game open |
|---|---|---|---|
| 30/05/2016 | 2 | 45 | 10.83 |
| 31/05/2016 | 1 | 74 | 17.71 |
| **Sum:** | **3** | **119** | **28.55** |
| **Mean (SD):** | **1.5 (0.70)** | **59.5 (20.50)** | **14.27 (4.87)** |

**Table 27. Summary of game usage for the median-usage case.**

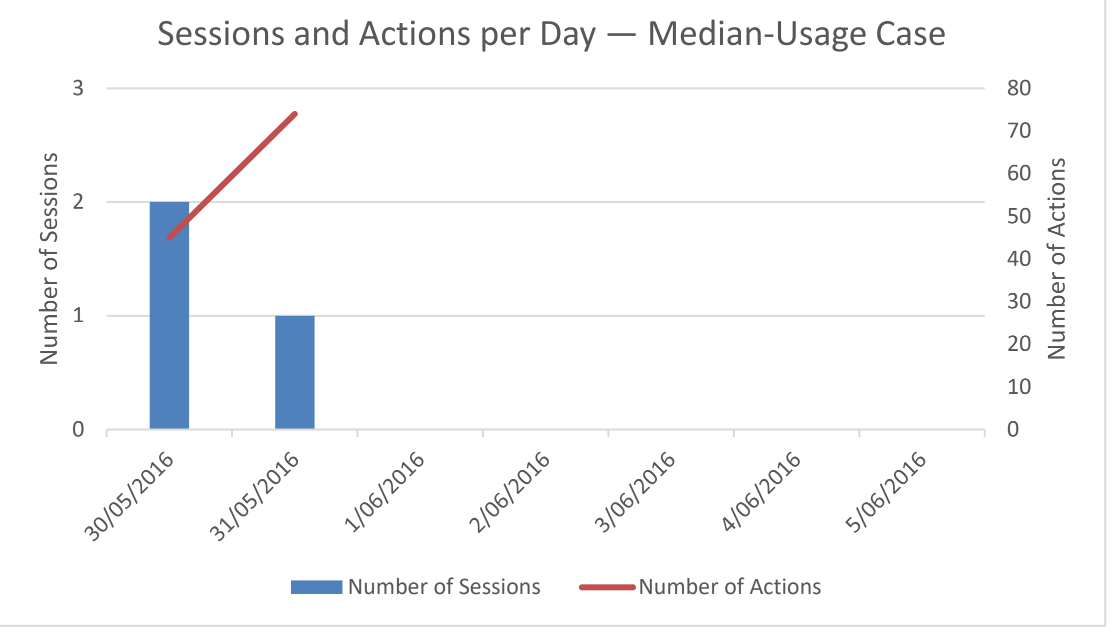



**Figure 79. Visual representation of game usage for the median-usage case.**

Figure 80 presents an individual breakdown of the user's game actions. Interestingly, this user did not run out of energy during any of their sessions. This user viewed the profile page more times than any other user, and completed 3 quests, which indicates a reasonable amount of interaction with the game content.

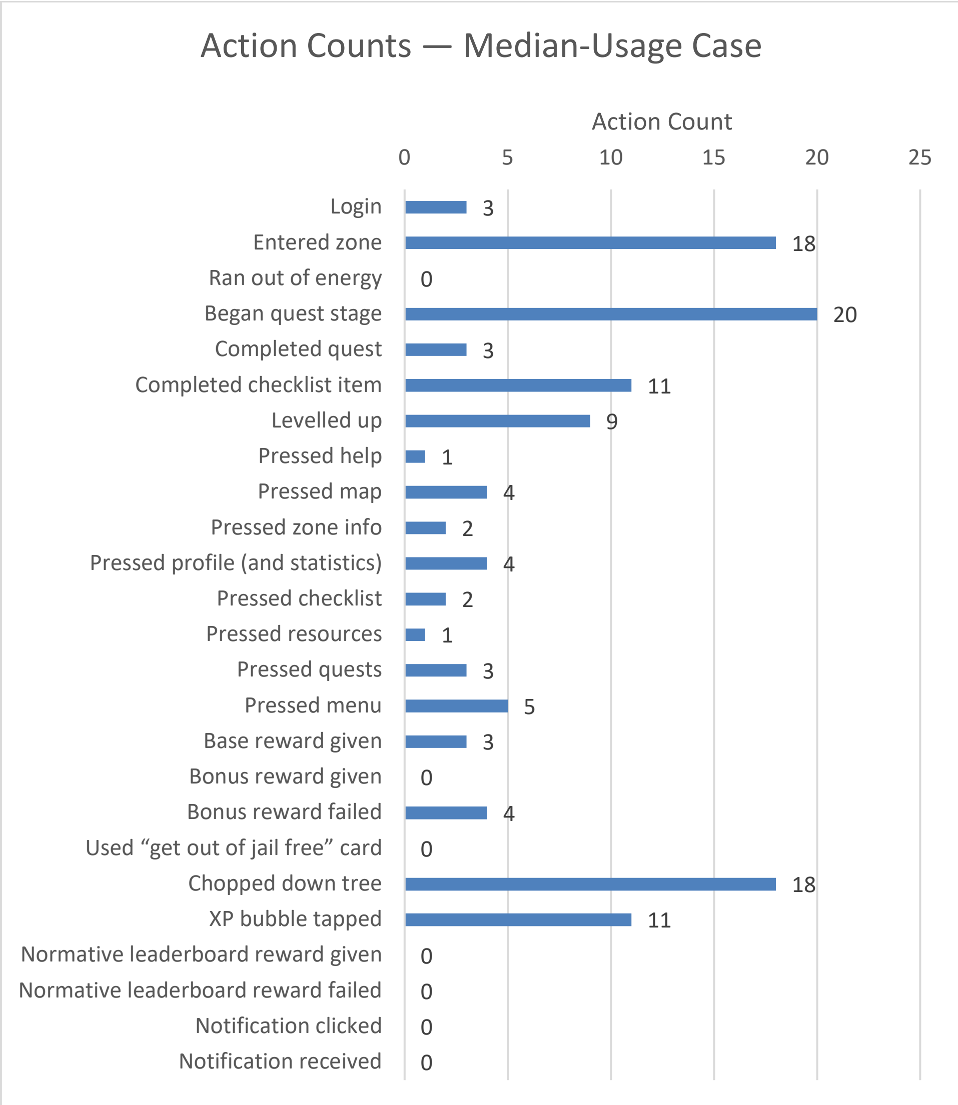



**Figure 80. Summary of game metric data for the median-usage case.**

#### *7.6.3.3 Energy Consumption*

Figure 81 shows for 12 of the 14 days after being given the game, their energy consumption was lower than the average of the $n = 20$ similar days for each of those days. However, the user was also consistently exhibiting a conservation effect before playing the game, and as a result, a significant difference pre-test/post-test was not found.

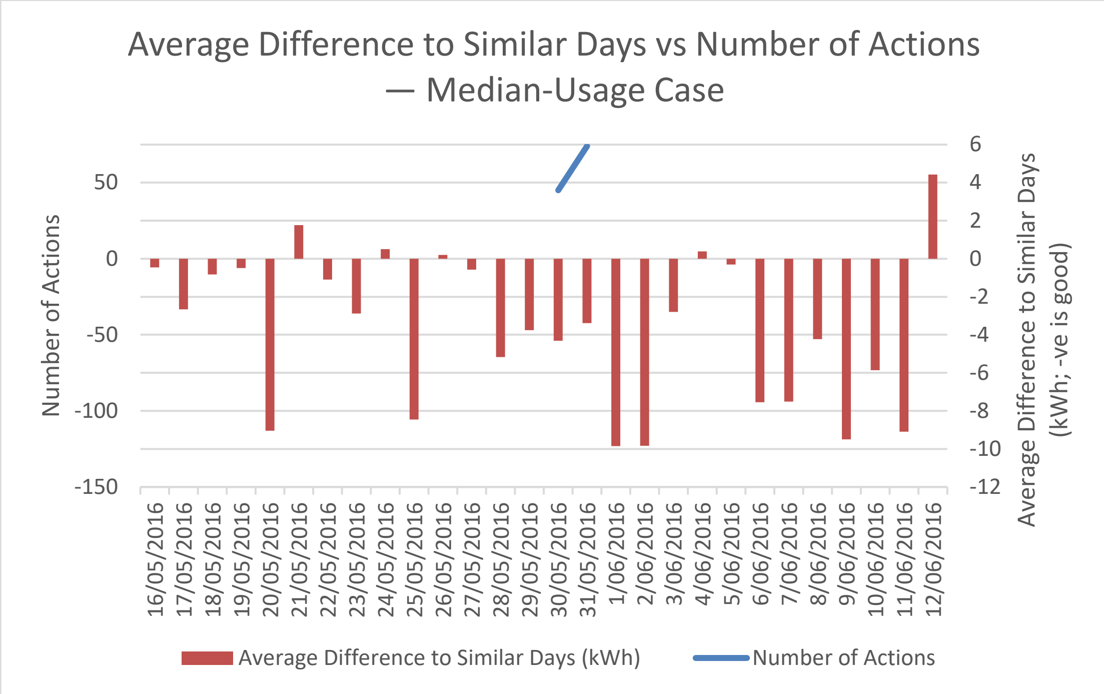



**Figure 81. Difference in energy consumption to similar days per day with game usage overlayed for the median-usage case.**

#### 7.6.3.4 Game Experience

For all of the Octalysis framework questions, the median-usage example user responded with "strongly disagree", and this was generally the case for the entire exit survey ($M = 1.2$, $SD = 0.74$). The only question this user "strongly agreed" with was question 18 "the treasure chest rewards in the game were unpredictable", which was essentially a factual response, as there was no way of knowing what a treasure chest in *Energy Explorer* would contain.

#### 7.6.3.5 Summary of Median-Usage Example User

The median-usage example user was another "very mindful" household when asked about energy conservation, although they did not report to partake in as many energy curtailment behaviours as the low-usage case. This user also played the game for 3 sessions, however many more actions were recorded than the low-usage case, and the total time played was 28.55 minutes. The participant used on average 5.0kWh less energy than similar days. When responding to the exit survey, again mostly "strongly disagree" responses were recorded.

### 7.6.4 Summary of Example Users

Three specific participants from the 8 who completed the exit survey were selected for further analysis based upon the number of in-game actions they participated it. A high-, low-, and median-usage player were each examined. Details about the participant and their household were provided (from both the entry and RBEES surveys), as well as analysis of their game usage, exit survey responses, and energy consumption.

The high-usage example user played the game for a total of 127 minutes over 7 days, whereas the low-usage case only played for 5 minutes. The median-usage case played for 28.55 minutes, although this was only over the same number of sessions as the low-usage case (3).

The low- and median-usage example users were generally energy conserving households, compared to the high-usage example. It is possible that the lower-usage cases felt that they were already operating at the optimal conservation capacity, and this concept is discussed further in Section 8.2.1.1.

When examining conservation effect within-participants, significant differences were not found. Generally, responses from the example users to the exit survey were negative, and surprisingly the most positive responses were given by the low-usage case.

## 7.7 Chapter Summary

This chapter has presented the results of the experiment conducted to test the effectiveness of the *Energy Explorer*. Results for the entry and exit surveys, game metrics, and energy consumption were described, and the relationships between these measures presented. The chapter concluded by looking at example users individually, selected by their usage of the game.

A significant difference in conservation effect change for participants in the treatment group compared to the control group was found when comparing 14 days before and 14 days after playing *Energy Explorer* ($U = 1567$, $n1 = 128$, $n2 = 19$, $p = 0.043$). Female participants on the first day of playing *Energy Explorer* also had a significantly better conservation effect than males.

Most participants stated they were familiar with mobile video games, and the average age of participants was 48.1. As participant age increased, familiarity with video games reduced. This elevated age of participants is discussed in the next chapter.

A total of 1,666 game actions were recorded (on average 83.3 actions per player), and the average total time playing the game was 23.4 minutes. Participants witnessed most features of the game, however did not play the game as much as was hoped. Participants generally disagreed with statements in the exit survey saying that game elements facilitated certain Behaviour Change Techniques.

High-, low-, and median-usage example users were examined. The low- and median-usage example users were energy conscious households, whereas the high-usage case was less conscious of energy conservation. The discussion in the next chapter explores how it is possible that these users were already conserving as much energy as they could, and felt the game offered no additional value to them.

Whilst this chapter has explored the results of the deployment of the Serious Game from a statistical point of view, this only provides some of the story. The next chapter draws upon the metrics and statistics seen here to build an empirical set of recommendations that are grounded in the real-world challenges experienced in delivering a Serious Game for energy conservation.

# 8 Discussion

Designing a Serious Game using the Behaviour Change Wheel methodology as a starting point was not only a novel task, it was also a challenging one. Whilst the results of this particular implementation of the Serious Game design showed only a small magnitude change in energy consumption by participants, it is possible that following a design process using the BCW may still bring about Serious Games superior to games designed without it due to the link to behavioural theory. Therefore, this chapter presents a detailed account of the challenges and lessons learned from this important process, in the hope that future researchers in the area of Serious Games may have a greater understanding of the intricacies of it. The discussion of these challenges is further strengthened by describing the issues faced when implementing and testing a game designed for energy conservation, again in the hope that future researchers considering testing a game for this purpose (or any other serious purpose) may be able to identify potential pitfalls before running their experiments. Figure 82 shows how this chapter represents the dissemination component of the Intervention Research model by Rothman & Thomas (1994).

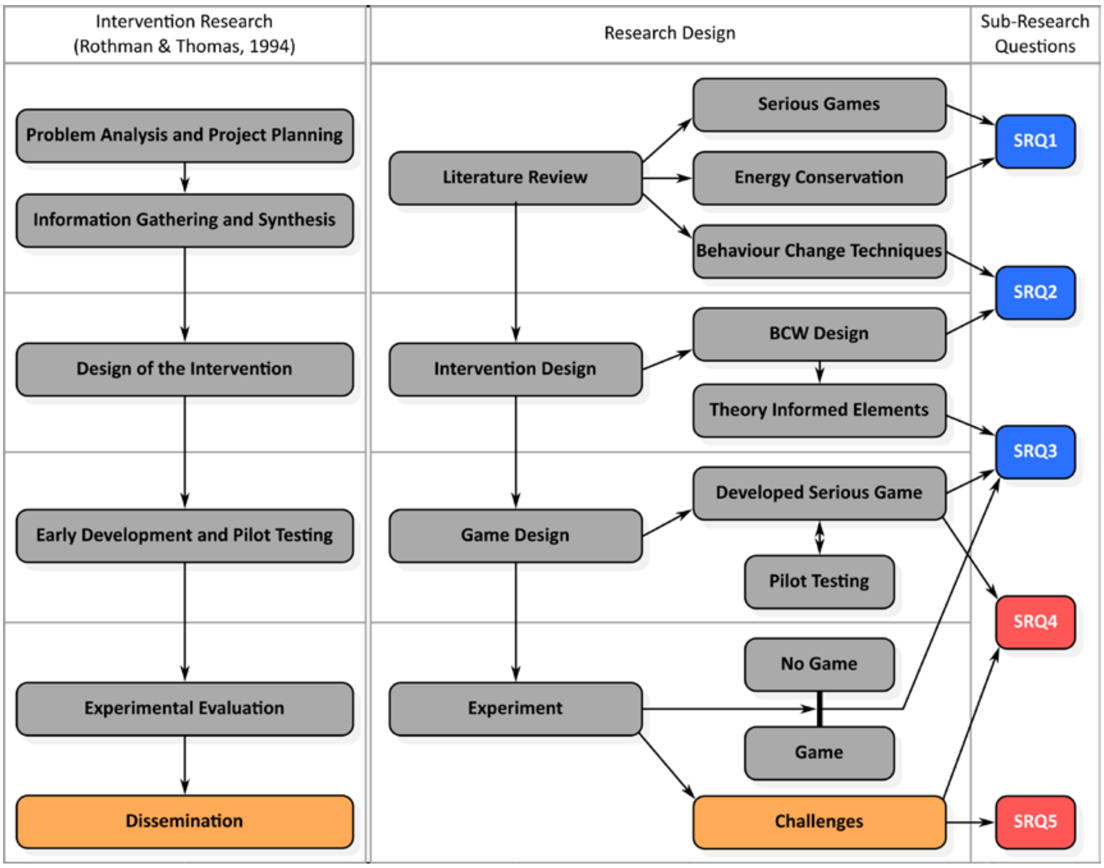



**Figure 82. The project methodology diagram, showing the component covered in in this chapter: the discussion of the challenges encountered during this project.**

This chapter is split into two core components, first challenges relating to the design process are described (addressing *SRQ4*) before practical issues with the implementation (addressing *SRQ5*).

## 8.1 Practical Lessons Learned from Design Phase

Developing a Serious Game using the Behaviour Change Wheel methodology involved many steps, and required a multidisciplinary approach. In addition, it was a process that had never been undertaken before, and so there is value in not only presenting the approach, but openly discussing the issues that arose while undertaking it. This section explores the challenges involved while conceptualising and designing the Serious Game, whereas the issues involved in the implementation and deployment of the game *Energy Explorer* are covered by Section 8.2.

### 8.1.1 Behaviour Change Wheel Not Used for Serious Games Before

Significant work was undertaken in the thesis to align the BCW to the domain of Serious Game design for energy conservation, and this has never been attempted before. Further work in this area could be guided by the findings in this thesis along with closer engagement with experts in the application of Behaviour Change Techniques.

At the time of writing, the BCW has primarily been used for health-related interventions—perhaps a consequence of the field of expertise of Michie and her co-authors being in health. As a result, there exist no examples of how one might transfer the BCW methodology to other areas that require knowledge of behaviour as a first step in creating an intervention. As a result, much of the design work associated with this project could be considered exploratory, in so much as the adaptation of the BCW to games for energy conservation was undertaken based on a common-sense transfer of understanding of the BCW and how it's stages might be understood into the context of energy conservation.

The only way to mitigate this problem is to continue research into applying the BCW to Serious Games. Given the wide range of domains that Serious Games can be applied to, future research is not limited to only the energy conservation domain. Upon reflection, the entire design process using the BCW could have benefited from continuous input and feedback from experts in the area of psychology and behaviour change who may be more familiar with the intricacies of the concepts covered by the BCW.

In terms of recommendations to for future work, researchers are advised to participate in discourse with experts in the field of behaviour change, and the target domain. Similarly, the challenges presented in this section could be mitigated by engaging in participatory design (see Section 8.1.8).

Using the set of recommendations discussed throughout this chapter, future research will be able to build upon the lessons learned in this work.

### 8.1.2 Lack of Linkage between Behaviour Change Techniques, Behaviour Change Theory, and Mechanisms of Action

At time of writing there is no extant literature defining a clear link between the Behaviour Change Techniques defined by Abraham & Michie (2008), and the taxonomy of Behaviour Change *Theories* in literature by Michie, West, et al. (2014). Recall that the BCTs simply indicate the type of action, while behaviour change theories provide a guide to achieving a behavioural outcome.

Personal communication from Susan Michie herself confirmed that this linkage was still in development at the time the intervention for this project was being designed (2014). Two years later, research from Michie's team (Connell et al. 2015) has begun formalizing this linkage, however the results are still preliminary in nature. The links were made by systematically reviewing more than 700 behaviour change interventions. They found that studies predominantly explained linkages between BCTs and theory, however the link between BCTs and mechanisms of action (MoA) were often poorly defined. Further research is now focussing on linking BCTs and plausible MoA. Four studies so far have examined the literature, and these are summarised by Johnston et al. (2017), and again, the results are still preliminary, and not immediately applicable to Serious Games.

With respect to *Energy Explorer*, this lack of a link between the required techniques and the theory through which to action it caused uncertainty in the interpretation of which theory (or theories) could best describe the chosen BCT. Since the selected theory helped guide the choice of game elements for inclusion in the Serious Game, this led to doubt as to whether suitable elements were chosen, and if they were implemented correctly.

In terms of providing guidance for future work, researchers are recommended to stay up-to-date on further work on improving the BCW through the new links for BCTs, in order to gain a better understanding of the BCTs they are implementing through their games. Such improvements to the BCW is likely to be in the form future work on MoA (Connell et al. 2015).

### 8.1.3 Lack of Existing Literature Linking Game Elements to Behaviour Change Techniques

This thesis contributes a significant extension to the BCW, linking Behaviour Change Techniques to game elements. Future work in this area should be informed by this process and build upon it. A major challenge in doing so is a lack of satisfactory literature on game elements and their link to behaviour change theory.

The previous section identified how research in all fields using the BCW often fail to explicitly define the mechanisms of action for BCTs (Connell et al. 2015). Game elements can be considered a mechanism of action, and very little literature has explored game elements in terms of psychological theory, and none have referred to Michie's BCTs. As a result, the final linkage between BCTs and game elements was always going to be exploratory.

Predominant theories and frameworks in video game literature were covered in Chapter 2, and studies primarily focus on Self-Determination Theory (Ryan & Deci 2000; Ryan et al. 2006), and Flow Theory (Csikszentmihalyi 1990). These theories however, are more within the domain of motivation and engagement rather than behaviour change. Consequently, literature to support suggestions that various game elements being suitable for implementing BCTs was sparse throughout this project.

With respect to this project, the undefined link between BCTs and game elements resulted in uncertainty over the choice of game elements used in *Energy Explorer*. Literature was unable to provide solid guidance for a number of topics, including but not limited to:

- whether dialog from fictional in-game characters could be used in the place of messages from researchers to facilitate various social BCTs (see Sections 4.3.2.4, 4.3.2.5, 4.3.2.8, and **Error! Reference source not found.**);
- whether the progress of an in-game avatar toward becoming a better energy saver could help a person associate their behaviour with their own identity (see Section 4.3.2.3.1);
- how quest rewards should be implemented in order to effectively provide incentive to players (see Section 4.3.2.9); and
- how traditional video games have implemented goal setting (see Section 4.3.2.10.2).

In this study, an exit survey was used to determine if players associated the game elements they witnessed with statements representing the BCT that element was intended to facilitate. Section 7.3 described that the results of this survey indicated that participants felt the game elements did not facilitate the chosen BCTs, however this was confounded by the lack of actual play time undertaken by participants.

In terms of providing guidance for future work, it is recommended that researchers thoroughly examine the game elements in previous Serious Games examples for how those elements can facilitate BCTs. Researchers should also consider further ways of validating the links between game elements and BCTs, beyond the exit survey approach taken for this project.

#### 8.1.4 Lack of a Concise Taxonomy of Game Elements and the Bias Towards Points, Badges, and Leaderboards

In contributing this new process of linking BCTs with game elements, it was found that there was a lack of a comprehensive, academically-defined set of game elements beyond points, badges, and leaderboards to consider for inclusion in the game.

There were limited studies that described game elements in isolation, independently of the game they were situated in. Some studies focussed on particular games or genres, such as Rapp (2017) who looked at World of Warcraft. Others were broad and described concepts that covered many elements such as Deterding et al. (2011). The Octalysis framework (Chou 2016) mainly described concepts rather than elements, and provided little more than anecdotal evidence to support its claims.

There was a lack of common language across studies, and in the absence of a taxonomy of elements, researchers looking for academically-defined elements must search manually each time with no clear starting point or intuitive search terms to use.

The majority of game element studies found presented information on points, badges, and leaderboards. Leaderboard literature focussed on the standard potentially demotivating "superstar" leaderboards rather than the normative leaderboards discussed in Section 4.3.2.1.7. Research into normative leaderboards therefore was primarily based on the more general and non-technology-based notion of normative feedback instead. There are now many examples of normative leaderboards in modern games, however academic literature about them is non-existent. "Rewards" literature in games was focussed primarily on superficial rewards such as badges, rather than in-game rewards that have meaning (i.e. items to fulfil a different quest, or make your character stronger). Again, this is likely the result of Gamification implementations lacking the rest of the game for which to provide "in-game" rewards for. Nacke & Deterding (2017) note the need for change in the Gamification space, and among the changes recommended is the need for more meaningful rewards beyond simply providing the user with badges.

With respect to the design of *Energy Explorer*, the search for academically-defined elements resulted in a large number of points, badges, and leaderboards studies. Given the desire to move beyond these elements described in the rationale for this work (see Section 2.3.2.7), these studies were of little value to the design phase. This resulted in a longer-than-expected search for suitable elements

In this study, the lack of a taxonomy of game elements and limited literature was mitigated by additional sourcing of suitable game elements using brainstorming drawing upon elements identified in traditional video games, as has been undertaken by others struggling with a similar lack of guidance (Morschheuser et al. 2017; Deterding 2015). This has its own limitations including the potential for bias towards elements existing in games that author liked, however this was unavoidable in order to obtain a full set of game elements to examine.

Guidance for future work in this area is to supplement academically-sourced game elements with elements determined through brainstorming. Additionally, researchers could undertake participatory design (see Section 8.1.8), and conduct focus groups with the target audience, with the purpose of discussing appropriate elements (see Section 8.1.8 for discussion on the lack of participatory design in this project).

Future work into developing a taxonomy of game elements would aid in the mitigation of this problem. Such a task would be a huge undertaking, however there is merit in focussing this to elements present in extant Serious Games only, or to Serious Games within a particular domain such as energy conservation. The latter option of choosing a specific Serious Game domain can be aided by the existence of systematic reviews such as the ones provided by Johnson et al. (2017) and Connolly et al. (2012). In developing this taxonomy, determining a common language to use when describing game elements would be useful, potentially making use of the popular “design lenses” terminology coined by Schell (2014), and “skill atoms” by Deterding (2015).

#### 8.1.5 Choosing a Serious Game containing the chosen Game Elements

This work presents a method of transitioning from a series of game elements in to a Serious Game whole. This was necessary as the elements in isolation cannot inform the way in which the full game would be developed. While this is a beneficial distinction, in that different games could be developed for the same intervention purpose using the same combination of game elements, the process of determining the game that contains this set of elements was a challenging one all the same.

With respect to this study, game elements chosen using the BCW process were generic, and it was not immediately clear what kind of game suited those elements. Although an evaluation of different game types was conducted (see Section 5.1), each type of game examined had advantages and disadvantages in terms of the requirements for selection, and ultimately the game that was chosen was a hybrid of different styles. This had the advantage of being a novel type of game, however it is possible that a lack of point of comparison for users (i.e. "what game is this similar to?") may have had a negative impact on reception of the game.

The method defined in this work is resilient to the issue of game choice if researchers undertake an evaluation of possible game types as described in Section 5.1. The evaluation was based upon the suitability of the game elements fitting into the game, how well players were expected to understand, control, and enjoy the game, as well as the ability required to develop such a game to meet the high standards of gamers. Game genres were considered based upon those found in the top games on the Android Google Play Store at the time.

In terms of providing recommendations to future researchers implementing this method who may come across similar difficulties in determining an appropriate game design to encompass the chosen game elements, it is recommended to evaluate possible game types. This could be conducted as presented in this work, however upon reflection, this process may be improved by factoring in the opinions of the target audience of a short-list of prototypes (again, with focus groups, and using a participatory design approach). The criteria for assessing game types was focussed more on practicality (i.e. development ability), and future work could extend this with more rigorous examination of the games themselves, perhaps using concepts such as "design lenses" which prompt designers to analyse games from a range of player-oriented perspectives (Schell 2014).

#### 8.1.6 Balance Between the "Serious" and the "Game" When Designing a Serious Game

A common consideration in Serious Game development is determining the amount of non-serious content to include in the game (i.e. the components which make the game resemble traditional video games). While a lot of effort goes into the "serious" component of Serious Games, it is evident by the quality of the produced games that more effort should go into the production values (such as graphics, sound, user interface, and general level of "polish") of these games (van der Spek et al. 2014). With the increased capabilities of game engines used by professional game developers, most modern games experienced by players exhibit a high level of quality. Heeter et al. (2011) state that "people who are avid gamers may be more apt to dislike a Serious Game than are non-gamers if the game violates their expectations of entertaining game play and high end commercial quality production values". As a result, games can be overlooked or dismissed even if they have fun gameplay mechanics if they do not meet these standards. Heeter et al. (2011) suggest that players "disliking" a game is the main cause of reduction in effectiveness of Serious Games. Serious Game studies primarily evaluate the effectiveness of the intervention, and the pleasure of the game experience itself (Vargas et al. 2014). However, at present there is no literature on the impact of the perceived quality of the game at the point of invitation on participant *uptake* of the game.

There is debate in the literature over whether making the Serious Game too much like a traditional entertainment game reduces the effectiveness of the Serious Game's ability to achieve its serious purpose (van der Spek et al. 2014; Gros 2016; Peery 2016). Recall from Section 2.1.4.2.1 that the Zyda (2005) definition of Serious Games values the contribution of entertaining aspects of traditional games, whereas Marsh (2011) suggests that entertainment is not a requirement for a game to be considered a Serious Game. Susi et al. (2007) argue that some commercial games not intended to be Serious Games can be labelled as such. The case for implementing entertainment features in Serious Games should consider the impact this may have on development time.

In terms of the design of *Energy Explorer*, the choice of game and its associated balance of serious and non-serious content being largely skewed toward the non-serious side caused development time to be greater than that of a simpler game. It is not clear whether the entertainment aspects of the game detracted from or obscured the serious components. Upon reflection, a simpler game may have resulted in reduced development time.

In this study, mitigation of the issue of increased development time stemming from non-serious content was accomplished by using the *Unity* game engine, which eliminated the need for separate codebases for the Android and iOS versions and the development of game engine code for low-level tasks such as displaying images and managing input). Most art assets were sourced from online repositories, and a consistent art style was ensured by constraining the use of external assets to be "pixel art", primarily used by the *Pokémon* series by Nintendo.

Therefore, in terms of guidance for future work, researchers should carefully consider the development implications of incorporating improved visuals, audio, interface, and gameplay, and to what extent this impacts the serious components of the game. Options for reducing the burden of development should be considered such as:

- reducing the *scope* of the chosen game design;
- employing a *professional game developer* or other external developer to code the game;

- making use *pre-existing game engines* and *asset stores* to source graphics and audio, rather than create it; and
- coding the game as a *mod* (game modification of an existing commercial game), rather than a standalone game.

Researchers employing the services of a *professional game development studio* need to fully consider the implications of additional cost, intellectual property, the extent of access to sensitive data of the external development team, the detrimental effects on the external development team if access to data is limited, and the added communication overhead both in terms of team availability and the need for a mutual language between the researchers and the game developers to avoid jargon. These downsides and challenges need to be weighed against the potential advantages of producing a higher quality game as described above. If an external team is not used researchers should consider being open and honest with their participants and inform participants that only a small group of non-professional game developers worked on the game, potentially lowering the expectations of end-users.

The increased capabilities and accessibility of game engines such as *Unity*[88] and *Unreal Engine*[89], as well as online sources for game assets such as the *Unity Asset Store*[90].which allows for the sharing of 3D models, textures, and even game code. Doing so can help counter the lack of artists on the research team, and reduce the time it takes to produce assets for the game. Usage rights allowances of assets need to be considered.

An alternative to developing a standalone game is to consider developing a game *mod*. As Scacchi (2010) points out, game mods come in a variety of forms: user interface customizations, game conversions, machinima, computer customization, and game console hacking. Modifications to the user interface of existing video games to include messaging, feedback, and other game elements is could be undertaken to produce a Serious Game. Further, game conversions allow for the game engine and pre-developed original game mechanics to be used to provide additional content or an entirely different game experience to that of the original game (Scacchi 2010). By creating a game conversion, researchers may not have to develop the core mechanics of the game (such as controls, camera movement, etc.), and may not need to create the graphics or audio of the game.

[88] http://unity3d.com

[89] https://www.unrealengine.com/

[90] https://www.assetstore.unity3d.com/en/

### 8.1.7 Focus on Curtailment Behaviours and Exclusion of Effectiveness Behaviours

This work has presented an example of a Serious Game design for energy conservation which focused primarily on curtailment behaviours, rather than effectiveness behaviours.

Effectiveness behaviours are broadly described as once-off, high-cost, high-impact behaviours such as selecting energy efficient appliances, and altering aspects of a home such as the type of heating methods used (see Section 4.2.2 and Gardner & Stern (2008) for a full description). The impact of enticing players to participate in effectiveness behaviours is potentially higher given the nature of those behaviours, and there may be value in pursing developing a game that targets them.

In the case of the *Energy Explorer* design, the exclusion of effectiveness behaviours was necessary to scope the development of the game to a specific set of curtailment behaviours, however upon reflection, providing energy literacy information to help promote effectiveness behaviours in addition to facilitating curtailment behaviours may have had a greater impact given the positive outcomes described by studies such as Brewer (2013) and Yam et al. (2017).

Therefore, in terms of providing guidance for future work, future iterations of Serious Games using the BCW methodology for energy conservation should consider targeting effectiveness behaviours. An implementation of such a game would have to consider the once-off nature of effectiveness behaviours, and would likely be less focussed on day-to-day energy consumption. One iteration of the idea might not even use smart meter data, but rather educate players by allowing them to perform many effectiveness behaviours in quick succession in a virtual environment.

### 8.1.8 The Need for Participatory Design

While this work was guided by the Human Centred Design methodology by Holloway & Kurniawan (2010), future work should consider augmenting this with participatory design. Many of the challenges described in this Section 8.1 have identified that participatory design would help mitigate the challenge.

Participatory design is described by Schuler & Namioka (1993) as an approach to design "in which the people destined to *use* the system play a critical role in *designing* it" (p. xi). Essentially, all stakeholders of the system are involved in the design process, in particular those who stand to benefit from it, in order to increase the benefit, they receive and produce a better product. Participatory design has been used in a number of Serious Game and Gamification studies such as Malinverni et al. (2017), Caro et al. (2017) and Nunes et al. (2016), and is becoming a popular approach given the value of eliciting the needs of and feedback from end-users (Nacke & Deterding 2017). It is also worth noting the game-based iteration of participatory design, the “GAMER” framework by Charles & McDonough (2014) and the concept for “playcentric design” (Fullerton 2014), which is an abductive process that involves rapid prototyping.

In terms of the *Energy Explorer* project, the design process for this project did not involve the end users until the main trial of the app. The experimental design meant that participants could not be exposed to the game before the main trial, lest the effects of doing so biased those participants later. Engaging in a participatory design approach would have enabled more opportunity to test the resultant game on various hardware, with users representative of the main trial group, which would have helped with a number of the implementation issues described in the Section 8.2 such as fragmentation of hardware, and user expectations. Participatory design implemented early on in the intervention design phase would have been beneficial in determining the target behaviours for the intervention, as participant feedback would have improved the assessment of behaviours using the BCW’s APEASE criteria (Section 4.1.4). Consultation with participants would have aided in the selection of game elements and the selection of the Serious Game to encompass the game elements, as it may have been possible to make choices better suited to the target audience.

In this study, a mitigating factor to the lack of participatory design was the pilot experiment which was conducted to gain feedback on the chosen game elements and bug-testing of the game. Subject matter experts from the CSIRO were consulted in the design, and tested a working version that interfaced with their smart meters, however these experts likely had different characteristics to the participants in the trial.

One approach could have taken a number of these participants and ran a pilot trial on them, and excluded them from the results of the main trial so as to not bias the results. This was considered but deemed to not be plausible due to the expected response rate to the invitation to play. Given the response rate that was exhibited from the 149 participants (13.4%), reducing this number with a pilot test resulting in ineligible participants would have harmed the ability to run the main trial. This is discussed later in this chapter in Section 8.2.1.5.

In terms of recommendations for future work in this area, researchers should ensure participant count is high enough to facilitate participatory design, or consider a research design which allows for participants to interact with iterative versions of the Serious Game. Additionally, researchers should engage in participatory design from an early stage where possible, including obtaining user feedback to help inform the various APEASE criteria analysis phases of the BCW, and guide the selection of game elements and encompassing game type.

#### 8.1.9 Potential Bias in Decision-Making Process from Single Researcher

This work has contributed to the knowledge in designing Serious Games by presenting a method for selecting target behaviours through prioritization (Section 4.2.2.2), and a method for selecting promising game genres from existing games (Section 5.1.1).

While in both cases, researchers from the appropriate fields (social sciences for the former, video game development and research for the latter) were consulted, these decision-making processes were primarily conducted by a single researcher (the author). It is possible that when the same process is conducted by a different researcher, there could be a different outcome. This is mitigated particularly for the behaviour prioritization as this is within the systematic Behaviour Change Wheel process, however the criteria for selecting promising game genres was a new set of criteria developed for this thesis. The fact that the same researcher determining the criteria was also the one evaluating games against these criteria is a potential limitation of this study. Recommendations to future research in this area is to involve multiple researchers on these components, and consider determining game selection criteria using a third-party (or use the selection criteria from this work), rather than having the same researcher conduct criteria development *and* evaluation.

#### 8.1.10 Summary of Practical Lessons Learned from Design Phase

In summary, this work contributes where there was previously a lack of prior research and guidance on how to apply the methodology of the BCW to Serious Games for energy conservation. Researchers are advised to participate in discourse with experts in the field of behaviour change and the target domain, build upon the lessons learned presented in this thesis.

The lack of a clear link between the Behaviour Change Techniques and the taxonomy of behaviour change theories by Michie, West, et al. (2014) was a significant challenge in this work. Researchers are recommended to stay up-to-date on further work on improving the BCW through the new links for BCTs, in order to gain a better understanding of the BCTs they are implementing through their games.

Additionally, this section has highlighted the lack of satisfactory literature on game elements and their link to behaviour change theory. It is recommended that researchers thoroughly examine the game elements in previous Serious Games examples for how those elements can facilitate BCTs, also consider further ways of validating the links between game elements and BCTs, beyond the exit survey approach taken for this project.

This work has found a lack of academically-defined game elements beyond points, badges, and leaderboards to consider for inclusion in the game. Researchers are advised to supplement academically-sourced game elements with elements determined through brainstorming. Additionally, researchers could conduct focus groups with the target audience, with the purpose of discussing appropriate elements.

Development time was impacted by the amount of non-serious content included in the game (i.e. the components which make the game resemble traditional video games). Researchers should carefully consider the development implications of incorporating improved visuals, audio, interface, and gameplay, and to what extent this impacts the serious components of the game. Additionally, researchers should consider reducing the scope of the game design, employing a professional game developer, use online asset stores, or creating a game mod.

This section discussed that future iterations of Serious Games using the BCW methodology for energy conservation should consider targeting effectiveness behaviours.

Due to the nature and practicalities of how this research was conducted, a number of decision-making points in this work were conducted by a single researcher (the author). We have seen that future teams working on projects such as this should consider democratizing or combining the results of multiple research team members for such decision-making points.

Finally, researchers should ensure participant count is high enough to facilitate participatory design, or consider a research design which allows for participants to interact with iterative versions of the Serious Game. Additionally, researchers should engage in participatory design from an early stage where possible, including obtaining user feedback to help inform the BCW process, and guide the selection of game elements and encompassing game type.

## 8.2 Practical Lessons Learned from Implementation and Deployment Phase

The previous section explored the issues involved in designing a Serious Game using the Behaviour Change Wheel methodology, how the problems were mitigated, and recommended ways in which future work can avoid or handle those issues. In describing the design phase, the issues were encountered *before* or *during the early phases of* the development of *Energy Explorer*. In this section, the focus is on the challenges and issues that arose during the *implementation* of the game, i.e. the development, testing, experimental, and analysis phases of the project. This section also explores challenges in implementing the Behaviour Change Techniques in the form of game elements.

### 8.2.1 Target Audience

This work leveraged access to smart meter data to provide a novel way of visualizing this data and integrating into the gameplay of a Serious Game. To accomplish this, as described in Chapter 6, the *Energy Explorer* implementation was designed and programmed to work for the participants of the RBEES trial run by the CSIRO. Access to such metering infrastructure for researchers is rare, and so additional pilot phases or focus groups would have severely limited the number of participants available for the main trial. As such, the benefits of tailoring the intervention to participant needs was lost.

Johnson et al. (2017) point out the limitations evident in many energy conservation game studies, with many reviewed papers conducting convenience sampling, recruiting from research subject pools (as was the case in this project), and generally providing insufficient information over the sampling method.

This section will describe a number of possible limitations as a result of testing with these participants.

#### *8.2.1.1 Participants Already Performing Behaviour at a High Level*

The deployment of *Energy Explorer* was to a population of participants who were already performing the target behaviour (energy conservation) at a high level, and hence any further improvements may have been minimal.

Behaviour change interventions can encounter a scenario where there is no improvement in the measured outcome (e.g. conservation effect, amount of rubbish collected, score on a depression questionnaire, etc.) compared to before the intervention due to the fact that the participants were *already* operating at their optimal capacity for change (i.e. there was no more room for improvement). Greeno (2002) points out that this is a common limitation of pre-test/post-test experimental designs.

With respect to the *Energy Explorer* deployment, the results in Section 6.2.1 suggest that the majority of the participant pool (i.e. those were sent an email notification) agreed (or strongly agreed) that they were an "energy conserving household", and 95.0% of participants stated that they already take steps to limit their energy in their homes. The participant pool was comprised entirely of participants of a previous energy-efficiency-related research project: RBEES. The RBEES participants were recruited by the CSIRO, lived in houses built after 2003, and were willing to have a smart meter installed in their home (Ambrose et al. 2013). There was no significant difference in self-reported energy consciousness between those who accepted the invitation to play the game, and those who did not, indicating that any energy-conservation characteristics were equally present in both groups.

For this project, this characteristic of participants already performing at a high level may have been a factor in the fact that only a small magnitude difference in conservation effect was observed, as most participants could not reduce their consumption further without taking extraordinary measures.

In terms of providing guidance for future work, it is recommended that researchers in this area be wary of using datasets for energy consumption data that might be restricted to containing data from those who are already energy conscious. Future researchers should consider comparing against data for the general population, but understand that proper comparisons may be difficult due to incompatible data (e.g. different units and timespans). Additionally, researchers should consider *targeted interventions* which are designed and provided to people who are identified as needing to change their behaviour. When using a dataset similar to the one used in this work, researchers could examine the dataset for users with existing problems. Using this analysis, researchers could target specific behaviours more accurately. For example, pre-analysis would reveal the times at which specific participants were at peak usage, or the types of days on which participants used their air conditioner. This lends itself well to the Behaviour Change Wheel systematic approach. This work used the BCW to examine energy behaviours in general, however examining the energy behaviours of a specific target audience using the BCW may prove to be highly effective. To accomplish this however, there is the additional challenge of obtaining consent from individual participants to access their data for such analysis.

#### *8.2.1.2 Age Group*

It is possible that the increased age reduces openness toward a video game, and their ability to use the game, both in terms of familiarity with mobile game interfaces and controls, and free time to play the game. Johnson et al. (2017) point out that many energy conservation game studies fail to report on the age of participants

In terms of the *Energy Explorer* deployment, the results in Section 7.1 found that the average age of participants in the study was 48.1 years ($SD = 9.492$). Ages of participants varied between 35 years for the youngest, and 65 years for the oldest. The youngest participant was older than the average age of gamers in Australia (33; IGEA (2016)). The age of participants in this trial is higher than the clustering of participants in other studies. Johnson et al. (2017) report that participant ages were more frequently between the ages of 18 and 30. Participants in the trial were homeowners (see next section), and so the high average age is somewhat unsurprising given that according to a 2015 study by ING Direct, the average age of homeowners in Australia was 37.7 (Devine 2015). Likely as a result of increasing house prices and increased cost of living, this average age is on the increase, up from 34.7 in 2005 (Devine 2015).

For the *Energy Explorer* study, the elevated age of the target audience may have contributed to the observed lack of use by participants. As shown in section 7.1.2 (Figure 66), familiarity with video games was strongly negatively correlated with participant age. Despite this lower familiarity with games for older participants, age was not found to be a factor in any of the other recorded measures (i.e. conservation effect, game experience, and game usage).

Nonetheless, in terms of providing recommendations for future work, researchers are advised to assess the age group of the target audience before designing the intervention, and tailoring the design toward them.

#### *8.2.1.3 Homeowners*

Studies in behaviour change for energy conservation often target homeowners as they are the ones with greatest facility to partake in *effectiveness behaviours* (described in Section 4.2.2.1) such as installing different appliances in the home. In addition, as the homeowner paying the electricity and gas bills, they are an ideal target with the incentive of reduced payments. The *Power Agent* (Gustafsson et al. 2009) game is an example of recommending participants work together as a household. Homeowners may have limited time to interact with the video games, although this was not observed in the data, with 55.0% of participants who played the game stating that "someone [was] home all day"[91]. Of the 24 studies examined by Johnson et al. (2017), only 7 were situated within a household setting (with others being conducted in laboratories, classrooms, universities, and workplaces).

In the case of *Energy Explorer*, the participant pool were all homeowners, which may have had an impact on the amount of free time available to the participant to interact with the game. It is not clear if the participants allowed other household members including their children to access the game.

[91] It should be noted that the "someone" referred to in the question may not have been the participant playing *Energy Explorer*.

Future researchers are recommended to again consider the target audience before developing the Serious Game. In the case that the participant pool is made up of homeowners, there may be value in designing the game to suggest that participants engage in playing the game with other household members. Researches should implement this in terms of allowing the household to work together as a team against other households, or compete with each other within the household. To facilitate competition within the household, energy usage for each of the household members would have to be determined which—depending on the data available—may be difficult. This information could be estimated using smart meters which can determine usage for different circuits, where each room is represented by a different circuit.

#### 8.2.1.4 Familiarity with Games

In discussing the balance between the entertainment and serious aspects of Serious Games, Section 8.1.6 described how the expectations of "avid gamers" may result in players disliking a game, and as a result reduce its overall effectiveness (Heeter et al. 2011).

It is likely that this predisposition to games contributes to the findings of Rapp (2015) whose qualitative analysis of popular Gamification implementations *FourSquare*, *Nike+*, and *GetGlue* revealed that many participants noted the differences between those implementations and "real games". Adoption of gamified experiences (and Serious Games) is dependent on previous game experience and attitude towards games (Landers & Callan 2012; Landers & Armstrong 2017).

Bindoff et al. (2014) found that only 37.5% of their participants stated that they were familiar with video games, and as such reported that a number of participants found their pharmacy simulator game difficult to use (the game used a number of traditional video game mechanics including a "first-person" perspective, aiming with the mouse, mouse-clicking to pick up items, and dialog trees). This lack of familiarity was particularly interesting given their participants were undergraduate pharmacy students. This chapter has already identified age as a determining factor for familiarity with games, however the Bindoff et al. (2014) study indicates that this can happen with younger participant groups as well.

With respect to *Energy Explorer*, the entry survey results in Section 7.1 suggest that the majority of users were familiar with video games, and mobile video games. This is unsurprising given the concept of the Ludification of Culture (previously introduced in Chapter 2), and the pervasiveness of games on platforms such as Facebook, and the prevalence of games on mobile devices.

In this study, high target audience familiarity with video games was attempted to be mitigated by ensuring *Energy Explorer* contained attractive graphics and enjoyable gameplay. It is possible however, that the long loading times, and lack of recognizable characters from recognizable characters from other media (or from pre-existing entertainment games) meant that the game did not meet the expectations participants had of mobile games, and therefore reduced their willingness to play. Low familiarity with games was addressed by ensuring that *Energy Explorer* was designed with easy to use controls, and featured no critical gameplay elements that required skill (such as platforming or fast reaction times), and this should have suited the older demographic of the participants. Give the lack of uptake of the game, this may not have been the case.

In terms of providing advice to future researchers, if participants have played games with strong production values before, then the researchers should ensure the graphical quality and gameplay experience is of a high enough level. The recommendations for development outlined in Section 8.1.6 are relevant here. Researchers may consider producing a simpler game with an overall higher quality. Future iterations of *Energy Explorer* could be designed with a different target audience in mind, opening the game up to controls and game mechanics that require greater skill or reaction times. Such modifications should be weighed against the potential impact on ease of use, and added development time

#### *8.2.1.5 Locations and Lack of Contact*

While Section **Error! Reference source not found.** has described how having participants from various locations can help with the external validity of the experiment, having participants located far from the researcher has an impact on the capability to conduct participatory design (see Section 8.1.8). Interestingly, this problem is unique to Games for Change, and is not something that happens in traditional video games, where extensive focus group testing, and alpha- and beta-testing is conducted.

In the case of *Energy Explorer*, the statistics reported in Section 6.2.1 showed that participants were located in 3 different areas of Australia: around Melbourne, Brisbane, and Adelaide. The distribution of users across these three areas was close to even, both in the original RBEES trial and in those who accepted the invitation to play the game.

Lack of contact with participants caused made it difficult to test the mobile application directly with participants, increased reliance on the automated data collection process which operated over the internet, and eliminated the use of participatory design on grounds of practicality.

Therefore, in terms of providing guidance for future work, it is recommended that researchers not avoid recruiting from different areas, but rather to address ahead-of-time the practicalities of conducting focus groups and interviews with participants for participatory design. In addition, it is important to consider the different weather conditions from each location, and control for this in analysis. The "similar days" approach described in Section 3.3.5 may be of value for this endeavour.

### 8.2.2 Access to Smart Meter Data

In contributing this novel approach to integrating smart meter data into a Serious Game, this work has highlighted some potential challenges related to variable access to, and inconsistent updating of, smart meter data.

When reading smart meter data, the following factors should be considered:

- the *frequency* at which new data is collected;
- the *granularity* of the collected data (note this is different to frequency, as it is possible to have say half-hour granularity updated at the end of each day);
- how to handle *variable frequency* of new data collection;
- how to handle *variable granularity* of collected data across participants and within each participant;
- the *format* of the data (units and channels);
- the *reliability* and *accuracy* of the data;
- the *speed* of querying the data; and
- any *privacy* or *ethical* concerns with the data.

*Frequency* and *granularity* of smart meter data has an impact on the type of intervention that can be designed. Higher-frequency of data updates can result in improved designs that make use of more immediate feedback—a trait that is recommended in energy conservation interventions (Ehrhardt-Martinez et al. 2010). For the game to react to smart meter data, it needs to read the most recently uploaded data. A greater time difference between the recorded data and the time at which it makes an effect on the game is likely to be detrimental as it weakens the link between the real-world energy conservation action and the in-game result. With high frequency updates to data, a game could respond to specific actions. For example, turning off the air conditioner could be immediately detected by the game, and result in having the in-game wind turned-off in the game (perhaps beneficial if the game is a golf game, perhaps detrimental if a sailing game).

Additionally, ethical concerns of the privacy of smart meter data may occur, and this is described later in Section 8.2.5.6.

In the case of *Energy Explorer*, the implementation was designed to react to energy consumption as recorded by a smart meter. Ensuring that smart meter data was easily and reliably accessible was a challenge in implementing this project. Possibly due to the large number of RBEES participants, the frequency of the usage data being uploaded was *variable* for each participant. At worst data was uploaded every 24 hours, and the game had to handle this as best it could. It was possible for a request for latest data to return an empty result for the current user, but still return a result for a comparison user. The game needed to draw comparison only for points in time where data existed for both users, and keep track of the data points for which comparison had already been made (i.e. to prevent duplicate rewards being delivered).

Granularity of data for *Energy Explorer* was at half-hourly intervals, although minute interval data was available, this data was not considered as reliable. As a result, the game could only update the user with feedback if a new game session was started more than 30 minutes after concluding the previous session. Combined with variable frequency, this amount of time could be as long as 24 hours between sessions.

The *format* of data in the *Energy Explorer* implementation was multiple channels with different units of measurement. In addition, each user had a different set of channels provided, with some overlap between users having the same channels, and some users having unique channels. Which channels could be compared between participants had to be determined programmatically since channels were allowed to be given custom names, when the meter was first registered[92]. Channels were only compared if the units of measurement matched.

In terms of advice to improve future work in this area, it is recommended that future researchers be aware of the ways in which smart meter data frequency, granularity, format, reliability, accuracy, and privacy may impact the implementation. It is important to ensure that the core mechanics of the game still operate when access to smart meter data is not available.

[92] The game code had to identify that channels named “AirCon”, “Air_Con”, “Air Conditioner”, and “AC” were equivalent.

### 8.2.3 Limited Testing

As previously mentioned, due to the convenience sample meant that in order to avoid reducing the pool of participants for the main trial of *Energy Explorer*, it wasn't possible to conduct earlier testing of prototypes, as it was desirable for all main-trial participants to be playing the game fresh and on equal footing.

The Human Centered Design (Holloway & Kurniawan 2010) approach recommends the use of testing, and the Intervention Research (Rothman & Thomas 1994) model refers to testing when describing the "early development and pilot testing" component.

In the case of *Energy Explorer*, the results presented in Section 6.1 for the pilot phase show that playtesting from the 6 experts was limited. These experts had limited time to play the game, and little incentive to do so, as no remuneration was offered. Additionally, these participants were not representative of the target audience of the main trial, making feedback on perception of the game limited. The mechanism for feedback from participants in the pilot phase lacked structure, and would have benefited from a defined exit survey.

For the main trial, the recorded game metrics (Section 7.2) indicated that some participants encountered trouble launching the game upon initial login. The difference in number of respondents to the entry survey, and those for whom valid game metric data was recorded (Section 6.2.1.2), provides further indication of this.

In terms of recommendations for future researchers, it is suggested that researchers conduct thorough testing of game functionality, with both experts and laypeople representative of the target audience. This is especially important when testing a full-game experience, due to the increased complexity of the game code. Researchers should consider the advantages and disadvantages of testing on users from the participant pool reserved for the main trial.

### 8.2.4 Mobile Platform Issues

This work represents a significant step forward in the development of a gameful way of representing smart meter data on a mobile platform. In doing so, we contribute findings of a number of issues inherent in developing for the mobile platform.

Challenges developing and testing on the mobile platform identified by Samuel & Pfahl (2016) include:

- *fragmentation* (variety of platforms, operating system versions, and hardware);
- *limited resources* (hardware, including memory, and screen size);

- *external software dependencies* (code interacting with operating system-level functionality and external programs);
- *frequent external communication* (application reads and writes to internally and externally hosted data sources);
- *variable user and usage context* (familiarity, ability, and preferences);
- *fast evolution* (input methods keep evolving, and always new apps to integrate with if possible); and
- limitations related to *platform implementation* (restrictions on testing processes).

In the case of *Energy* Explorer, most of the issues identified above were experienced in some way. Although Samuel & Pfahl (2016) looked at these issues purely from a testing standpoint, they are indicative of the challenges experienced in developing for mobile in general. The following subsections explore these different aspects individually.

It should be noted that *evolution* and external *software dependencies* were not a direct challenge for *Energy Explorer* as the game code did not use operating system-level functionality, or interact with other apps. Researchers developing Serious Games on mobile may likely face the challenge of interfacing with external applications and operating system functionality, such as the phone's camera or microphone. When targeting both Android and iOS systems, researchers should also consider the development cost of ensuring external dependencies work across both operating systems, and consider using software tools such as Unity or Cordova[93] to reduce the development time needed.

#### *8.2.4.1 Fragmentation*

Fragmentation refers to the variability in hardware and operating system versions (Samuel & Pfahl 2016). Android native applications are written in *Java*, whereas native iOS applications are coded in *Objective-C*. Solutions exist to enable developers to program for both without needing to maintain two parallel codebases, such as the *Unity* game engine, and *Cordova* which embeds a website programmed in *HTML* and *JavaScript* to have consistent appearance across platforms. Fragmentation is also a factor in many of the other mobile platform issues described in this section, such as *limited resources*, *external software dependencies,* and *platform-specific implementations.*

In the case of *Energy Explorer*, the results of Section 6.1.2 showed that amongst the 6 participants involved in the pilot phase, each had a different device. Although it was not

[93] https://cordova.apache.org/

recorded for the main trial, variation amongst devices and operating systems may also have been present.

The issue of fragmentation across operating systems (Android and iOS) was mitigated by the use of the *Unity* game engine.

In terms of recommendations for future work, it is recommended that future researchers consider conduct testing on a wide range of devices and platforms. Researchers may limit participation to a specific platform, however the effects of any bias of this must be documented. Additionally, participants without the required devices could be provided with hardware, however the cost of doing so and the impact on the player experience should be considered. Researchers should also consider the use of tools that reduce the development burden of targeting multiple platforms such as *Unity* or *Cordova*.

#### *8.2.4.2 Limited Resources*

Mobile devices have associated limitations to the resource available to applications, in aesthetic form (screen size, input method), and in terms of performance (memory capacity) (Samuel & Pfahl 2016). When developing full Serious Game experiences, the memory limit may be reached easier than a simple Gamification solution.

In the case of *Energy Explorer*, the results of Section 6.1.2 showed that the lowest hardware specification the game was tested on at the time was a Nexus 4 (approximately 3 years old at that time). Although it was not recorded for the main trial, it is possible that older devices were used by the main trial users.

In cases where older hardware was used, the game would reach a memory limit. This limit could be reached during the loading process (explaining some of the users who did not log any “entered world” actions, see Section 7.2), or mid-game—in both cases causing the game to terminate.

On older hardware, the procedural generation process of new levels took longer expected, and this process was slowed down by the phone having to render the current level concurrently with this. A considerable amount of effort went into ensuring that the procedural generation process was fast, however, as outlined in Section 6.1.4, this was ultimately removed from the game client, and generation was instead completed at build-time to avoid having extra computation.

In terms of recommendations for future work, it is recommended that develop the game software within the constraints of the lowest expected hardware that participants will use.

Researchers can limit participation to devices with a minimum set of requirements, however again the bias this may introduce should be documented.

#### 8.2.4.3 Frequent External Communication

This mobile issue refers to the reading and writing to internal or external data sources (Samuel & Pfahl 2016).

*Energy Explorer* relied heavily on *frequent external communication* to interact with the smart meter data, and for recording game metric data for analysis. The game code had to handle the case where users were not connected to the internet, but still functioned. Connectionless functionality prioritised the user needs, for example, with the exception of the initial "Login" screen process, user progress was not impeded with an "Internet connection required" dialog or similar.

It is possible that some users' data was lost due to usage while offline, since a method for "buffering" collected data (and uploading it when a connection was found) was not implemented for *Energy Explorer*.

The speed at which the data could be transferred to the participants' phones was variable, based upon if their connection was over a cellular network or Wi-Fi router. For this project, the data payload was often small (less than 5KB), and so transmission speed itself was likely to be negligible. Instead, the processing time collecting the data from the RBEES database was where additional time was taken (as described in Section 8.2.2, querying the RBEES data set took a variable amount of time).

In terms of recommendations for future work, researchers should consider payload size, handling variable internet connectivity, and consider caching techniques to mitigate issues with external data dependencies.

#### 8.2.4.4 Variable User and Usage Context

Usage context, such as where and under what time constraints the game is played can also impact how the game is played. Internet connectivity can change, as can the user's ability to focus or engage with the game if they are otherwise distracted (it is interesting to note that evolving capabilities of phones to display more than one application on screen at once exacerbate this problem).

In the case of *Energy Explorer*, it was never specified when and where players should play, in order to obtain realistic usage data, and so participants may have attempted to play the game in settings that did not suit play (e.g. crowded or noisy areas, or places with poor or intermittent internet connectivity).

Future researchers may consider prescribing a specific usage context to be adhered, for example: ensuring participants played in their home, to reduce the time-delay between energy-saving actions and in-game rewards, and/or ensuring players included other family members such as children in the usage of the app, such as in the study by Gustafsson et al. (2009)). This may be difficult to enforce in full field trials, as constant surveillance is neither ethical nor practical. An alternative is to test the game purely in a focus group or laboratory setting, however realistic usage data would may not be obtained using these methods.

#### *8.2.4.5 Platform-Specific Distribution*

As outlined in Section 6.2.2.3, deployment did not make use of the Google Play store or Apple App Store for distribution, since users of the app were required to be from the RBEES trial. For iOS, an automated distribution process with a number of steps was used. It is possible that this alternate process for installing an application was not trusted by some participants, or was too cumbersome, resulting in incomplete registrations. For Android, users were instructed to change the security settings on their device to allow applications to be installed from sources other than the Google Play Store, which may have been interpreted by users as untrustworthy.

Trust issues may have been mitigated due to the prominence of the CSIRO and University of Tasmania logos, as the CSIRO is a well-known and respected institution in Australia. The University of Tasmania is well-known and respected within the state of Tasmania, however it is possible that the participants from Melbourne, Adelaide, and Brisbane had not heard of the University. Despite this, verifying the legitimacy of the University would have been easy for participants using the Internet. Email correspondence came from a CSIRO email address, and from a member of the original RBEES research team, so participant trust should have been maximised in this project.

In terms of providing guidance for future work, researchers should consider the impact of distribution through means other than the Google Play and Apple App Stores. Using the public stores may result in higher participant counts, however it is important to consider the implications of such a wide reach on the experiment design. If distribution via the Apple App Store is deemed unsuitable for a project, the *Fastlane Pilot* software is recommended for automating the invitation process.

### 8.2.5 Practical Lessons in Implementing Behaviour Change Techniques Through Game Elements

This work contributes examples of utilizing game elements to operationalize specific BCTs. This section describes the challenges found in doing this, with reference to the exit survey data which specifically asked for user feedback on these game elements. It has been previously noted however that it is difficult draw any solid conclusions from this data due to the low number of respondents to the exit survey.

#### *8.2.5.1 Participant Count Impact on Normative Feedback*

The normative leaderboard component in *Energy Explorer* is a novel contribution of this work. Future research should ensure that when using such an element, that there is a sufficiently high participant count in order to have accurately *similar* users. Literature suggests that the more relevant the people you are compared to are, the higher the effect of the normative feedback (Loock et al. 2012; Goldstein et al. 2008). Within populations where individuals are reasonably varied, it follows that a large participant count is needed to find sufficiently similar people.

In the case of *Energy Explorer*, game metrics results presented in Section 7.2 indicated an underuse of the normative leaderboards in *Energy Explorer*. Game experience results presented in Section 7.3 demonstrated a general disagreement from participants that the leaderboards motivated them to change their behaviour[94].

The normative feedback elements of *Energy Explorer* intended to show users their energy usage compared to other, similar users. This implementation of the game showed users comparisons to other players of the game, rather than using the entire pool of RBEES participants. Given the low number of respondents to the invitation to play the game, this meant that it was difficult to provide sufficiently similar users. This problem was exacerbated earlier on in the trial when there were fewer participants.

A recommendation for improving future work implementing normative feedback is to ensure a large number of participants so as to improve the "similar user" algorithm results. Where this is not possible (e.g. small participant pool, or staggered deployment of the game where population of players fluctuates), another option is to present fictional users with "fake" results to users either in place of, or in conjunction with data from other users. This brings with it its own set of challenges, such as ensuring the data is believable, as well as from a

[94] Exit survey questions 9, 10, 12, 13, 14, 26, and 35.

research design point of view, ensuring the positive and negative feedback (where participant consumption is better or worse than the fake data) is controlled and factored into analysis.

#### *8.2.5.2 Explicit Level-Up Rewards*

A level-up system was implemented in *Energy Explorer* to facilitate the *feedback on behaviour, social comparison,* and *reward* BCTs. This implementation could have been improved, as the level-up system needed to inform players better as to what reward they were due to get in an attempt to foster *meaning* in the system.

Participants in the study by Rapp (2015) stated that they believed that rewards in games were required to have some meaning within the game system. For example, they suggest that rewards should "unlock contents, opportunities or privileges" (Rapp 2015, p.78).

In *Energy Explorer* the in-game meaning of rewards for completing quests was reasonably clear, with the expected reward shown at the start of the quest, and players were taught that the "XP" reward meant they would become closer to "levelling up". Item rewards for quests had in-game meaning in that they could be used later in the game to complete other quests, although this was not immediately clear (even though some dialog suggested that the items would be useful later). Similarly, the in-game reward for completing checklist items was "XP".

However, the in-game reward for levelling up in *Energy Explorer* was not immediately clear, other than that the player was taught that the goal was to reach as high a level as possible. In addition to simply being associated with a higher level number, levelling up also changed what was available to the player to discover in while exploring, such as more interesting "puzzle" zones, other non-player characters (NPCs) speaking to the player to give more quests, and different items available in chests. This information, however, was built into the game code, and intended to be experienced by the player, rather than explicitly told to the player (this is common in many modern games).

A lack of explicit level-up rewards may have led to participants being unable to find meaning in *why* they should level up in the game. Tutorial dialogue (see Appendix J.1) attempted to mitigate this problem, however more explicit information should have been provided. This could have been implemented to the extent that players could always view a screen with a list of rewards given at each level. The findings from the exit survey align with this[95].

[95] Exit Survey questions 8, 24, and 29.

In terms of advice for future work, researchers should ensure that in-game rewards are clearly defined. Rewards should also not only be clearly stated, but designers should ensure that the player is aware of the *meaning* of the rewards (e.g. "collecting XP will level-up your character", "levelling-up your character will allow you access to more areas in the game world, and more powerful weapons").

#### ***8.2.5.3 Using Game Environment and Resources as a form of Feedback on Behaviour***

This contributed a novel form of *feedback on behaviour* in the form of dynamically changing the game environment and distribution of in-game resources based upon smart meter data. This was also the main form of implementing the *reward*, *information about social and environment consequences*, *salience of consequences*, and *punishment / behaviour cost* BCTs (and this is discussed later in the next section). A significant challenge in implementing this was ensuring that the player was able to both predict and understand changes in the environment in order for this feedback to effective. This work highlights the difficulty of doing this successfully, as exit survey responses indicated general disagreement on the questions which aimed to assess this[96].

While the differences in weather graphically were distinct, a challenge was how to represent the current weather status and the impact of future weather statuses on particular zones. The impact of improved weather was intended to bring about rewards in terms of opening up new areas, and making it cost less energy to traverse a zone. This had to be indicated to players on the user interface, but in some cases this wasn't indicated. For example, a "rockfall" which would disappear in improved weather was not obvious to players that it would disappear as the only way users could determine this was by making their character walk over and "examine" it. Since this itself costs energy, it is unlikely that players every examined such an object (and it was not clear to players that they *could* examine it). While this issue was specific to the design of *Energy Explorer*, it highlights the finding that researchers should spend time ensuring that the effects of weather or environmental changes are sensible, properly indicated, and predictable.

Feedback in terms of how many resources were given to players as a reward for their energy consumption was reasonably well indicated by the game, but as will be discussed in the next section, the meaning of these resources as a reward was a perhaps lacking in the design of *Energy Explorer*.

[96] Exit survey questions 4, 6, 22, 23, 31, 32).

#### 8.2.5.4 Promise of Reward and Avoidance of Punishment

Changing weather conditions and bonus resource rewards were a core form of the *reward*, *punishment* and consequence-related BCTs. However there was general disagreement from participants in the exit survey of these elements serving the role they were intended to accomplish[97]. This is in part likely due to the way the resources were implemented in *Energy Explorer.* Particularly, in many cases what wasn't clear was what that resource was for. This was likely to happen early in the game where players hadn't learned the purpose of some resources. This lack of attached meaning to the resources reduces their capacity for use as rewards for these BCTs. Future researchers are urged to ensure that resources are properly understood by players, particularly early on in the experience if those resources are to form part of the rewards and punishment BCTs.

A concept discussed at multiple parts of the game prototyping and design chapter of this thesis was the concept of having the game environment become more hazardous or difficult as a form of punishment players would want to avoid. It should be noted that even in the final version of *Energy Explorer,* this "punishment" resulted in more dynamic and challenging environments. Designers using this technique are cautioned to ensure that punishments don't become the more attractive option for players (because they player may be after more of a challenge or enjoy the visuals of the difficult weather), lest they end up with players *deliberately* using more energy (or exhibiting the desired behaviour less) in order to be punished. There was no evidence to suggest this happened in the deployment of *Energy Explorer*, but is a consideration that is worth mentioning all the same.

#### 8.2.5.5 Linking Identity with Player Avatar

*Energy Explorer* featured player avatars in order to facilitate the *identity associated with changed behaviour* BCT. While results for exit survey questions[98] relating to this element were *somewhat* higher than questions pertaining to other elements, there was still a general level of disagreement amongst participants for this.

It is possible that a general lack of engagement with the game resulted in players not associating strongly with their character. The avatar implementation was a basic one, and only provided limited options for players to personalize their character, thus it is possible that

[97] Exit survey questions 19, 20, 21, 34, 35, 37.

[98] Exit survey questions 11, 27, 31.

players weren't able to create a character that either appealed to them or matched their real-life identity, further reducing the association with the character.

Future researchers using player avatars to facilitate the *identity associated with changed behaviour* BCT are advised to ensure that the avatar system is robust enough to allow for player customization.

#### *8.2.5.6 Facilitating Social Behaviour Change Techniques through a Serious Game Implementation*

This work presents a practical workaround to facilitating social BCTs (e.g. incentivising messages, approval, etc.) by implementing these through fictional characters.

The literature for BCTs often refers to interventions that make use of in-person interactions and physical rewards in situations, rather than interactions that occur within in a computerised environment (Michie et al. 2013). Even technology-based interventions tend to include an in-person or phone-based component to facilitate social BCTs where participants would be informed of the approval/disapproval of their actions by someone with authority such as the researcher running the project. There is still no clear consensus in the literature on the impact of messaging from fictional game characters.

In the case of *Energy* Explorer, the chosen BCTs which were originally intended for a real-world environment, had to be embedded in a virtual, on-line experience. Some social BCTs were facilitated by in-game characters, rather than people with perceived authority. Upon reflection, additional messaging from real-people may have helped facilitate the social BCTs.

Therefore, in terms of recommendations to future researchers, further study into the use of messaging from fictional characters should be undertaken. Where possible, future work should consider the use of messaging from real people with authority in place of, or in addition to, fictional characters.

### 8.2.6 Ethical Concerns over the use of Smart Meter Data

Although participants in the trial did not raise any ethical concerns, upon reflection of the *Energy Explorer* experiment, it is important to discuss ethical concerns which may limit the uptake of the Serious Game for energy conservation.

If ethical concerns are not addressed in invitational materials for an energy conservation Serious Game, recipients may not want to participate in the study. Energy data can reveal patterns such as when residents are sleeping or when the house is empty (McKenna et al. 2012; Lisovich et al. 2010; Quinn 2009; Hargreaves et al. 2010), and so anonymised data may be required without further ethical procedures being observed.

In the case of *Energy Explorer*, ethical concerns were mitigated by participants being identified only by username (noting that participants were urged to select usernames which did not link to their real names, as seen in Figure 95 in Appendix N).

In terms of guidance for future work, it is important for researchers developing Games for Change in the energy conservation domain to consider the potential ethical issues that may arise when deploying their games. When implementing normative feedback, researchers need to consider *privacy* concerns over showing the energy usage data of one user to another. Ensuring the participants cannot identify each other by stressing that they enter a non-identifiable username is one approach to avoiding the ethical concerns of showing individual smart meter data. When working with more localised samples of participants where individuals are more likely to know each other, or in cases where using real names is *beneficial* to the normative feedback, researchers should be aware that this can lead to additional development work ensuring that data and names are only shared with authorised people.

### 8.2.7 Summary of Practical Lessons Learned from Implementation and Deployment Phase

In summary, in conducting the deployment of *Energy Explorer* this work contributes a number of findings that future researchers should consider when partaking in future research in this area. Factors involving the target audience were identified.

Depending on the sampling of participants, they may be already performing the target behaviour (energy conservation) at a high level. It is recommended that researchers in this area be wary of using datasets for energy consumption data that might be restricted those who are already energy conscious. Researchers should consider *targeted interventions* which are designed and provided to people who are identified as needing to change their behaviour.

Additionally, researchers are advised to assess the age group of the target audience before designing the intervention, and tailoring the design toward them. In a similar vein, there may be value in designing the game to suggest that participants engage in playing the game with other household members.

Target audience can also be a factor in terms of their familiarity with games. If participants have played games with strong production values before, then researchers should ensure the graphical quality and gameplay experience is of a high enough level.

This study found that there can be issues with participants from varying and remote locations of leading to a lack of ability to contact them. It is recommended that researchers address ahead-of-time the practicalities of conducting focus groups and interviews with participants for participatory design. In addition, it is important to consider the different weather conditions from each location, and control for this in analysis.

In presenting a novel approach to visualizing smart meter data, is the findings of this experiment recommend that future researchers be aware of the ways in which smart meter data frequency, granularity, format, reliability, accuracy, privacy, and availability may impact the implementation.

It is suggested that researchers conduct thorough testing of game functionality, with both experts and laymen representative of the target audience. This is particularly important on a mobile platform, and this section identified a number of issues inherent in developing for such a platform, including fragmentation of hardware, limited resources, frequent external communication, variable usage contexts, and platform-specific distribution.

Researchers are urged to ensure that participant counts are high enough to facilitate normative feedback. Where researchers cannot ensure a large enough number of participants for the "similar user" algorithm, they can present fictional users with "fake" results to users either in place of, or in conjunction with data from other users. When developing level-up systems, it is recommended that designers ensure that rewards (or the mere fact that there are rewards) is indicated to players in order to attach some meaning to the level-up system. Issues surrounding the implementation of game environment and resources directly responding to energy consumption as a form of feedback, reward, and punishment were identified, highlighting a need to ensure that players can predict, understand, and find meaning from changes to these elements. Additionally, this section suggested the need to ensure that player avatar systems provide enough customization to players in order to increase the likelihood they will form an attachment to their character.

Since a number of social BCTs were chosen, there was a practical need given the participant group size to implement these through fictional characters. Further study into the use of messaging from fictional characters should be undertaken. Future work should consider the use of messaging from real people with authority in place of, or in addition to, fictional characters.

Finally, this section has highlighted some possible ethical considerations that may limit uptake of Serious Games for energy conservation. Researchers are advised to pre-empt and alleviate any participant concerns, and act ethically with smart meter data.

## 8.3 Summary of Recommendations

This chapter has presented the challenges faced in the design and implementation phases of this project. Recommendations were given for each challenge, and Table 28 summarises these recommendations.

| Lessons Learned | Recommendations |
|---|---|
| **Design Phase** | |
| No previous work on combining BCW with Serious Games | Participate in discourse with experts in the field of behavior change and the target domain |
| | Build upon this work and lessons learnt from this thesis |
| No defined linkage between BCTs and theories | Keep up-to-date on literature from Michie et al. |
| | Consider the work by Connell et al. (2015) on mechanisms of action (MoA) |
| No defined linkage between BCTs game elements | Thoroughly examine game elements used in previous Serious Game studies |
| | Validate links between game elements and BCTs beyond the exit survey approach in this project |
| Lack of taxonomy of game elements and bias toward points, badges, and leaderboards | Supplement academically-sourced game elements with elements determined through brainstorming |
| | Obtain ideas from target audience on what game elements are suitable through focus groups |
| Choosing a Serious Game containing the chosen game elements | Evaluate possible game types, using criteria in Section 5.1.1 |
| Balance of serious and entertainment in designed game | Determine this balance based upon the context of the game, target audience, and development skillset |
| | To develop interventions with high production values, consider the Unity game engine, and make use of the Unity Asset Store |
| | Consider creating a game mod, to reduce development time as core game components are already developed |
| Focus on curtailment behaviours | Consider targeting effectiveness behaviours |
| Lack of participatory design | Ensure participant count is high enough to facilitate participatory design |
| | Consider a research design which allows for participants to interact with iterative versions of the Serious Game |
| | Use participatory design to inform APEASE components of BCW |
| | Use participatory design to guide select of game elements and encompassing game type |
| Potential bias during decision-making stages | Have multiple researchers involved in behaviour prioritization and game genre selection |
| **Implementation and Deployment Challenges** | |
| *Target audience* | |
| - Participants already saving energy | Be wary of datasets for energy consumption or participants from previous energy-related studies |
| | Consider targeted interventions designed specifically for people with problem energy behaviours |
| - Age group | Assess age group prior to deployment, and tailor design toward this |
| - Homeowners | Consider targeting entire household, and promote team-based play |
| | Within-household competition using room circuits |
| - Familiarity with video games | Ensure graphical quality and gameplay experience is of a high enough level |

| **Lessons Learned** | **Recommendations** |
|---|---|
| - Lack of contact | Assess ahead-of-time the practicalities of conducting focus groups and interviews with participants |
| | Consider the different weather conditions from each location, and control for this in analysis |
| Access to smart meter data | Be aware of the ways in which smart meter data frequency, granularity, format, reliability, query speed, accuracy, privacy, and availability may impact the implementation |
| Testing issues | Conduct thorough software testing |
| | Use testers representative of those in the main trial, or consider recruiting testers from main participant pool |
| *Mobile platform* | |
| - Fragmentation of hardware | Test using a wide range of devices, and operating systems |
| | Limit participation to a specific platform |
| | Consider the use of tools that reduce the development burden of targeting multiple platforms such as Unity or Cordova |
| - Limited Resources | Develop the game software within the constraints of the lowest expected hardware configuration |
| | Limit participation to devices with a minimum set of requirements |
| - Frequent external communication | Design software to handle variable network connectivity levels (Wi-Fi, mobile data, none) |
| | Consider payload size, and caching techniques |
| - Variable user and usage context | Design toward when and how players will engage with the game |
| | Consider prescribing usage of game to participants (i.e. require a minimum amount of use) |
| | Consider testing game in a laboratory setting |
| - Platform-Specific Distribution | Consider ways to ensure installation process is trustworthy to participants |
| | Use Fastlane Pilot software to automate and speed up the iOS TestFlight deployment process |
| *BCT-specific lessons* | |
| - Participant count impact on normative feedback | Ensure participant count is high enough to facilitate normative feedback |
| | If participant count is low, consider presenting players with fictional users, with appropriate "fake" data |
| - Explicit level-up rewards | If using level-up rewards, ensure that meaningful rewards are given, and that these rewards are explicitly defined for players (e.g. using a progression screen) |
| - Using game environment and resources for *feedback on behaviour* | Ensure environment changes are sensible, properly indicated, and predictable |
| - Using game environment and resources for *promise of reward / punishment* | Ensure players understand the purpose and meaning of resources from early-on in the game |
| | Be cautious of providing punishments to players which are ultimately something players might strive to make occur due to increased challenge or pleasing aesthetics |
| - Using player avatars for *associating identity with changed behaviour* | Ensure player avatar systems are robust and customizable |
| - Facilitating social BCTs within a Serious Game context | Conduct further study into the effectiveness of fictional characters to facilitate social BCTS |
| | Include messaging from real people with authority |
| Ethical concerns | Ensure that invitation to participate assures participants that their data will be secure |

| Lessons Learned | Recommendations |
|---|---|
| | When using normative feedback, ensure participants use usernames that are non-identifiable to other participants |

**Table 28. Summary of recommendations for the design and implementation challenges for this project.**

## 8.4 Chapter Summary

Designing and implementing a Serious Game using the Behaviour Change Wheel methodology posed a plethora of challenges, and as this is the first project to attempt this, the possible opportunities to build upon this work are numerous. This chapter has presented these challenges both in terms of the intervention design phase, and the implementation and analysis phase.

Design challenges were identified surrounding the evolving and relatively new nature of the BCW, and a large amount of missing literature on how various game elements could facilitate the chosen BCTS. Bringing together the game elements into a Serious Game was similarly challenging, as was attempting to strike the right balance of entertainment and fun in the game. Future opportunities for focussing on effectiveness behaviours instead of curtailment behaviours were identified, as was the concept of implementing participatory design as part of the methodology.

The participants in the study were identified as a potential problem for the study, in that they were older than the average gamer, and were potentially already energy conscious. Practical issues were described, such as problems with reliable access to the smart meter data, testing issues, and the plethora of difficulties associated with targeting a mobile platform. These issues were presented along with advice for future researchers to be aware of.

Game-specific issues were presented, such as the impact of a low sample size on the normative leaderboards element, as well as the need for a more defined levelling-up system, player avatar system, and the need for an easier-to-understand model for dynamic weather and resources. Finally, the impact of the large amount of data collected by the smart meters was discussed in terms of delays in processing, and ensuring the reported results were understandable.

It is important to discuss these issues, as this work is the first to implement the BCW for a Serious Game. The BCW is a powerful methodology, and the position of this thesis is that future work in the area should make use of it. Researchers should be made aware of the pitfalls and lessons learned from using the BCW in this context.

The next chapter synthesizes these challenges and opportunities, as part of addressing the research questions for this work

.

# 9 Conclusions

The guiding research question of this work asked of the opportunities and challenges in designing a theory-informed Serious Game. In order to answer that question, multiple sub-research questions were developed, focussing on how both Serious Games and behaviour change theory have been used independently for energy conservation in the past, how to bring them together during the design process, and the challenges involved in both undertaking and implementing that design.

This conclusion chapter synthesises the answers to each of the sub-research questions, before bringing these together to answer the main overarching research question. The chapter concludes by summarising the main contributions of this work.

## 9.1 Sub-Research Question 1

> *How have Serious Games been used to influence energy behaviour in the past and how could they be improved?*

The purpose statement for this work was to explore how games design and behaviour change techniques could be combined for energy conservation. This first sub-research question addressed the existing work on Serious Games in the energy conservation space, with a focus on the limitations and opportunities within that domain.

Chapter 2 presented a number of previous examples of Serious Games with the purpose of changing residential energy behaviour. Of the examples, the *Kukui Cup* (Brewer et al. 2011) was the most developed Serious Game for energy conservation, featuring leaderboards, video content, and competition and cooperation among students in University accommodation. Other games such as *Energy Battle* (Geelen et al. 2012), and *Power Agent* (Gustafsson et al. 2009) were more exemplary of games with actual game content such as narrative, characters, and gameplay elements. These studies were compared with studies described as Gamification examples such as *JouleBug* (Elliott 2012) which awarded users pins for completing various energy conservation tasks, and the wide-reaching *OPower* (Laskey & Kavazovic 2010) study.

It was clear from the examples given that some implementations could be considered Gamification rather than Serious Games, and the difference between the two was described as Gamification concentrating on the use of game elements within a non-gaming context compared to Serious Games which are video games "whole" with a serious purpose. In some cases, games were described as Serious Games but were closer to Gamification implementations. As a result, the studies presented were predominately website- or app-based, rather than whole games. The games were a far cry from traditional video games where players control an avatar, traverse rich environments, and interact with complex mechanics, both in terms of entertainment value and production values. They too were dissimilar to more advanced Serious Game applications in other domains such as the early *America's Army* (United States Army 2002), *Pharmacy Simulator* (Bindoff et al. 2014), and *Quittr* (Bindoff et al. 2016). The game elements used in the majority of energy domain examples were predominately forms of points, badges, and leaderboards.

Further to their shortcomings in terms of enjoyable game elements, the examples showed that both Gamification and Serious Game studies make little or no use of psychological theory and behaviour change theories, or at least when they do they predominately reference *Self Determination Theory* (Ryan & Deci 2000) and *Flow Theory* (Csikszentmihalyi 1990).

The issues of lacking theory and entertainment value each represent opportunities for further work in the domain of Serious Games for energy conservation that we should make better or more explicit use of behaviour change theory, and develop a fully-fledged Serious Games with greater production values.

In summary, the answer for this sub-research question is:

> *Serious Games have been used in the past to educate and incentivise people to reduce their residential energy consumption, as evidenced by work such as the Kukui Cup, Power Agent, Energy Battle, JouleBug, and OPower. Some Serious Games for energy conservation are similar to Gamification rather than Serious Games, and make little or no use of psychological and behaviour change theories. Additionally, production values in Serious Games stand to be improved, Advanced Metering Infrastructure and the increasing prevalence of smart meters mean researchers can not only analyse the effectiveness of a Serious Game intervention, but also develop games which react to energy usage of participants, potentially in real-time.*

## 9.2 Sub-Research Question 2

> *How can behaviour change theories be used to influence residential energy behaviour?*

The second sub-research question addressed the purpose statement and main research question by exploring the behaviour change theory component of these statements. Existing work in the energy conservation behaviour change space was explored.

The lack of theory used in energy domain Serious Games prompted the need for understanding ways in which behaviour change theory had been used in non-gaming contexts for energy conservation. Chapter 2 explored this and found that non-technology based solutions largely tested the effectiveness of applying *Social Normative Theory* (Perkins & Berkowitz 1986) in the form of *social norms*. Implemented as different forms of messaging, normative feedback told people how their consumption compared to that of relevant others (Schultz et al. 2007; Foster et al. 2010; Laskey & Kavazovic 2010) . Additionally, messaging that indicated to people that it was socially accepted and approved of to conserve energy were found to be effective. A simple injunctive norm (societal expectations of behaviour), in the form of a smiley face or an unhappy face on an energy bill resulted in a 2–5% aggregate increase in energy savings (Laskey & Kavazovic 2010).

Surprisingly, Serious Games in the energy conservation domain were found to not make reference to Social Normative Theory, representing one particular opportunity to implement theory in games.

While the literature on non-gaming interventions showed how theory can be used for energy conservation, answers were also found as part of the process of determining game elements that facilitate the BCTs described in Chapter 4. The literature on how elements can be used was sparse, however Rapp (2017) highlighted the applicability of *Expectancy-Value Theory* (Wigfield & Eccles 2000), *Avatar Identification* (Hefner et al. 2007; Gee 2003), and the *Transtheoretical Model* (Prochaska & Velicer 1997). The designed intervention shows new ways in which behaviour change theory can be used in an energy conservation context.

Based upon the literature found the summary answer to this sub-research question is:

> *Behaviour change theory has been used in the energy domain in the form of social normative theory. Social normative theory was applied to allow people to compare their energy usage to others. More relevant others made for more effective social feedback. There is an opportunity to use expectancy-value theory, avatar identification, and the transtheoretical model within the energy conservation domain through a Serious Game intervention.*

## 9.3 Sub-Research Question 3

> *How can we design a Serious Game that integrates game elements and behaviour change techniques within an energy conservation context?*

The problem statement in Chapter 2 stated a need for improved design of Serious Games within the energy conservation domain. This sub-research question was intended to address this by presenting a novel methodology that makes use of the Behaviour Change Wheel in a Serious Games context. Chapter 3 describes the overarching methodology used to design a

Serious Game for energy conservation, based upon the Intervention Research model (Rothman & Thomas 1994) and Human-Centered Design (Holloway & Kurniawan 2010). Given there were no suitable Serious Games in the literature that integrate game elements and behaviour change techniques which could be examined to address this question, this project focussed primarily on filling this gap in knowledge by undertaking a novel design process and reporting upon it. Chapter 4 presented the design phase, and Chapter 5 described how the intervention design was developed into a Serious Game titled *Energy Explorer*. Chapter 6 described the experiment used to evaluate the Serious Game, and the pilot phase that contributed to its design, and Chapter 7 presented the results from the experiment.

This thesis has shown the process of applying the Behaviour Change Wheel methodology (Michie et al. 2011) to the field of Serious Games. This process began by first understanding the target behaviour to change; in this case energy consumption. Specific aspects of energy consumption were identified, particularly the curtailment behaviours of *air conditioner* temperature adjustment, *turning off lights* when not in a room, and reducing *stand-by electricity consumption*. Intervention functions for addressing this were determined using the APEASE criteria by Michie et al. (2011), and the most promising ones for this project were *persuasion*, *incentivisation*, *coercion*, and *modelling*. According to Michie et al. (2011), each of these intervention functions have a set of behaviour change techniques from the larger set. The BCTs for each intervention function were again examined using the APEASE criteria, and ultimately 14 different BCTs were chosen, primarily focussing on providing feedback on behaviour, social comparison, and rewards.

With the mode of delivery predetermined to be a Serious Game on a mobile phone, the next step of operationalising the BCTs in the form of game elements was presented (illustrated by Figure 83). A combination of literature-based elements (sourced from Deterding et al. (2011), Chou (2016), Rapp (2017), Reeves & Read (2009), and Johnson et al. (2017)) and brainstorming resulted in a defined linkage between BCTs and high-level game elements such as game environment, resources, quests, characters, social systems, and leaderboards was developed. In total 16 unique elements were defined, and some were determined to address multiple BCTs, a linkage which was summarised in Table 17.

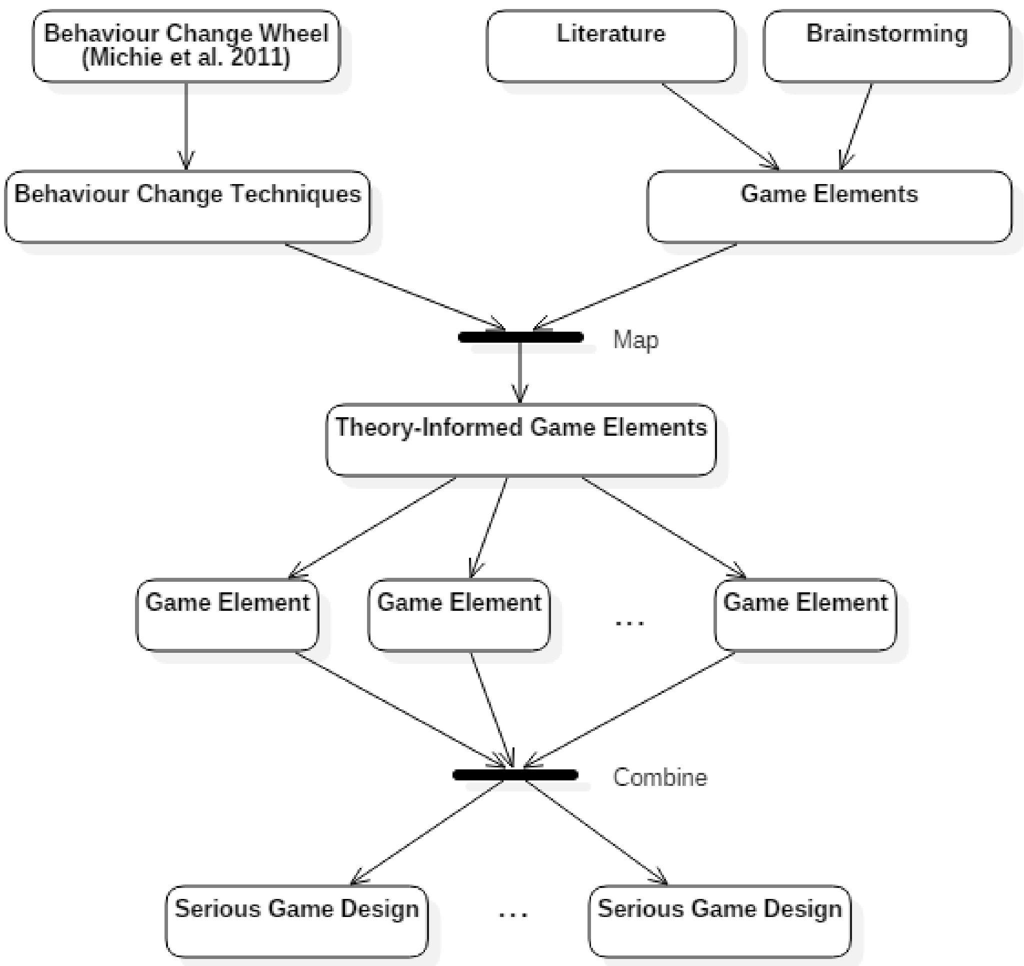



**Figure 83. The process linking the Behaviour Change Wheel to theory-informed game elements, and multiple Serious Game designs.**

This process of using the Behaviour Change Wheel to define BCTs, linking them to game elements, and bringing them together into a cohesive Serious Game is the core contribution of this work, and represents a potentially powerful new way of designing Serious Games for not only energy conservation, but other domains as well.

In Chapter 5, the chosen game elements were combined into a fully-fledged Serious Game. Four prototypes were developed, showcasing the fact that the designed intervention could be implemented in many different ways, despite having the same goal. This is a key contribution of this thesis: the method of determining game elements does not restrict researchers to a particular game type, and indeed there is an opportunity to compare multiple game implementations stemming from the same intervention strategy.

The *Energy Explorer* prototype is an exploration game with mechanics that are tightly linked to real-world energy consumption. Players traverse a semi-procedurally generated game world, completing quests, collecting items, and finding new areas. The amount players are able to play is governed by their in-game "energy" resource, which in turn is governed by their energy consumption. Perhaps the most novel component of *Energy Explorer* is the impact of real-world energy usage on the game-world's weather. Positive behaviours result in sunnier, and more vibrant environments which cost less in-game energy to traverse (in some cases free-travel), whereas negative behaviours result in a dilapidated, weather-torn environment which is slower to traverse and costs more in-game energy. Effect on in-game weather is plausible in many game types and genre, and how future implementations progress with this idea will be interesting to follow. It is possible to complete the main gameplay aspects of *Energy Explorer* with no improvement in conservation behaviour, however progress increases dramatically with positive behaviours as quest requirements are obtained faster, and more of the game world can be traversed. The prototype brings together the elements from the BCW process into a Serious Game whole and represents the final part of the design component.

The Serious Game implementation was tested and improved as the result of a pilot phase, and then implemented on participants in the field on their person devices. Chapter 6 described the outcome of the pilot phase which involved subject matter experts from the CSIRO in Newcastle, and resulted in a number of changes to messaging, the discovery of multiple device-specific bugs, and the testing of the smart meter integration across multiple devices. For the main experiment, participants were recruited from the Residential Building Energy Efficiency Survey (RBEES), all of whom had smart meters which the game was designed to interface with. Data collected included energy consumption, game usage in terms of metrics, entry and exit surveys, and the original RBEES survey data.

Chapter 7 presented the results of the main experiment, in which 20 participants responded to the invitation to play. Using a pre-test/post-test experiment design, difference in energy consumption to relevant similar days was compared before and after playing the game. Results showed a low magnitude yet significant change in conservation effect (defined as average difference in consumption compared to the 20 most similar days, in order to control for weather effects) for participants who played the game compared to those who did not between the 14-day period before and 14 days after being given access to the game. For the first day playing *Energy Explorer*, female participants had a significantly better conservation effect, although again the magnitude of this was low.

The average age of participants was much higher than the average age of gamers, and as age increased, familiarity with video games decreased. 55% of participants were "very" or "extremely" mindful of their household energy consumption, and 95% of participants who played the game stated that they took steps to limit their household use of energy. These numbers were similar to that of the RBEES participant pool, indicating a bias toward energy consciousness.

Participants interacted with the Serious Game for on average 23.4 minutes, and completed 83.3 game actions each, which indicates a general under-use of the game by participants. Game experience question responses from participants indicated that players disagreed that the implemented game elements facilitated the chosen BCTs.

Individual participants were examined who represented high-, median-, and low-usage of the game as recorded by the game metrics. The player who played the game the most was less conscious of their energy usage than the median- and low-usage example users.

This work has presented the following answer for sub-research question 3:

> *The Behaviour Change Wheel can be applied to the domain of Serious Games to integrate Behaviour Change Techniques (BCTs) into the design. The BCW was used in the context of a Serious Game for residential energy behaviour change. Using the BCW, the target behaviours can be understood in detail, and appropriate techniques (BCTs) can be determined. BCTs can be linked to game elements which are sourced from literature and a brainstorming process. The linkage of game elements to BCTs should draw upon the growing extant literature on video games. Game elements can then be combined into a fully-fledged Serious Game. An iterative design process is recommended where the software is improved to suit the target audience.*
>
> *The effectiveness of such a design in practice is not yet known. Analysis of energy conservation effect on participants who played the game compared to those who did not showed a small magnitude yet significant reduction in energy usage. Limitations with the deployment of the Serious Game including a bias resulting from a convenience sample mean that further evaluation of designs using this method is required.*

## 9.4 Sub-Research Question 4

> *What are the challenges involved in designing a Serious Game for changing residential energy behaviour?*

The purpose of this work was to *explore* the opportunity of combining game design and behaviour change techniques. The design process of *Energy Explorer* was a novel one, and one that it is hoped that it may be built upon further in future research. As such, it is important to not only present this design process but also discuss the challenges involved in the process, so as to highlight the lessons learned, and potential pitfalls when extending this method.

An extensive discussion was presented in Chapter 8, and many challenges were described, primarily relating to the need to extend the Behaviour Change Wheel to suit game design, and the sparsity of literature both on game elements and the psychological properties of game elements. These challenges were summarised in Table 28.

The BCW is still relatively new, and in 2017, research by Susan Michie and her team is ongoing on gaining a better understanding of the interplay between behaviour change techniques, theories, and mechanisms of action. As a result, the process of defining BCTs in terms of theory is still not fully defined, perhaps leaving teams utilizing the BCW with some doubt over their interpretations. Further to this, BCTs certainly have not been linked to game elements before, and so the process of doing so purely based upon literature was essentially unfeasible. Experimental study into each of the multitude of possible game elements was not a plausible approach within this project, and so a process of brainstorming was conducted to complete the process of linking BCTs to elements.

These issues themselves as presented in this thesis highlight the need for the ongoing work on the BCW to continue, as well as for more research into individual game elements. Game element research could be advanced by producing taxonomies of elements, as well detailing their behaviour change properties—even better if done within the context of BCTs.

The final step of the design process was to determine the Serious Game in which the chosen game elements would be contained. Again, this process has never been defined academically before, and so recommendations to future researchers were given, to consider the development ability of the team, the flexibility and suitability of the game type to facilitate the game elements, and the entertainment value and popularity of the game.

Also explored was the ongoing debate over how much entertainment content should go into a Serious Game before the message or purpose of the game is overshadowed. *Energy Explorer* represents a Serious Game whole, with graphics, narrative, and gameplay elements intended to promote entertainment, while including limited explicit energy conservation messaging. While there may not be an answer to what is the right balance other than "it depends" on the domain, target audience, and purpose of the game, this nonetheless remains a challenge that was faced, and likely to be faced by future teams.

This work used the BCW to focus on energy curtailment behaviours which are low-cost, repeatable actions that can conserve energy (or the lack of engaging in that action which results in conservation), as opposed to effectiveness behaviours which are higher-cost, once-off actions that have long lasting conservation effects such as installing energy efficient light-bulbs. Future researchers are encouraged to consider this avenue of energy behaviour.

Finally, the design process in this project likely suffered from the lack of Participatory Design. Limited participant count and access prevented the effective use of such an approach, however it is clear in conclusion that future iterations of this methodology should allow scoping and prototyping to be informed in-part by the opinions of the likely end-users of the Serious Game.

The answer to this sub-research question is:

> *Combining behaviour change techniques and energy conservation using the Behaviour Change Wheel brings with it myriad design challenges, stemming from the lack of defined knowledge linking BCTs to game elements, and work needs to look at adapting recent studies on mechanisms of action (MoA) to game elements. Literature on game elements themselves is sparse beyond that of Gamification's points, badges, and leaderboards, and researchers may find it difficult to find elements to facilitate BCTs without partaking in extensive brainstorming activities. Researchers need also carefully balance the level of "seriousness" in their games with entertainment based upon target audience and development skill level. When using a small sample of users to facilitate energy consumption data collection, issues surrounding the ability to effectively employ participatory design methods can be diminished if researchers want to avoid contaminating their participant pool for a larger "main" trial; thus alternate experiment designs with iterative versions of the game should be considered.*

## 9.5 Sub-Research Question 5

> *What factors can influence the likelihood of successes of a Serious Game for changing residential energy behaviour?*

The discussion in Chapter 8 focussed not only on design challenges, but also on the limitations and lessons learned implementing a Serious Game developed using the BCW process. These challenges, summarised in Table 28, were primarily regarding the demographic of the participants, smart meter data, and software-issues such as bugs, and the implementation of the chosen game elements.

The participants in both the control and experimental groups were members of the original RBEES trial—a trial which they were recruited for which was about energy efficiency. As a result, it is possible that the participants were *already* energy conscious and conserving energy at or near to their full capacity, and this was reflected in their original survey responses, where the majority of RBEES participants either agreed or strongly agreed to the statement "we are an energy conscious household". Having a wealth of detailed smart meter data came at the cost of a potential bias in attitudes of participants. Additionally, the age of the participant group was higher than the average age of a gamer, although self-reported familiarity with games was high. With a high familiarity with mobile games, participants may have had high expectations for the quality of the developed Serious Game, and proceeded to not engage with the game after witnessing bugs or long loading times. As described previously, not having direct access to participants during the development process also reduced the suitability of the game for the target audience.

Smart meter data access posed problems during the experiment, and while these were primarily implementation-specific, the issues encountered surround availability, reliability, granularity, format, variability, and frequency are still highly relevant to future researchers integrating smart meter data into their games.

Targeting a mobile platform allows for widespread distribution, and greater opportunity for participants to engage with the game, however it brings with a multitude of issues which were described in Chapter 8, including the different ways, and times in which users interact with the game (and the expectations and requirements that go along with that), fragmentation of hardware and operating systems, reliance on operating system- or device-specific functionality, and the fast-growing nature of mobile market.

Some game elements needed further revision before testing. Low participant numbers resulted in limited entries on the normative leaderboards, which could have been counteracted by fictional entries. These fictional entries could have been programmatically created to be deliberately higher on the leaderboard to bring about further conservation. Level-up rewards followed the recommendations in literature to have in-game effects, however these effects were not known-ahead of time, reducing their effectiveness as incentive, and the effects on internal workings of the game such as improved chance to display certain more advanced areas were hidden from the player. As a result, levelling-up did not perhaps did not provide players with a sense of progress like it was intended to do, leading players to believe they had seen all aspects of the game, when in reality those aspects were simply locked until a certain level requirement was met.

Chapter 8 also covered a plethora of ways in which *Energy Explorer* could have been expanded, and help provide a clearer picture of the intended grand design of the game in the thesis. Some of the elements from the BCW process were not implemented due to time and scope constraints, such as the social components of clans and news feeds, world building and crafting, and more advanced social normative comparison. Furthermore, game mechanics which were not related to BCTs were described that would have increased the depth of gameplay through more advanced exploration mechanics and combat.

Analysis was another challenge for future researchers to be aware of. With the smart meter database accessed in this project, the speed of transfer of data for analysis combined with the amount of data available (i.e. 60 second intervals across multiple channels per user over a period of many years) caused delays in processing data analysis. Additionally, presenting cohesive and understandable results from such a large dataset was similarly challenging.

Finally, ethical concerns of the use of smart meters were discussed. Although there was nothing that indicated that ethical concerns were part of this study, smart meter data can be used to determine behaviour patterns such as when a house is occupied, or when people eat. This information could be used to facilitate burglary or targeted advertising.

In summary, the answer to this sub-research question is:

> *Biases in energy consciousness stemming from convenience samples that may be required in order to gain appropriate access to smart meter data can be a factor which influences the likelihood of success of a Serious Game for energy conservation, as participants are already conserving a great deal of energy. Targeting participants from alternate datasets with less bias toward energy conscious households may be a worthier endeavour, as there may be more opportunity to reduce energy consumption. Other participant-related factors include the age of participants, which was strongly negatively correlated with reported familiarity with video games. High familiarity may result in high (and unmet) expectations, whereas low familiarity may result in difficulty understanding game controls and concepts.*
>
> *Other factors that may influence the success of a Serious Game for energy conservation include those related to the mobile platform, specifically the range of hardware and software across users resulting in higher chance of software failure, variability in usage contexts, and deployment without using official platform stores. Smart meters present deployment challenges surrounding access, reliability, frequency, and granularity*

*Finally, reduced effectiveness of normative feedback due to low participant counts, level-up rewards and the workings of dynamic resource and weather systems not being explicitly portrayed to players, and ethical concerns surrounding smart meters may factors that influence the likelihood of success of a Serious Game for energy conservation.*

## 9.6 Main Research Question

The literature review chapter identified the opportunity to improve the design of Serious Games for residential energy behaviour by pointing out the need for theory-informed game design, and the design and implementation phases of this work have exemplified this opportunity by making use of the Behaviour Change Wheel to combine behaviour change techniques and game elements into a Serious Game.

A problem statement was developed in Chapter 2:

*Serious Games for changing residential energy behaviour suffer from a limited set of game design elements, and do not effectively integrate behaviour change techniques in their design.*

To address this problem, this work aimed to present a method for combining Serious Games and behaviour change techniques, and to describe the lessons learned in designing and deploying a Serious Game with this. The purpose statement to formalize this was:

*The purpose of this work is to explore the opportunity to integrate games design and behaviour change techniques to develop a Serious Game for changing residential energy behaviour, and to discuss the challenges involved in doing so.*

The guiding question of this work asked:

*What are the opportunities and challenges in integrating both games design and behaviour change techniques towards the development of a Serious Game for changing residential energy behaviour?*

This work has presented a design methodology in which games design and behaviour change techniques can be integrated to produce a Serious Game. This was accomplished within the domain of residential energy behaviour, however the process and many of the lessons learned can be applied to any domain for Serious Games, making the presented method all-the-more valuable.

There are many challenges involved in bringing together game elements and behaviour change techniques, and this work has described these at length. Video game and game element literature is still maturing, and so determining suitable elements for BCTs was difficult and hard to define academically. Choosing a Serious Game containing the chosen elements was also challenging, and a number of possible prototypes were created. Recommendations for future research in this area include employing a Participatory Design approach, and considering the balance between entertainment value and "serious" concepts within a Serious Game.

Evaluation of the developed Serious Game showed no significant difference between participants, and a number of issues with the implementation game *Energy Explorer* were identified. The target audience were already energy conscious and potentially already saving energy at a high level. Additionally, the participants were familiar with mobile video games, and so long load times, and other features may have been considered unacceptable and resulted in reduced engagement. Challenges developing for the mobile platform were presented, including fragmentation of hardware and operating system across devices, variable usage contexts, and limited hardware capabilities for games.

Challenges were faced in implementing the chosen game elements. The functionality and effectiveness of normative leaderboards can be improved with fictional entries when participant count is low, and levelling-up rewards should be made more explicit to players. Some elements were not implemented due to time and scope constraints, such as clans, world building, and social features.

The answer to main research question that guided this work is:

> *The Behaviour Change Wheel presents an opportunity to integrate behaviour change techniques and Serious Games design. Smart meters are a technology that can be used to enable real-time feedback in a Serious Game for energy conservation. Game elements which facilitate behaviour change techniques such as quests, avatars, levelling-up, and social systems can be combined to form a fully-fledged Serious Game, and these elements can react with smart meter data. Challenges in taking this approach include the need for further work on the Behaviour Change Wheel, limitations in extant literature on game elements, balancing production values and Serious Game content, choice of target behaviours, and the inability to use participatory design due to a small participant pool. When deploying such a game, biases in the energy consciousness of participants may be a factor, whereas this may be alleviated by targeting high energy users. Familiarity with games, and age of participants if participant pool is homeowners may also be a factor. Challenges inherent in mobile platform development and deployment may be faced, and low participant counts can limit the effectiveness of normative feedback through leaderboards.*

With the main research question addressed, the next and final section of this chapter outlines the contributions of answering this question.

## 9.7 Contributions

This section outlines the contributions of the thesis to theory, practice, and methodology.

### 9.7.1 Contributions to Theory

Prior to this work, knowledge existed on how to develop Games for Change for an effectively limitless set of application domains (Michael & Chen 2005; Connolly et al. 2012). Additionally, knowledge of behaviour change theory had been applied to a wide range of areas (Abraham & Michie 2008). Both Games for Change and behaviour change theory have previously been used independently in the area of energy conservation (Johnson et al. 2017; Schultz 2010), however the literature review has shown that the two were rarely combined, or when they were, limitations existed in the integration (see review in Sections 2.1.4.3 and 2.3.2.7). In presenting the application of the Behaviour Change Wheel to Serious Games in the context of energy conservation, this work has contributed a way of improving Serious Game design with theory. This was done by providing an example the BCW being used in the area of Serious Games which has never been done before, and the plethora of recommendations which have been identified by answering SRQ4 (and detailed specification in Chapter 8) will provide a clear guide for future researchers applying the BCW to their work. This contributes to the body of knowledge in the fields of psychology, Games for Change, and energy conservation. The process of applying the BCW to an energy conservation game can be applied to Serious Games in general. This work *extends* the BCW to provide a crucial missing link between Behaviour Change Techniques and game elements, and provides a practical example of operationalizing and justifying the chosen elements in a Serious Game. Further to this contribution, findings around implementing certain game elements with BCTs in mind were presented in Section 8.2.5 and summarised in SRQ4.

This work has shown that the BCW (and particularly the presented extended version) is a promising way of augmenting Serious Game design, by prompting designers to think about the behaviours they are intending to change in a more systematic way—something which Chapter 2 showed has traditionally not been undertaken in this area. This thesis exposes and discusses the pitfalls involved in undertaking the BCW in the context of Serious Games, and this is synthesized in Section 8.3.

This work has contributed knowledge on how various game elements such as quests (Howard 2008), checklist items, social systems , and levelling-up systems can facilitate select BCTs defined by Michie et al. (2011). The *Energy Explorer* software extends existing work providing energy usage feedback to participants using smart meter data by implementing this in a full mobile game experience (Ehrhardt-Martinez et al. 2010; Parker et al. 2008; Mountain 2006).

This thesis contributes to the ever-growing body of work to mitigate Climate Change—the importance of which is extremely high given its impact on food and water availability, and weather conditions worldwide (IPCC 2015).

Providing energy feedback in the residential sector may save up to 100 billion kilowatt-hours of electricity annually in the United States alone by 2030 (Ehrhardt-Martinez et al. 2010). Currently provided energy feedback systems are not sufficient to provide meaningful motivation and behaviour change, and research has called for improved energy feedback systems (McKerracher & Torriti 2013; Strengers 2008; Houde et al. 2012; Nusca 2011).

### 9.7.2 Contributions to Practice

This work has contributed to practice by presenting a practical working example of a Serious Game which integrates behaviour change theories as determined by the Behaviour Change Wheel. Further to this, the challenges and lessons learned from going through this process contribute to practice, as future researchers can be aware of the things they should avoid and consider when extending this work (Chapter 8).

*Energy Explorer* is a Serious Game with elements and production values close to a traditional entertainment video game. The game contributes to a growing body of work in academia of Serious Games with strong production values such as the studies by Bindoff et al. (2014). The game also provides an example of a fully-fledged game, which is not often seen within the energy conservation Games for Change space (Johnson et al. 2017).

In addition, the system architecture used to facilitate the *Energy Explorer* Serious Game represents a contribution to practice, as details of how it enables the transmission of smart meter data to a Serious Game on demand. Johnson et al. (2017) note the lack of transparency about how some energy conservation games collect energy conservation data. The system was defined in a way that games other than *Energy Explorer* could be used.

Finally, alternate prototype video games to *Energy Explorer* using the chosen game elements were presented (described in greater detail in Appendix D). The ways in which these games could facilitate behaviour change and implement the game elements were described in the hope that future researchers may implement or build upon these designs.

The advantages of the development of successful Serious Games for reducing energy consumption are expected to be experienced not only by the planet itself due to reduced $CO_2$ emissions (IPCC 2015), but also by many in the energy supply chain (Faruqui et al. 2010; Ehrhardt-Martinez et al. 2010). This work contributes to this effort by presenting *Energy Explorer*.

### 9.7.3 Contributions to Methodology

The methodological contribution of this work is the novel extension of the Behaviour Change Wheel to apply it the domain of Serious Games. Previously, there have been a wide range of studies using the BCW, but none focussing on Games for Change. This work has presented a step by step method for developing a Serious Game using the BCW. First, as the BCW suggests, the target behaviours must be defined and understood, and intervention functions selected. From these intervention functions, Behaviour Change Techniques are chosen. This work then presents an augmentation to the BCW's step for developing an intervention strategy, by showing how to link game elements to these BCTs. From there, plausible game types are considered (including the possibility of producing multiple game types) that suit the game elements and BCTs.

Recommendations to future researchers to avoid or mitigate the challenges and issues that may be faced when implementing this method for designing and deploying a Serious Game were presented. These recommendations are a core part of the methodological contribution of this work, as they show how the novel process presented could be improved.

Recall that Johnson et al. (2017) stated the need for more studies which attempt to isolate the impact of a Serious Game compared to no intervention by using a control group design. This work has contributed to this need, by providing an example of an experiment using a control group design within the domain of energy conservation Games for Change.

## 9.8 Chapter Summary

Video games are growing in popularity in both entertainment and academic contexts. Serious Games, which are video games with a serious purpose other than entertainment, and Gamification—the use of game elements in non-gaming contexts—are being used in areas such as education, training, therapy, and scientific discovery. This thesis has presented an argument for embedding behaviour change theory into the core of the design process of creating Serious Games both in general and within the domain of residential energy conservation. Serious Games for energy conservation are lacking in the use of theory in their designs, with many games relying on points, badges, and leaderboards.

This work has presented a systematic way of integrating game design and behaviour change theory by employing the Behaviour Change Wheel methodology. The results of using the BCW to explore target energy conservation behaviours, and ultimately determine intervention functions, and behaviour change techniques have been presented. BCTs were linked to game elements using a mix of literature and brainstorming, resulting in an intervention strategy. From here a process of combining these game elements into a Serious Game whole was described—a process which can result in multiple different game ideas.

The Serious Game *Energy Explorer* is an exploration game where the player completes quests in a semi-procedurally generated world to reveal a narrative. The game provided feedback to players on their energy consumption both explicitly through the in-game interface, and implicitly by influencing the game resources and game environment. Social comparison was facilitated with normative leaderboards, and reward and incentives were implemented through quests, checklists, daily rewards, and levelling-up. The game was tested on 20 participants recruited from the Residential Building Energy Efficiency Survey originally conducted by the CSIRO in 2012.

A total of 1,666 game actions were recorded (on average 83.3 actions per player), and the average total time playing the game was 23.4 minutes. Participants witnessed most features of the game, however did not play the game as much as hoped.

A significant difference in conservation effect change for participants in the treatment group compared to the control group was found when comparing 14 days before and 14 days after playing *Energy Explorer*. On the first day of playing the game, female participants a significantly better conservation effect than males. While significance was found, the magnitude difference was small.

A range of challenges were encountered throughout the design and implementation phases, and lessons learned and recommendations to future researchers employing the BCW for a Serious Game have been provided. The BCW is still being developed, as is literature on game elements and the ways in which games can bring about behaviour change. Issues were identified with the demographic of the participant group, access to smart meter data, and software and hardware issues related to the mobile platform.

In the fight to mitigate Climate Change, researchers are exploring ways of reducing energy consumption. Serious Games can and have been used to bring about residential energy behaviour change, however until now have not been informed by behaviour change theory. The Behaviour Change Wheel represents a promising opportunity to improve Serious Game designs, and game elements are a way of implementing Behaviour Change Techniques. Using the systematic method presented in this work and the lessons learned herein, future Serious Games for energy conservation and other domains may include behaviour change theory in their design.

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# Appendix A Experiment Internal and External Validity

## A.1 Internal Validity

Since a true experimental approach was taken with control groups, the internal validity of the experiment is high. The control group allows confounding effects to be countered by the fact that this group would also have the same effects applied to them as the treatment groups. Campbell & Stanley (1963) identify eight factors that affect internal validity, and these are presented below in terms of how the research design handles them:

- *history*:
  - *issue*: events occurring between the measurements—events that could impact the dependent variable include (but are not limited to): weather changes (which was expected to occur due to seasonal effects), changes to household size, changes to household efficiency measures (installation of more efficiency appliances etc.), and absence due to holiday or work;
  - *control*: any external event that caused a difference for the treatment groups would also cause a difference for the control group Additionally, seasonal effects within-participant are controlled by the use of the "similar days" calculation described previously;
- *maturation*:
  - *issue*: where participants change simply due to the passage of time, rather than the effects of the intervention;
  - *control*: this should occur equally in both the control and treatment groups, and short duration of game testing (less than one month);
- *testing*:
  - *issue*: the effect of taking the first test upon the second test;
  - *control*: energy consumption tests in this case do not require participant interaction, as data is sourced from automated database;
- *instrumentation*:
  - *issue*: changes in calibration of measuring equipment;
  - *control*: the same equipment was used for all of the RBEES participants, and any discrepancy between them would manfiest equally in both the control and treatment groups;

- *statistical regression*:
  - *issue*: group selection based upon extreme pre-test scores;
  - *control*: control group assignment determined by non-acceptance of invitation—this assignment of users was unavoidable, in order to maximise participant count;
- *selection*:
  - *issue*: bias based upon groupings;
  - *control*: normally controlled by random control group assignment, however the need for participants to accept the invitation to play the game introduces a non-response bias whereby members of that group will likely only include those with a positive impression of the game, and a will to play the game. This form of bias is a common issue with the validity of invitation-based interventions such as this, and should be combatted by obtaining a high number of participants (Sackett 1979);
- *experimental mortality:*
  - *issue:* disproportional loss of participants from the groups;
  - *control:* higher participant counts; and
- *selection-maturation interaction*:
  - *issue*: maturation effects caused by selection process;
  - *control:* maturation not expected to have an impact due to short game testing duration.

Energy usage is highly dependent on weather conditions, however as described for the history alternate hypothesis, the control group addresses this. However, participants in the RBEES cohort were from different locations with different weather conditions (Melbourne, Brisbane, and Adelaide). Thus, in addition to comparison between the control and treatment groups, comparison was made between the three groups for each of the three locations. Since a similar days comparison was employed, the impact of differences in weather conditions (particularly differences in humidity) were minimised.

Given this, the internal validity of the project is high, with the only alternate explanation for difference in control and treatment groups to be based upon response to the invitation to the game.

## A.2 External Validity

Despite measures to minimise bias for the internal validity of the project, there are some issues in terms of the external validity or generalizability of the study. These issues are presented in a brief form here, and expanded upon in detail in the discussion in Chapter 8. It should be acknowledged that further research on a different sample is needed before any causal inferences on the general population can be made.

Rothwell (2005) list a number of ways in which external validity of a project can be analysed. This was done generally in the domain of health-related interventions; however, the concepts are generalizable to provide a suitable guide for the issues presented in this section. The following issues were identified by Rothwell (2005):

- *setting* of the trial;
- *selection* of patients;
- *characteristics* of randomised patients;
- *differences* between the trial protocol and routine practice;
- *outcome measures* and *follow-up*; and
- *adverse effects* of treatment.

The main issue with external validity for this project was the population from which participants were recruited. Whilst there were no overwhelmingly different characteristics within the participant group, the group in its entirety represent a population who are consenting participants in the Residential Building Energy Efficiency Standards project. According to Ambrose et al. (2013) these participants generally identified with being energy conserving households, and their houses were all constructed within the past 13 years. The RBEES participants when surveyed in 2013 did however have a self-reported spread in terms identifying with being “high”, “moderate”, or “low”, energy consumers (see characteristics in Section 6.2.1.3). It is important to note the RBEES trial did not consist of any request or intervention to bring about improved energy behaviour, however exposure to the survey for RBEES may have provided information bias to the participants by alerting them to energy efficiency and curtailment behaviours. A full description of the RBEES participants is provided by Ambrose et al. (2013), and summarised in Section 6.2.1.1. In addition, the RBEES participants were used as the participant pool for the Low Carbon Readiness Index (LCRI) survey [99], which was conducted throughout 2015and 2016, including the time when participants were invited to play the Serious Game. The LCRI project surveyed participants

[99] At time of writing this work was not published, a summary of the LCRI project can be found at http://www.lowcarbonlivingcrc.com.au/research/program-3-engaged-communities/rp3012-environmental-attitudes-low-carbon-behavioural

on their environmental attitudes, and again no intervention took place to confound the results of this project.

In terms of the setting of the trail, the view on external validity varies based upon the perspective of critique. From the perspective of generalising to an Australian population, the split of participants across three major capital cities (Melbourne, Brisbane, and Adelaide) is favourable given the distance between these locations. However, from a more global perspective, the participants are exclusively from Australia. Further longitudinal studies are required to address this issue. Additionally, the game trial only lasted a few weeks, and so further testing with a greater post period would help investigate any long-term effects.

# Appendix B Theoretical Domains Framework Analysis

In order to obtain a greater understanding of the target behaviours, the extended version of COM-B, the TDF was used for analysis, however in the interests of brevity were excluded from the main thesis narrative. This appendix first describes the TDF, before presenting the results of this analysis for completeness.

## B.1 Theoretical Domains Framework

An extension to the COM-B model is the Theoretical Domains Framework (TDF, Cane et al. 2012) which effectively subdivides the core components of COM-B into 14 different areas as described in Michie et al. (2014):

- *knowledge*: awareness of the existence of something;
- *skills*: ability or proficiency acquired through practice;
- *social/professional role and identity*: set of behaviours and personal qualities of an individual in a social or work setting;
- *beliefs about capabilities*: acceptance of truth or reality regarding ability, talent, or facility that can be put to constructive use;
- *beliefs about consequences*: acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation;
- *optimism*: confidence that things will happen for the best or that goals will be attained;
- *reinforcement*: increasing the probability of a response by arranging a dependent relationship between the response and a stimulus (negative or positive);
- *intentions*: conscious decision to perform a behaviour;
- *goals*: mental representation of outcomes that an individual wants to achieve;
- *memory, attention, and decision processes*: ability to retain information, focus selectively on aspects of the environment, and choose between alternatives;
- *environmental context and resources*: any circumstance where a situation or environment discourages or encourages the development of skills and abilities, independence, social competence, and adaptive behaviour;
- *social influences*: interpersonal processes which cause individuals to change their thoughts, feelings, or behaviours;
- *emotion*: complex reaction patterns involving experiential, behavioural, and physiological elements, by which an individual attempts to deal with an event; and
- *behavioural regulation*: anything that is aimed at managing or changing objectively observed or measured actions.

As **Error! Reference source not found.** shows, the TDF domains map to the components of the COM-B model, and thus can be considered another layer in the behaviour change wheel.

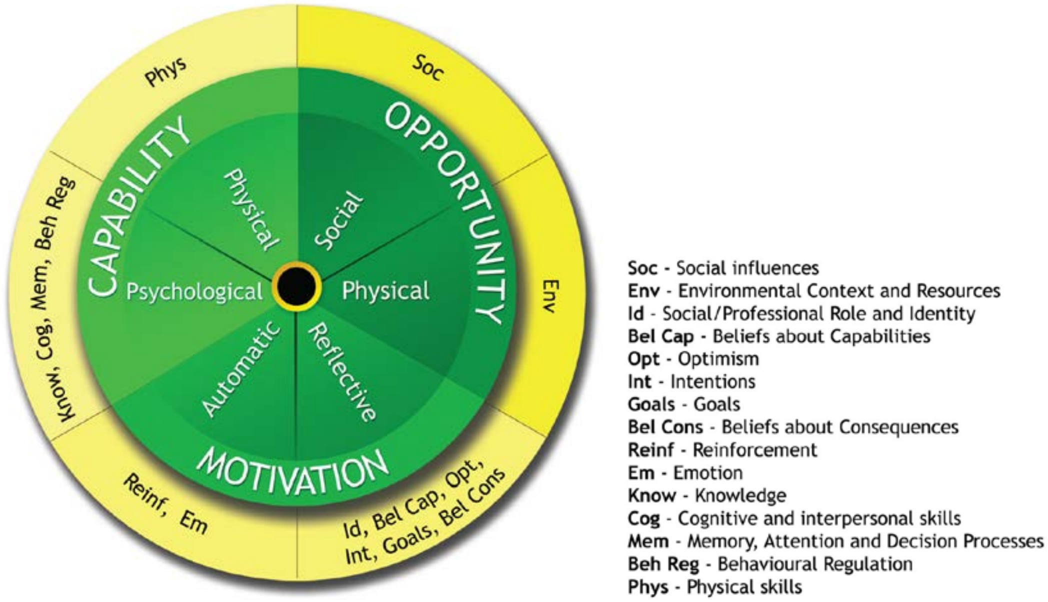


**Figure 84. Components of the Theoretical Domains Framework (Cane et al. 2012) represented in terms of the COM-B model (Michie et al. 2011). It should be noted that 15 components are listed in this diagram, as it appears physical skills, and cognitive and interpersonal skills were combined in Michie et al. (2014) as simply "skills".**

The TDF was originally designed by Michie et al. (2005) with a team of 32 international behavioural experts, and later validated and refined in 2012 by Cane et al. with a team of 36 experts. Questionnaires have been developed based upon various versions of the TDF for researchers to use to discover more about the behaviours they are targeting (Taylor, Parveen, et al. 2013; Taylor, Lawton, et al. 2013; Huijg et al. 2014).

## B.2 Results

The results of this analysis using the TDF are presented in Table 29, Table 30, and Table 31.

Only the stand-by electricity behaviour has physical skills as a relevant element, due to the possible need for physical access to get to the off switch for appliances. Stand-by electricity and air conditioner usage both had environmental context and resources considered relevant but for different reasons. Air conditioning required the need to reduce physical urges, whereas stand-by electricity was related to physical access. All behaviours had knowledge, memory, attention, decision processes, and behavioural regulation as plausible areas. Social elements of TDF were identified for all behaviours as household "leaders" could inspire other household members. Believing that changing behaviour will have a positive environmental and monetary impact was considered plausible. Given the behaviours are repeatable curtailment behaviours, reinforcement was plausible for forming habits. Emotion was identified for all behaviours with the idea that overcoming the urge to maintain a comfortable lifestyle at the detriment of energy conservation was a plausible option.

Some elements such as intentions, cognitive skills, and beliefs about capabilities were not considered relevant as most people already are aware that they *should* be engaging in these behaviours.

| **Target Behaviour:** | **Adjusting air conditioner usage** | |
|---|---|---|
| **COM-B** | **TDF** | **Relevance of domain** |
| Physical capability | Physical skills | Not relevant as physical skill to use air conditioner controls is held by most relevant household members |
| Psychological capability | **Knowledge** | Know how to create and apply if-then rules for adjusting the temperature of the air conditioner |
| | Cognitive and interpersonal skills | Not relevant |
| | **Memory, attention and decision processes** | Notice change in temperature and adjust air conditioner appropriately |
| | **Behavioural regulation** | Develop a habit of adjusting temperature on a regular basis |
| Physical opportunity | **Environmental context and resources** | Overcome physical urges to remain comfortable using air conditioner temperature alone, and use other methods for temperature adjustment |
| Social opportunity | **Social influences** | The opportunity to witness or know that other households are employing this behaviour |
| Reflective motivation | **Professional/social role and identity** | Household “leaders” (owner, eldest etc.) should lead the attempt to do this behaviour in the home |
| | Beliefs about capabilities | Not relevant |
| | **Optimism** | See beliefs about consequences |
| | **Beliefs about consequences** | Belief that adjusting air conditioner temperature will have a monetary and environmental impact |
| | Intentions | Not relevant as many have an intention to improve energy consumption |
| | **Goals** | Many lack clear knowledge of what air conditioner temperatures they should target, and when |
| | **Reinforcement** | Reinforce routines and habits |

| **Target Behaviour:** | **Adjusting air conditioner usage** | |
|---|---|---|
| **COM-B** | **TDF** | **Relevance of domain** |
| Automatic motivation | **Emotion** | Overcome desires for comfort through room temperature afforded by air conditioner, and use other means for warmth/cooling |

**Table 29. TDF Analysis of target behaviour: adjusting air conditioner usage.**

| **Target Behaviour** | **Turning off lights when you are not in a room** | |
|---|---|---|
| **COM-B** | **TDF** | **Relevance of domain** |
| Physical capability | Physical skills | Not relevant as physical skill to use light switches is held by most relevant household members |
| Psychological capability | **Knowledge** | Know how to create and apply if-then rules for turning off lights when exiting a room (i.e. turn off light when leaving a room empty) |
| | Cognitive and interpersonal skills | Not relevant |
| | **Memory, attention and decision processes** | Remember to perform the behaviour when if-then rule applies (i.e. they have left the room empty) |
| | **Behavioural regulation** | Develop a habit of turning off the lights when leaving a room empty |
| Physical opportunity | Environmental context and resources | Not relevant |
| Social opportunity | **Social influences** | The opportunity to witness or know that other households are employing this behaviour |
| Reflective motivation | **Professional/social role and identity** | Household "leaders" (owner, eldest etc.) should lead the attempt to do this behaviour in the home |
| | Beliefs about capabilities | Not relevant |
| | **Optimism** | See beliefs about consequences |
| | **Beliefs about consequences** | Belief that effective light usage will have a monetary and environmental impact |
| | Intentions | Not relevant as many have an intention to improve energy consumption |
| | **Goals** | Aim to always perform the behaviour (important as the behaviour is very frequent) |
| Automatic motivation | **Reinforcement** | Reinforce routines and habits |
| | **Emotion** | Overcome desires for having an easier lifestyle by having lights already on upon entering a room |

**Table 30. TDF Analysis of target behaviour: turning off lights when you are not in a room.**

| **Target Behaviour:** | **Standby electricity consumption** | |
|---|---|---|
| **COM-B** | **TDF** | **Relevance of domain** |
| Physical capability | **Physical skills** | Physical access to "complete-off" function sometimes difficult |
| Psychological capability | **Knowledge** | Know how to create and apply if-then rules for turning a device completely off (if finished using a device then turn it completely off) |
| | Cognitive and interpersonal skills | Not relevant |
| | **Memory, attention and decision processes** | Remember to turn devices completely-off instead of the often easier standby mode |
| | **Behavioural regulation** | Develop a habit of completely turning off devices on a regular basis |
| Physical opportunity | **Environmental context and resources** | Physical access to "complete-off" function |
| Social opportunity | **Social influences** | The opportunity to witness or know that other households are employing this behaviour |
| Reflective motivation | **Professional/social role and identity** | Household "leaders" (owner, eldest etc.) should lead the attempt to do this behaviour in the home |
| | Beliefs about capabilities | Not relevant |
| | Optimism | See beliefs about consequences |
| | **Beliefs about consequences** | Belief that standby consumption will have a monetary and environmental impact |
| | Intentions | Not relevant as many have an intention to improve energy consumption |
| | **Goals** | Aim to ensure unused devices are turned completely off. |
| Automatic motivation | **Reinforcement** | Reinforce routines and habits |
| | **Emotion** | Overcome desires for having an easier lifestyle by having devices be easier to turn on from standby mode |

**Table 31. TDF Analysis of target behaviour: standby electricity consumption.**

The TDF analysis is summarised in Table 32.

| **Air conditioner usage** | **Turning off lights** | **Standby electricity consumption** |
|---|---|---|
| **Psychological Capability**<br>Knowledge<br>Memory, attention and decision processes<br>Behavioural regulation | **Psychological Capability**<br>Knowledge<br>Memory, attention and decision processes<br>Behavioural regulation | **Psychological Capability**<br>Knowledge<br>Memory, attention and decision processes<br>Behavioural regulation |
| **Social Opportunity**<br>Social influences | **Social Opportunity**<br>Social influences | **Social Opportunity**<br>Social influences |

| Air conditioner usage | Turning off lights | Standby electricity consumption |
|---|---|---|
| **Reflective Motivation**<br>Professional/social role and identity<br>Optimism<br>Beliefs about consequences<br>Goals | **Reflective Motivation**<br>Professional/social role and identity<br>Optimism<br>Beliefs about consequences<br>Goals | **Reflective Motivation**<br>Professional/social role and identity<br>Beliefs about consequences<br>Goals |
| **Automatic Motivation**<br>Reinforcement<br>Emotion | **Automatic Motivation**<br>Reinforcement<br>Emotion | **Automatic Motivation**<br>Reinforcement<br>Emotion |

**Table 32. Summary of TDF analysis of target behaviours.**

# Appendix C Brainstormed Game Elements

Section 4.3.1 described a process by which game elements were sourced from literature and via brainstorming. This appendix lists the elements that were determined from this process in Table 33. The order in which these elements are presented is the order in which they were added to the list of elements.

| | |
|---|---|
| In-game Currency | Restricted Zones |
| Resources / Collectables | Restricted and Rare Items |
| Daily Rewards / Streak Rewards | Treasure Chests |
| Avatars / Player Characters | Boss Battles |
| Non-Player Characters | Quest Choice |
| Level-Up | Community Vote |
| Quests | Community Forum |
| Leaderboard | Chat |
| Normative Leaderboard | Gifting / Trading |
| Achievements[100] | Procedural Levels |
| Friend System | Game Mode Customization |
| Clan System | Skins |
| Team System | Bragging |
| Content Creation | Temporary Boosts |
| Content Sharing | Tutorials |
| Narrative | Difficulty Levels |
| Timed Challenges | Player Profiles / Statistics Screens |
| Weather Effects | Notifications / Reminders |
| Day/Night Cycle | Monuments / Statues |

**Table 33. Brainstormed Game Elements**

[100] In-game achievements, as opposed to badges

# Appendix D Potential Prototypes

This appendix first shows the full result of the analysis of the top 50 games on the Google Play Store, before exploring in detail the four different prototyped game types. In the hope that future researchers may be inspired to use a game type listed here, details on possible ways of incorporating smart meter data and the chosen game elements are given. All prototypes were developed using the *Unity* game engine, and source code can be obtained upon request.

## D.1 Considered Game Types

Initial choices for the type of game to create were inspired by systematically examining the top 50 games on the Google Play Store (which is the primary distribution method for Android mobile devices). The process for game selection in this project is described in Section 5.1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rally Racer Drift | Racing | 4 | 5 | 8 | 8 | 19 | Fuel |
| Clash of Clans | Strategy | 2 | 6 | 7 | 8 | 19 | Resources |
| Kim Kardashian: Hollywood | Point and click | 3 | 4 | 3 | 5 | 19 | Number of Actions |
| Texas Holdem Live Power | Card | 7 | 0 | 4 | 5 | 18 | N/A |
| Battle Mechs | Shooter | 2 | 6 | 7 | 6 | 17 | Ammunition linked to usage |

Table 34 shows the games that were evaluated. In addition, the table lists the genre, and identified ways in which a custom version of that game could be modified to respond to smart meter data (used as part of determining the *suitability* criteria).

| Game Name | Genre | Ease of Development | Suitability for Game Elements | Skill Level Required | Appeal / Entertainment | Score | Use of Smart Meter Data |
|---|---|---|---|---|---|---|---|
| **Candy Crush Saga** | Match 3 | 9 | 6 | 2 | 10 | **33** | Times to play / difficulty |
| **Flow Free** | Puzzle | 10 | 8 | 1 | 5 | **32** | Levels/time, distance of pipes that can be used |
| **The Simpsons Tapped Out** | Simulation | 5 | 10 | 2 | 9 | **32** | Resources, building access |
| **Temple Run 2** | Endless runner | 8 | 10 | 5 | 8 | **31** | Times to play, difficulty, powerups |
| **Jetpack Joyride** | Endless runner | 8 | 9 | 6 | 10 | **31** | Distance/powerups/plays |
| Pet Rescue Saga | Match 3 | 9 | 6 | 3 | 8 | 30 | Times to play |
| Fruit Ninja Free | Shooter | 9 | 4 | 2 | 9 | 30 | Frequency of fruit, powerups? |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Frozen Free Fall | Match 3 | 9 | 6 | 3 | 8 | 30 | Times to play |
| Subway Surfers | Endless runner | 8 | 7 | 3 | 8 | 30 | Times to play / difficulty |
| Bubbles Burst | Match 3 | 10 | 6 | 3 | 6 | 29 | Times to play, how many bubbles |
| SWAT Shooting | Shooter | 8 | 6 | 1 | 6 | 29 | Ammo |
| Plants vs zombies | Tower defense | 7 | 6 | 4 | 9 | 28 | Sunflowers |
| Angry Birds | Physics | 9 | 5 | 4 | 8 | 28 | Number of birds/powerups |
| Forest Mania | Match 3 | 8 | 6 | 2 | 6 | 28 | Times to play / difficulty |
| Traffic Racer | Endless runner | 9 | 7 | 6 | 6 | 26 | Times to play / difficulty |
| Farm Heroes Saga | Match 3 | 8 | 6 | 6 | 8 | 26 | Times to play / difficulty |
| Despicable Me | Endless runner | 8 | 6 | 6 | 8 | 26 | Times to play / difficulty, money, costumes, powerups |
| Piano Tiles | Rythmn | 10 | 5 | 3 | 4 | 26 | Times to play / difficulty |
| 2048 Number Puzzle Game | Puzzle / Board | 10 | 2 | 2 | 6 | 26 | Times to play |
| My Talking Tom | Virtual pet | 5 | 7 | 1 | 5 | 26 | Resources |
| 100 Ballz | Physics | 10 | 5 | 6 | 6 | 25 | Number of balls to drop |
| Clash of Lords 2 | Realtime Strategy | 6 | 6 | 5 | 8 | 25 | Resources |
| Do not Tap The White Tile | Rythmn | 10 | 5 | 3 | 3 | 25 | Times to play / difficulty |
| Dumb Ways to Die | Minigames | 7 | 5 | 2 | 5 | 25 | Times to play / difficulty |
| Scratch That Logo Quiz | Quiz | 10 | 3 | 1 | 3 | 25 | Level access, time limit, scratch amount |
| Bingo Fever | Board | 10 | 3 | 1 | 3 | 25 | Number of boards |
| Sonic Dash | Endless runner | 8 | 7 | 7 | 6 | 24 | Powerups |
| Transformers Age of Extinction | Shooter | 7 | 6 | 6 | 7 | 24 | Resources |
| Hay Day | Simulation | 6 | 8 | 6 | 6 | 24 | Money |
| Hill Climb Racing | Endless Runner | 6 | 8 | 6 | 6 | 24 | Times to play / difficulty, fuel/vehicles |
| Words With Friends | Board | 7 | 3 | 3 | 7 | 24 | Influence available letters |
| Suduko Master | Puzzle | 7 | 2 | 1 | 6 | 24 | Times to play |
| The Line-Keep In | Endless Runner | 8 | 7 | 7 | 5 | 23 | Times to play / difficulty |
| 4 Pics 1 Word | Quiz | 7 | 3 | 1 | 4 | 23 | Matches/powerups (letter removers) |
| Cut the Rope 2 | Puzzle | 6 | 5 | 7 | 8 | 22 | Times to play |
| Stickman ClickDeath Model | Point and click | 8 | 5 | 6 | 5 | 22 | Number of clicks |
| Angry Birds Epic | Role playing | 4 | 6 | 6 | 8 | 22 | Money, attack points, character strength, travel distance |
| 8 Ball Pool | Sport | 8 | 4 | 4 | 4 | 22 | Powerups/matches |
| Word search | Puzzle | 7 | 3 | 1 | 3 | 22 | Hints |
| Dragons: Rise of Berk | Simulation | 5 | 8 | 7 | 5 | 21 | Resources |
| Cleopatra Casino - FREE SLOTS | Slots | 10 | 1 | 0 | 0 | 21 | Spins/money |
| Slots Fever | Slots | 10 | 1 | 0 | 0 | 21 | Spins/money |
| Boom Beach | Realtime strategy | 3 | 6 | 7 | 8 | 20 | Resources |
| Ace Fishing: Paradise Blue | Fishing | 7 | 3 | 3 | 3 | 20 | Times to play, money |
| Solitaire | Card | 7 | 1 | 1 | 3 | 20 | Times to play |
| Rally Racer Drift | Racing | 4 | 5 | 8 | 8 | 19 | Fuel |
| Clash of Clans | Strategy | 2 | 6 | 7 | 8 | 19 | Resources |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kim Kardashian: Hollywood | Point and click | 3 | 4 | 3 | 5 | 19 | Number of Actions |
| Texas Holdem Live Power | Card | 7 | 0 | 4 | 5 | 18 | N/A |
| Battle Mechs | Shooter | 2 | 6 | 7 | 6 | 17 | Ammunition linked to usage |

**Table 34. List of games examined on the Google Play Store, with scores for various criteria. Games chosen for prototype development highlighted.**

## D.2 Puzzle Prototype

The review of games on the Google Play Store indicated that puzzle games were popular. Often the usage context of mobile devices requires that gameplay can be experienced in smaller time periods than games played on PCs (Samuel & Pfahl 2016). It is also conceivable that gameplay which can be paused and resumed at any time is desirable. Many puzzle games offer this functionality, as levels tend to be short, and the ability to pause and resume at any time does not hinder the experience.

A puzzle game prototype was developed, which was based on the existing game *Flow* (Big Duck Games LLC 2012), and is pictured in Figure 85. The game is played within a grid-based environment, and the player's goal is to link various starting locations to their matching end locations with a pipe they draw with their hand. Pipe segments are constrained to be within each grid cell, and must be adjacent to either a starting point, end point, or another pipe segment of a matching colour. For the puzzle to be complete, every cell in the grid must contain either a starting point, end point, or pipe segment, which adds further complexity to the win condition. Grid cells cannot contain more than one pipe segment, unless that cell already contains a "bridge" pipe segment, in which case that cell can contain a total of two segments.

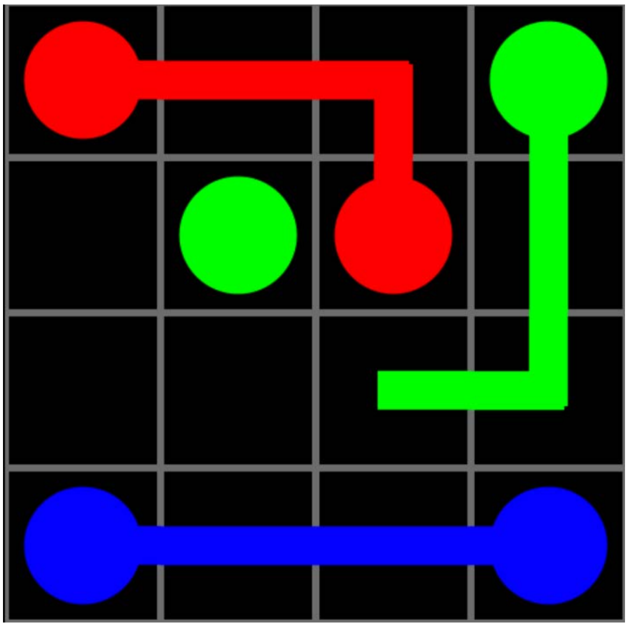

**Figure 85. Screenshot of the puzzle game prototype in the style of *Flow* (Big Duck Games LLC 2012).**

The grid contains an equal number of horizontal and vertical cells, and each starting location has exactly one matching ending location. The difficulty of the game changes dynamically based upon the size of the grid (which in this version ranges from 4 to 8), and the number of starting and ending location pairs (which varied between 3 and 8). Some levels may only have one solution based upon the configuration of the end points, and other sparser levels may have multiple solutions. Upon completion of a level, the player is shown how long it took them to solve the puzzle, and then presented with a choice to try another puzzle with the same parameters (grid size, and number of end points), or to generate a puzzle with different parameters.

To reduce development time, and to increase replayability, levels were procedrually generated. The algorithm to accomplish this was run on the phone, and primarily consisted of trial and error until a level was produced with a valid solution.

In terms of the game selection criteria, the *skill level* criterion was the highest amongst the different game types due to this game's unique property of offering a wide range of difficulty levels. The largest grid size (8x8) with 3 colours is very easy as it has many possible solutions, and a solution can be found even on grid sizes of 5x5 with a brute force approach. The game controls are simple, and players can undo their actions easily, which makes this style of puzzle game much easier than many other types of puzzle games.

The *appeal* of the game was considered around average, as the simplicity of the gameplay, and the ability to play the game for even a short period of time were believed to aid in this.

However, it was determined that the *entertainment factor* of the game may quickly reduce over time given the simplicity of graphics and gameplay, despite the almost infinite number of possible levels. *Ability to develop* the game scored highest out of all of the games, as the majority of the hard work was completed in the prototype phase, and the remainder of the work would have involved improving the quality of the graphics.

The main reason the puzzle game prototype was not chosen however was its low *suitability* for implementing the chosen game elements. In this case, the energy resource governed by energy conservation had little use in this game type. Amongst the limited options were making each placement of a pipe segment consume a unit of the energy resource, and simply making each new level generation consume the energy resource. The environment governed by energy conservation again had little use in this game type due to the limited and abstract game environment used (i.e. the grid). The addition of "blocker" grid spaces was considered, where pipe segments could not be placed, and increasing the amount of those generated in a level when conservation was not occurring. This idea was expected to be too frustrating to players, and also had difficult implications for the procedrual generation (increased number of impossible levels, which in turn increased the generation time of levels). The checklist game element was possible in this game (as with all the games), however with limited variation in actions the checklist would likely have been too short. Additionally, game elements such as the quests and narrative seemed to have no place at all in the game. For normative rewards, there are limited in-game items or resources which could be given as a reward.

As a result of these issues, the puzzle game was not chosen as the main game for the project.

## D.3 Endless Runner Prototypes

Many of the games on the Google Play Store can be considered "endless runners". The main objective of this style of game is to survive for as long as possible, while the difficulty of the game ramps up. The player typically traverses the environment without returning to previous locations, and with little-to-no choice in where to go next. Once the player fails the level, they have to start again at the start, and levels are usually procedurally generated to prevent repetition. Players compete for high scores since there is no "win" condition (hence the description "endless").

Two prototypes of endless runner games were developed, one based upon *Temple Run* (Imangi Studios 2011), the other based upon *Jetpack Joyride* (Halfbrick Studios 2011).

The first prototype shown in Figure 86 was the only 3D game of the prototypes. The player controls an avatar (represented in the prototype as a sphere, but in a future iteration would likely have been a humanoid character) left and right on the screen while the character moves forward along a path automatically at a speed which linearly increases (i.e. has a constant low acceleration). Left and right movements are accomplished by dragging horizontally on the screen (player movement is at a 1:1 ratio with drag movement). When the character reaches a turn on the path, the player must react by swiping in the correct direction. When the character reaches an intersection in the path, the player may choose which direction to travel by swiping in that direction. Failure to swipe in the correct direction at a turn, or failure to swipe at all at a turn or intersection results in death for the character (i.e. the level ends). Touching the green sections of ground would speed the character up, and touching red sections of ground would result in death for the character.

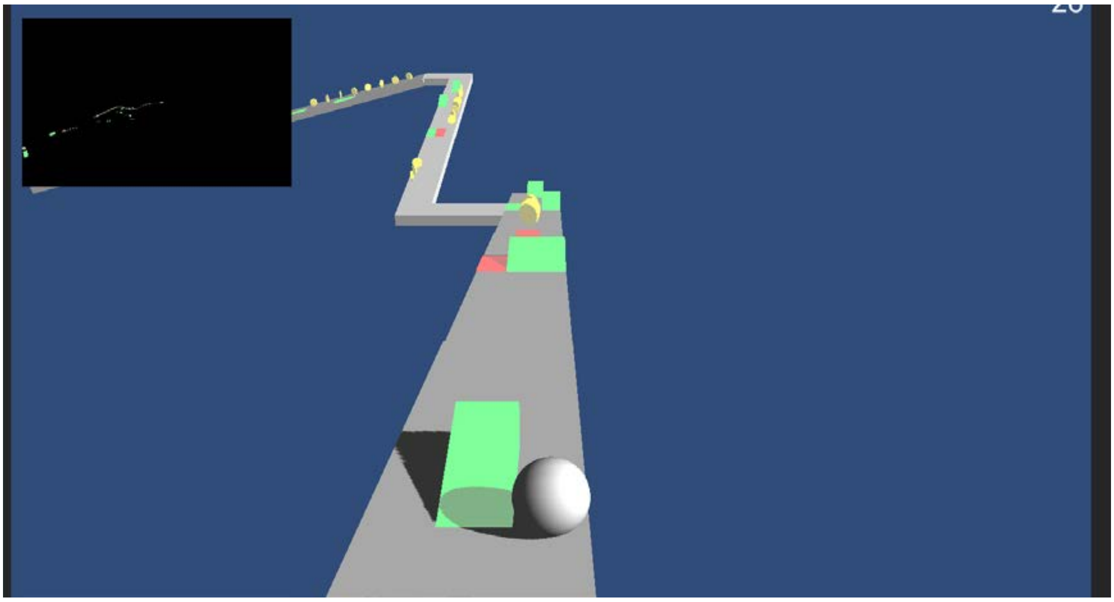

**Figure 86. Screenshot of endless runner prototype game in the style of *Temple Run* (Imangi Studios 2011). Real world energy consumption would dictate powerup distribution, and the difficulty of the procedurally generated levels.**

In the second prototype (Figure 87), the player again controlled a character (represented by a sphere, which would in a future iteration would likely be a vehicle like a helicopter) up and down on the screen, while the character continued to move right along the screen at a constant speed through a cave environment. Control was accomplished by holding down anywhere on the screen to make the character move upwards. The character would automatically fall at a rate lower than gravity (since the character is intended to be a helicopter). Collision with the top or bottom of the cave would result in death for the player, as well as any “floating” sections of the environment.

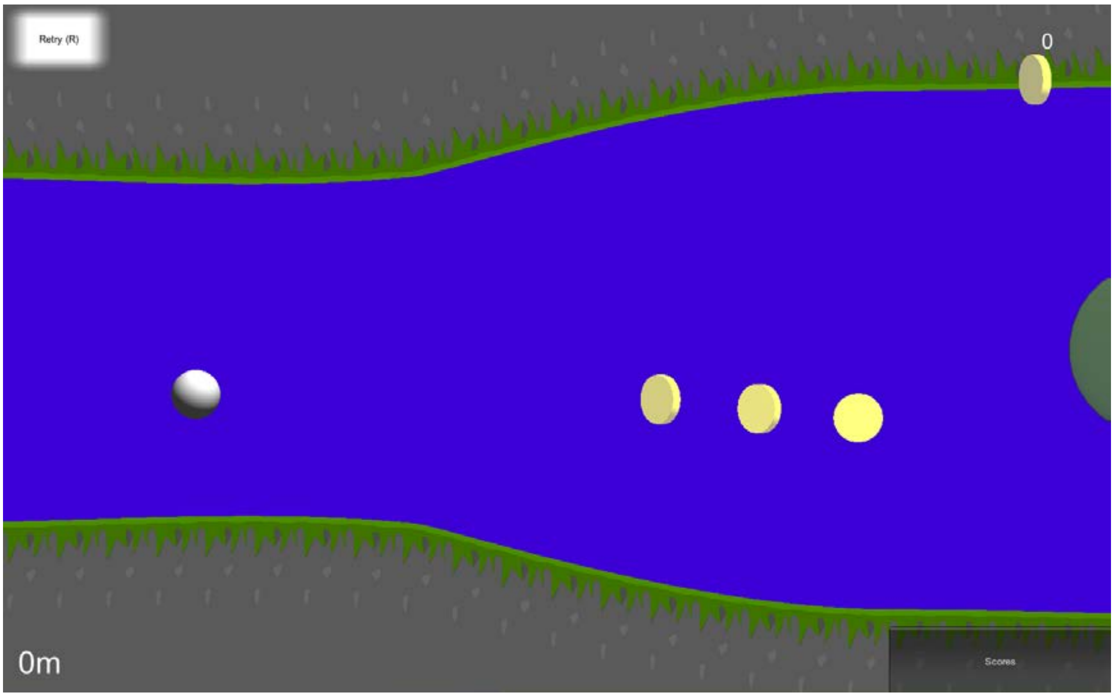


**Figure 87. Screenshot of the endless runner prototype game in the style of *Jetpack Joyride* (Halfbrick Studios 2011). Real world energy consumption would have the same effect as described in Figure 86.**

In both versions of the game, players could also collect coins, which would add to their final score. In addition, players could collect powerups which would give the character additional abilities for 30 seconds before reverting. Powerups included a “magnet” which allowed the player to collect coins by travelling close to them (rather than just colliding with them), “super speed” which increased the speed of the player, and “invulnerability” which allowed the player to be immune to the conditions that would otherwise kill them.

Levels were generated using a procedural generation method, to reduce development time and increase replayability. The generation algorithm chose randomly from a pool of game world “chunks” containing the shape of the world, the coins, and powerups. To ensure the difficulty increased, different pools of level checks were used depending on how far the player had travelled at that point.

Players scored points based upon the distance they travelled, and the number of coins they collected.

In terms of the *skill level* required to play the game, this type of game was determined to require the most skill to play, because despite having a simple control scheme, it requires the user to react quickly, and frequently. Due to this, the game was also expected to *appeal* more to gamers than the general population (the participant group was not expected to identify as gamers). Additionally, the length of time required to play the game in a particular sitting was expected to be high which likely would not appeal to non-gamers, compared to some of the other games considered. With appropriate graphics, and the fast-paced nature of the gameplay, the endless runner prototypes were expected to have the highest *entertainment factor* of the considered games.

Since the first prototype game was 3D, extra *development* over the 2D versions was expected, and at the time the development team had little experience creating 3D games. For both prototype games, the graphical requirements to suit the endless runner style were expected to have a meaningful impact on development time.

The endless runner prototypes were generally well *suited to the chosen game elements*. The game environment could easily be changed based upon the player's energy consumption. The energy resource could be used to place a limit on the total distance the player could travel in a day, or the number of attempts at playing they could partake in. Personalization on the player avatar could be achieved without issue in this type of game, however game elements such as narrative, and quests were considered less suitable for the game. Quests in endless runner games are traditionally implemented more as checklist items that the player must complete over multiple runs of the game, rather than based in narrative. As a result, the specialised quests game element was deemed to not be able to be implemented without being detached from the gameplay. The character level game element could be used in this style of game however the rewards for levelling up were likely to have little gameplay meaning since the player starts a new path each time they play. Level up rewards were likely to be cosmetic on the avatar, or provide access to different pools of level chunks for the procedural generation. The latter idea however would have a significant impact on the variety and amount of level chunks that would need to be developed, and so the level up element was not considered suitable. Again, there were limited options for in-game item rewards for the normative rewards element.

## D.4 Match 3 Prototype

One of the most popular games on the Google Play Store is *Candy Crush Saga* (King 2012), which is considered to be a match 3 game. To aid in the prototyping of the match 3 prototype, the *Match 3 Starter Kit*[101] on the Unity Asset Store was used as a starting point for the code, as shown in Figure 88.

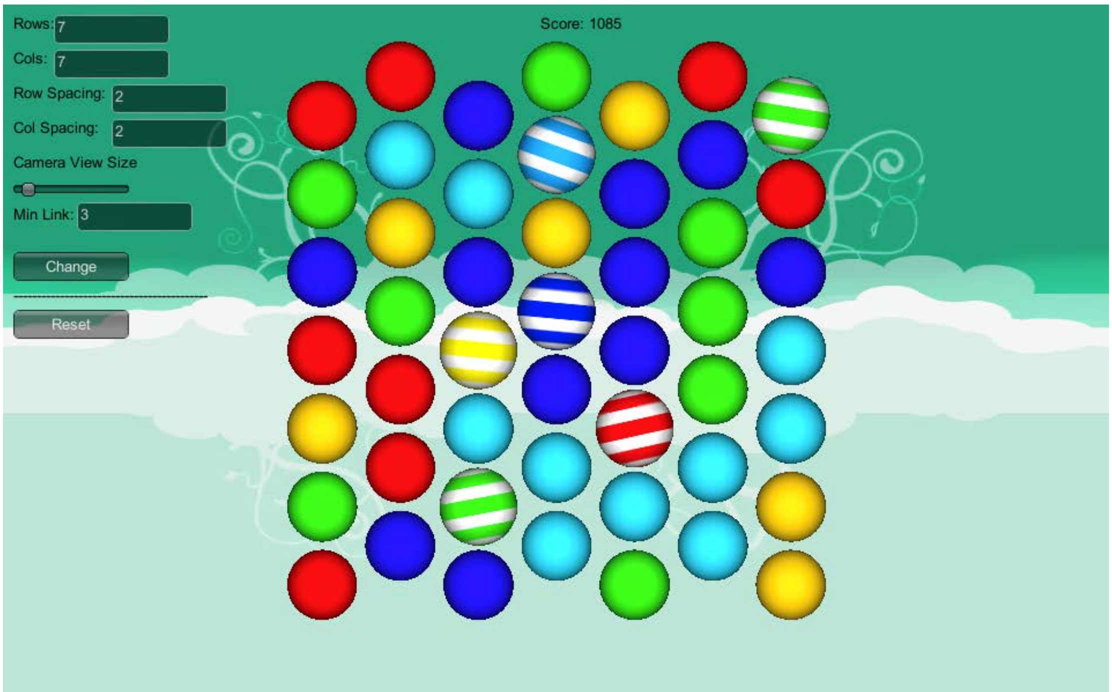


**Figure 88. Screenshot of the match 3 game prototype built using the *Match 3 Starter Kit*, in the style of *Candy Crush Saga* (King 2012).**

The game environment uses an offset grid pattern, such that a cell is surrounded by 6 neighbouring cells. Each cell contains a ball, which is assigned a certain colour. At the start of the game, a random colour is assigned to each ball. Players need to find groupings of adjacent balls of the same colour, and are rewarded with points multiplied by the number of balls in the group. The game can be configured to have a minimum number of balls to be classified as a group (defaults to 3; hence "match 3"). A group is identified by a player by completing a single drag between all the balls in the group, however the drag cannot go over any single ball more than one time, and can only pass between adjacent matching coloured balls, which increases the complexity of group identification.

Once a group has been identified, the balls in that group are removed, and replaced with new randomly generated balls. If a group of 4 or more is identified, the final ball in the group (i.e. the last one dragged over) is not replaced with a random ball, but rather with a "powerup ball" (represented with stripes) of the same colour as the original ball. When this ball is included in a group later in the game, additional points are awarded to the player, and all the

[101] https://www.assetstore.unity3d.com/en/#!/content/112622

neighbouring balls of that ball are also replaced as part of the replacement process (any powerup balls neighbouring will also be triggered, causing a chain reaction). The game can be configured to have different grid sizes, and different minimum group sizes to adjust the difficulty level of the game.

While the *development time* was considered to be low for this game type since only interface and graphical polish was required. *Skill level* for the game is low, as the random generation always guarantees possible moves. The general *appeal* and *entertainment factor* of games like *Candy Crush* was considered high, although in this case was determined to be dependent on the level of polish in the game. Similar to the puzzle game prototype however, the facility to implement the various game elements such as quests, narrative, and energy-consumption-governed resources and game environment was deemed to be low. The main plausible option for a resource to be governed by energy consumption was the player's number of "lives". Lives in *Candy Crush* are implemented as the number of times you can attempt a level. Once the number of lives reaches zero, the player must either wait for lives to replenish (automatically increased by 1 every 15 minutes), or purchase more. In the prototype, this would require the addition of level requirements such as "find X number of red balls" etc. There were limited options for changing the game environment based upon consumption, however the number of rows, colours, and power-ups could react to usage.

## D.5 Simulation Prototype

In the simulation game prototype, players are able to build their own small city, with the goal of placing as many different types of buildings in their city as they can. The game (Figure 89) is roughly based upon *Simpsons: Tapped Out* (Electronic Arts 2012).


**Figure 89. Screenshot of the simulation game prototype game, in the style of *The Simpsons: Tapped Out* (Electronic Arts 2012). Amount of money given to player, quality of buildings in the city, and availability of buildings (including bonus buildings) determined by real world energy consumption.**

To place a building, the player needs to spend money. The player primarily earns money by clicking on existing buildings in their city to collect the rent from that building. Rent money can be collected from different buildings at different rates of real world time, and in different amounts. For example, one building may produce $5 every one hour, whereas another building may produce $10 every three hours. The rent money rate of time refers to how long the player must wait until they can collect money again, however money does not "stack"— i.e. if a player has a building that produces $5/hour, and returns 3 hours later, they will still only receive $5 instead of $15 when they tap on the building. This mechanic is used to give players incentive to return to the game frequently to earn money from their buildings.

The rate at which a building produces money can be increased by upgrading that building for a once-off cost, or by completing quests. More expensive buildings also generally have a greater yield from rent once placed.

In addition to placing buildings, the player can place characters into the city, and assign those characters to buildings where they "work". Working characters earn a salary, which the player collects by tapping on the building once their job is completed. Salary collection works in the same way that rent collection, however the player must consider which characters to assign to which building, as not all characters can work in all buildings.

Buildings and characters also produce a certain amount of XP (experience points), at the same rate at which rent or salary is collected. Once the player collects a certain amount of XP, their level would increase. Some buildings and characters are only available to place once the player is a certain level (and the correct amount of money). In addition to XP and money, buildings and characters can also produce items, which are usually relevant to the building type or character type (e.g. a cinema might produce rolls of film, or a library might produce books). Whenever a player collects money and XP from a building or character, they have the chance to collect the item. This chance is variable for each item/building (multiple buildings may produce the same item but with different probability), with some items being considered "rare".

Cosmetic items can be added to the city, such as roads, trees, and banana stands, and often these items are required to be placed to fulfil quests given to the player. Quests provide the player with a general guide of what to do in the game, which is important given the sandbox nature of the game (players may not learn how to play otherwise, or learning would have to occur by reading many pages of text, similar to this description). Quests often involve collecting a certain quota of items, which in turn might require building a specific building to obtain that item (the user interface indicates what items a building produces).

The game was *suitable* for the chosen game elements with the exception of a player avatar of which there was none (although an avatar could be represented on the user interface, and customized). The energy resource game element could be linked to the money resource in this game type, or be an additional resource that governs what buildings are available to the player (e.g. buildings could be locked, despite the player having enough money and being an appropriate level). The game environment could react to energy consumption by adjusting the weather in an exaggerated and hastened Climate Change simulation. In addition, the quality of buildings could be effected by the game environment, which would alter their rent output, and the chance for natural disasters would increase, which could either permanently destroy buildings or temporarily make them unable to produce money. The existence of items allows for the quest game element to work well, and indeed quests are used to guide the player through the game, and specialized quests could be implemented by requiring items only produced by buildings when the game environment is healthy (including healthiness governed by certain smart meter channels such as air conditioning). Narrative could be implemented through the quest-line, however the extent to which narrative could be conveyed was considered to be limited, based upon experience of narrative in the games that provided inspiration for the prototype. The wealth of items available in the game made it suitable for normative rewards.

In terms of the *required skill level* for the game, this was not expected to be high since players who make "poor" choices in building their city will still be able to progress over time. However, the perceived complexity of the game was considered to have an impact on the *appeal* of the game to non-gamers. This could be countered by ensuring that the early-game phase is simple (similar to *Farmville*), however this would not counter the initial thoughts looking at promotional materials for the game. Appeal may have been increased by the ability to play the game in small chunks, however the *entertainment factor* without recognizable characters (such as those in *Family Guy: The Quest for Stuff* and *Simpsons: Tapped Out*) was considered to be medium-to-low. The biggest factor in terms of selection criteria for this style of game was the *development time*. The assets found for the prototype version of the simulation game were all in a particular "pixel art" style in an isometric projection. The asset pack however was limited to a small number of buildings, and so to have a full game experience, additional assets matching the art style would need to be produced. Pixel-art is time consuming to produce, and this problem was exacerbated by the projection, and the multiple frames of animation required for the characters who could walk around the city. Additional development of item images, and determining the correct values for rate of money/XP/items was expected to incur the greatest development time out of the prototype games.

# Appendix E Additional Features Not Implemented in Energy Explorer

The BCW process produced a large number of game element options, and while all of these were used when considering the appropriateness of each of the types of game, not all of them were ultimately implemented due to time and scope constraints. This section briefly describes some of these elements, in the hope that future researchers can find inspiration from the elements described herein.

Unimplemented features included:

- *clans/teams* where the energy consumption of multiple players is combined, and players are incentivised to meet clan objectives and compete with other clans;
- *world building* where players can place decorative items and buildings, be visited by other players and have weather reflecting the owner's energy consumption;
- *additional social system features* such as "likes" and comments on a social feed;
- *challengers* for additional social comparison;
- more advanced use of the phone *notification system*; and
- additional *exploration mechanics* including light, and dangerous animals;

These features are described in the following sections. Additionally, the community score, goal setting, and monuments game elements from Section 4.3 were not implemented, although the description of how they would be implemented in *Energy Explorer* is omitted for space reasons.

## E.1 Clans

One of the game elements highlighted for the social comparison BCTs was that of *clans* as part of the social system in the game. Clans were intended to be implemented in *Energy Explorer* by grouping players together. This could have been implemented via automatic grouping based upon similarity criteria, or through the friendship interface.

When viewing the clan interface, players would be able to see the progress of other players within that clan, as well as the overall progress for the clan. This was partially implemented, and an example is shown in Figure 90.

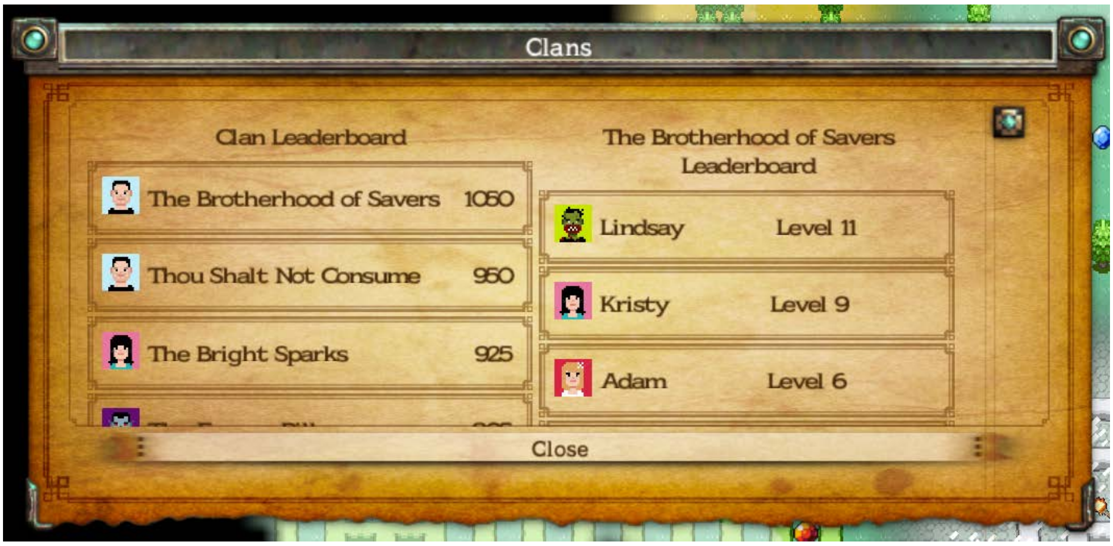


**Figure 90. The clan interface as it would have appeared in *Energy Explorer*.**

Game progression (dictated by real-world energy use) would contribute to a *clan score* and this is used to rank clans. Cooperation would be fostered by not wanting to let the clan down by letting another clan achieve a higher rank. Competition within the clan would be fostered by wanting to be the best ranked within a clan on the clan leaderboard.

## E.2 World Building

The ability for players to customize the game environment and claim areas for their own was a considered feature for *Energy Explorer*, however was ultimately decided to be outside the scope of development. When a player would visit a generated zone, they would be given the option to "claim" that zone for their own. Once they had done this, other players would then have a chance of finding this new zone when traversing their world.

When a player entered a zone owned by another player, they would see who it belongs to, as well as see that player's progress and energy consumption. The weather in an owned zone is also dictated by the player who owns it, and so a player visiting the zone of another player who was using too much energy would see a dilapidated, dangerous, environment.

Players would customize their owned zones by placing items they had collected down on the ground. These items (including buildings) would be visible to other players, but not collectable, acting somewhat as a "showcase" of the things they have found.

The zone info screen would provide information to players about the name the owner gave the zone, as well as a custom message they wrote about it (Figure 91).


**Figure 91. The zone info screen in *Energy Explorer* as it would appear when visiting and owned zone.**

To add to the world building component, many games feature a crafting system that increases the number of items and resources possible for the player to find, without the need for additional quest or environment content. Crafting also pushes players to plan and optimize their use of resources carefully, as certain amounts of resources are required to create other items. Crafting in *Energy Explorer* would allow players to create items they could show off in their owned zones, for example 10 units of the wood resources could be used to create a fireplace object, which the player could place in the game world for aesthetic purposes.

## E.3 Social System—"Likes" and Social Feed

In order to support the approval of others BCT without the use of fictional characters, the social system in *Energy Explorer* needed to be more advanced by including a social feed which players could post accomplishments both regarding in-game events, and energy-related actions which other players could then "like" and comment on. This was beyond the scope for this project, however it remains to be one of the most promising elements for the social BCTs. This could have also been implemented by integrating with a pre-existing social network such as Facebook, however this too would have had ethical implications for the sharing of data outside of the study.

## E.4 Challengers

Additional social comparison could have been accomplished in *Energy Explorer* by selecting other players as "challengers" with whom to compete with on energy conservation in order to obtain in-game rewards. The details on this were not expanded upon, but may have included a weekly pairing in which two players would compete each day, as well as a different daily challenger each day. A prototype of the interface for this is shown in Figure 92.


**Figure 92. A prototype of the "challenger" interface for *Energy Explorer*.**

## E.5 Additional Notification System Usage

The notification system was under-developed in *Energy Explorer*, and simply displayed a reminder to players every day to play the game. These notifications were simply "scheduled notifications" and "push notifications" which use more advanced logic for display time and content were not used due to scope.

The game server would have been responsible for presenting push notifications to players, and could have been triggered for events such as when the player exceeded their peak usage from the previous day, when conservation criteria had been met for the specialized quests, when the player's in-game energy had been replenished, and much more. Notifications could have even begun new gameplay challenges when it was detected the player was beginning the disengage, such as presenting a new quest, which is opened upon tapping the notification.

## E.6 Additional Exploration Mechanics

An original iteration of *Energy Explorer* married the concept of exploration with darkness and light, and this is evidenced in many of the screenshots presented here (black areas in the environment). The player would be unable to see beyond where they had already previously explored, and would reveal the world a certain radius around them as they travelled. In addition, light sources in the world would light up areas they player had not visited in the distance. This was intended to add a level of challenge to the game, as well as mystery as to where they would go next. An additional game mechanic was also considered where the player could throw a light source in front of them to reveal the world in that direction, or perform a burst of light to increase the radius of light around them. Both of these actions would be limited in how frequently the player could perform them.

The main reason for this not being in the final version of the game was performance, as the masking of various aspects of the world resulted in low framerates on devices.

On top of these exploration mechanics, the availability of animals in areas based upon weather was considered, along with the concept of dangerous animals and harmless animals. Dangerous animals would be more likely to appear in bad weather, however they were not implemented due to the associated need for additional mechanics such as the animals attacking the player, which would lead to the need for player "health", as well as combat, and combat-related items. For similar reasons, other mini-game elements were also not implemented in *Energy Explorer*, despite their potential for improving the game.

# Appendix F Game Metrics Recorded

In the context of the *Energy Explorer* implementation, actions were recorded when a player:

- *logged in* to the game (including auto-login upon re-launching the app);
- *entered a new procedurally generated or pre-made zone;*
- *ran out of energy*;
- *began* a quest, or began a new stage of a quest;
- *completed* a quest;
- *completed a checklist item*;
- increased their *player level*;
- pressed the *help* button on the interface;
- pressed the *map* button on the interface;
- pressed the *zone info* button on the interface;
- pressed the *profile* button on the interface (and to view the statistics screen);
- pressed the *checklist* button on the interface;
- pressed the *resources* button on the interface (including pressing the resources along the top of the screen);
- pressed the *quests* button on the interface;
- pressed the *main menu* button on the interface;
- were awarded with the *base reward* for returning to the game after more than 1 hour;
- were awarded with the *bonus reward* for reducing their energy consumption as recorded by their smart meter within the last 24 hours;
- were awarded with the *below average consumption award* for using less energy than other users in the study;
- *failed* to be awarded with the bonus reward (and shown a screen displaying this);
- *failed* to be awarded with the below average consumption reward (and shown a screen displaying this);
- ran out of energy and opted to use their single *get out of jail free card* to be given extra energy to continue playing;
- *chopped down a tree* in the game;
- tapped on one of the *XP bubbles* available in some zones (mini-game);
- *received a notification* on their phone to play the game; and
- *tapped on a notification* to play the game shown on their phone.

# Appendix G Game Metrics Results

This appendix presents the data tables for the recorded game metrics in *Energy Explorer*. Summary statistics are presented in Table 35, and Table 36 shows an individual breakdown of game usage per player. Table 37 shows a correlation matrix for the game metrics.

| | Sum[102] | Min | Max | Median | Mean | Standard deviation |
|---|---|---|---|---|---|---|
| Login | 152 | 2 | 26 | 8.0 | 7.6 | 5.8 |
| Entered zone | 137 | 0 | 39 | 3.5 | 6.9 | 9.9 |
| Ran out of energy | 3 | 0 | 1 | 0.0 | 0.2 | 0.4 |
| Began quest stage | 196 | 0 | 35 | 5.5 | 9.8 | 11.0 |
| Completed quest | 31 | 0 | 7 | 0.5 | 1.6 | 2.3 |
| Completed checklist item | 117 | 0 | 23 | 4.0 | 5.9 | 6.6 |
| Levelled up | 107 | 0 | 27 | 2.0 | 5.4 | 7.1 |
| Pressed help | 16 | 0 | 3 | 0.5 | 0.8 | 1.0 |
| Pressed map | 57 | 0 | 13 | 1.0 | 2.9 | 4.0 |
| Pressed zone info | 24 | 0 | 4 | 0.5 | 1.2 | 1.5 |
| Pressed profile (and statistics) | 25 | 0 | 4 | 1.0 | 1.3 | 1.3 |
| Pressed checklist | 60 | 0 | 18 | 2.0 | 3.0 | 4.0 |
| Pressed resources | 20 | 0 | 5 | 0.0 | 1.0 | 1.5 |
| Pressed quests | 36 | 0 | 9 | 1.0 | 1.8 | 2.3 |
| Pressed menu | 43 | 0 | 8 | 1.0 | 2.2 | 2.6 |
| Base reward given | 66 | 0 | 11 | 3.0 | 3.3 | 2.6 |
| Bonus reward given | 1 | 0 | 1 | 0.0 | 0.1 | 0.2 |
| Bonus reward failed | 104 | 0 | 12 | 4.0 | 5.2 | 3.9 |
| Used "get out of jail free" card | 1 | 0 | 1 | 0.0 | 0.1 | 0.2 |
| Chopped down tree | 303 | 0 | 92 | 6.5 | 15.2 | 25.4 |
| XP bubble tapped | 144 | 0 | 47 | 2.0 | 7.2 | 11.4 |
| Normative leaderboard reward failed | 9 | 0 | 2 | 0.0 | 0.5 | 0.7 |
| Normative leaderboard reward given | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Notification clicked | 2 | 0 | 1 | 0.0 | 0.6 | 2.0 |
| Notification received | 12 | 0 | 9 | 0.0 | 0.7 | 5.8 |

**Table 35. Descriptive statistics for the recorded game metrics.**

[102] Across all users

| UserID | LogIn | EnterWorld | RunOutOfEnergy | BeganQuestStage | CompleteQuest | CompleteChecklist | ReachedLevel | PressedHelp | PressedMap | PressedZone | PressedProfile | PressedChecklist | PressedResources | PressedQuests | PressedMenu | BaseRewardGiven | BonusRewardGiven | BonusRewardMisse | UsedGetOutOfJailFr | ChoppedDownTree | XPBubbleClicked | AverageRewardMis | NotificiationClicked | NotificiationReceive | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3** | 8 | 3 | - | 18 | 2 | 6 | - | - | - | - | - | 1 | - | - | - | 2 | - | 4 | - | 26 | - | 1 | - | - | **71** |
| **6** | 3 | 18 | - | 20 | 3 | 11 | 9 | 1 | 4 | 2 | **4** | 2 | 1 | 3 | 5 | 3 | - | 4 | - | 18 | 11 | - | - | - | **122** |
| **8** | 8 | 1 | - | 2 | - | 1 | 2 | - | 2 | - | 1 | 1 | - | - | 1 | 3 | - | - | - | 1 | 1 | - | - | - | **24** |
| **9** | 10 | - | - | - | - | - | - | - | 1 | - | 3 | 2 | 3 | 1 | 6 | - | - | - | - | - | - | - | - | - | **26** |
| **11** | 10 | 12 | **1** | 2 | - | 9 | 12 | 2 | 7 | **4** | 3 | 1 | 4 | 2 | 2 | 5 | - | **12** | **1** | 20 | 15 | **2** | - | 1 | **127** |
| **13** | 8 | - | - | 1 | - | - | - | 1 | 2 | - | 1 | 2 | 2 | 5 | 1 | 1 | - | 4 | - | - | - | 1 | - | 1 | **30** |
| **16** | **26** | **39** | **1** | **35** | **7** | **23** | **27** | **3** | 9 | 2 | 3 | **18** | **5** | **9** | **8** | **11** | - | **12** | - | 79 | **47** | - | - | - | **364** |
| **18** | 12 | 6 | - | 14 | 3 | 10 | 12 | - | 3 | 2 | 1 | 2 | 1 | 3 | 1 | 5 | - | 8 | - | 18 | 15 | - | - | - | **116** |
| **20** | 8 | 22 | - | 32 | 6 | 18 | 15 | 1 | **13** | **4** | 2 | 6 | - | 3 | 1 | 8 | **1** | 7 | - | 16 | 21 | - | - | - | **184** |
| **23** | 2 | 4 | - | 7 | 1 | 5 | 9 | - | 1 | 3 | - | 7 | - | 1 | - | 3 | - | 4 | - | 7 | 9 | 1 | - | - | **64** |
| **25** | 2 | 1 | - | 6 | 1 | 3 | - | 2 | - | 2 | - | 4 | - | 1 | 6 | 1 | - | 4 | - | 4 | - | 1 | - | 1 | **39** |
| **26** | 5 | 2 | - | 4 | - | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | - | 1 | 5 | - | **12** | - | 6 | 1 | - | - | - | **48** |
| **28** | 8 | 4 | - | 5 | - | 2 | 2 | - | - | - | 2 | - | - | - | - | 4 | - | 8 | - | 2 | 2 | - | - | - | **39** |
| **29** | 3 | - | - | 2 | - | - | - | - | 1 | - | - | - | - | 1 | 1 | 3 | - | 9 | - | - | - | **2** | **1** | - | **23** |
| **32** | 2 | 3 | **1** | 8 | 1 | 5 | 6 | - | - | - | 1 | 2 | - | - | 6 | 2 | - | 4 | - | 8 | 7 | - | - | - | **56** |
| **34** | 2 | 2 | - | 4 | - | 1 | - | - | - | - | - | - | - | - | - | 2 | - | 4 | - | 1 | - | - | - | - | **16** |
| **35** | 8 | 5 | - | 2 | - | 3 | 2 | - | 1 | - | - | 3 | 1 | - | - | 3 | - | - | - | 4 | 2 | - | - | - | **34** |
| **36** | 2 | 1 | - | 6 | 1 | 3 | 1 | - | - | - | - | 2 | - | 2 | - | 2 | - | 4 | - | 1 | 1 | - | - | - | **26** |
| **41** | 11 | 14 | - | 28 | 6 | 15 | 9 | 2 | 11 | **4** | 2 | 5 | - | 4 | 3 | 3 | - | 4 | - | **92** | 12 | 1 | **1** | **9** | **236** |
| **42** | 14 | - | - | - | - | - | - | 2 | 1 | - | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | **21** |
| **Sum** | **152** | **137** | **3** | **196** | **31** | **117** | **107** | **16** | **57** | **24** | **25** | **60** | **20** | **36** | **43** | **66** | **1** | **104** | **1** | **303** | **144** | **9** | **2** | **12** | **1666** |
| **Mean** | **7.6** | **6.9** | **0.2** | **9.8** | **1.6** | **5.9** | **5.4** | **0.8** | **2.9** | **1.2** | **1.3** | **3.0** | **1.0** | **1.8** | **2.2** | **3.3** | **0.1** | **5.2** | **0.1** | **15.2** | **7.2** | **0.5** | **0.1** | **0.6** | **83.3** |
| **SD** | **5.8** | **9.9** | **0.4** | **11.0** | **2.3** | **6.6** | **7.1** | **1.0** | **4.0** | **1.5** | **1.3** | **4.0** | **1.5** | **2.3** | **2.6** | **2.6** | **0.2** | **3.9** | **0.2** | **25.4** | **11.4** | **0.7** | **0.3** | **2.0** | |

**Table 36. Summary statistics of recorded game metrics per player.**

| | Login | EnterWorld | RunOutOfEnergy | BeganQuestStage | CompleteQuest | CompleteChecklist | ReachedLevel | PressedHelp | PressedMap | PressedZone | PressedProfile | PressedChecklist | PressedResources | PressedQuests | PressedMenu | BaseRewardGiven | BonusRewardGiven | BonusRewardMissed | UsedGetOutOfJail FreeCard | ChoppedDownTree | XPBubbleClicked | AverageRewardMissed | NotificiationClicked | NotificiationReceived | Total Action Count | Total Types of Actions | Session Count | Total Session Length | Average Session Length | Average Actions Per Session |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Login** | **1** | **.634** | .380 | **.454** | **.519** | **.559** | **.622** | **.541** | **.504** | .182 | .382 | **.636** | **.683** | **.681** | .326 | **.554** | .016 | .244 | .098 | **.611** | **.698** | -.152 | -.036 | .127 | **.693** | .238 | **.809** | **.733** | .124 | -.071 |
| **EnterWorld** | **.634** | **1** | **.487** | **.851** | **.849** | **.939** | **.922** | **.559** | **.793** | **.586** | **.609** | **.813** | **.498** | **.776** | **.476** | **.843** | .361 | **.464** | .123 | **.733** | **.946** | -.122 | .005 | .151 | **.942** | **.661** | **.864** | **.935** | **.721** | **.475** |
| **RunOutOfEnergy** | .380 | **.487** | **1** | .204 | .211 | .426 | **.584** | .372 | .271 | .224 | .361 | .428 | **.580** | .356 | **.536** | **.445** | -.096 | **.453** | **.546** | .348 | **.597** | .136 | -.140 | -.057 | **.479** | .432 | **.524** | **.557** | .394 | .197 |
| **BeganQuestStage** | **.454** | **.851** | .204 | **1** | **.979** | **.936** | **.767** | .387 | **.773** | **.584** | .404 | **.687** | .106 | **.653** | .347 | **.689** | **.476** | .316 | -.167 | **.791** | **.776** | -.141 | .162 | .342 | **.885** | **.608** | **.653** | **.768** | **.745** | **.681** |
| **CompleteQuest** | **.519** | **.849** | .211 | **.979** | **1** | **.944** | **.798** | .440 | **.821** | **.625** | .397 | **.733** | .155 | **.726** | .390 | **.676** | **.459** | .287 | -.160 | **.827** | **.807** | -.133 | .217 | .418 | **.914** | **.633** | **.696** | **.790** | **.706** | **.619** |
| **CompleteChecklist** | **.559** | **.939** | .426 | **.936** | **.944** | **1** | **.923** | **.498** | **.856** | **.721** | **.520** | **.753** | .334 | **.728** | .405 | **.802** | .436 | **.444** | .113 | **.803** | **.913** | -.066 | .086 | .306 | **.960** | **.763** | **.809** | **.862** | **.760** | **.618** |
| **ReachedLevel** | **.622** | **.922** | **.584** | **.767** | **.798** | **.923** | **1** | **.466** | **.756** | **.669** | **.533** | **.808** | **.502** | **.750** | .427 | **.858** | .319 | **.521** | .220 | **.678** | **.983** | -.066 | -.041 | .106 | **.913** | **.739** | **.858** | **.898** | **.726** | **.476** |
| **PressedHelp** | **.541** | **.559** | .372 | .387 | .440 | **.498** | **.466** | **1** | **.535** | **.502** | .405 | **.520** | **.563** | **.583** | **.462** | .404 | .047 | .424 | .281 | **.561** | **.523** | .137 | .068 | .349 | **.610** | **.556** | **.592** | **.625** | .397 | .145 |
| **PressedMap** | **.504** | **.793** | .271 | **.773** | **.821** | **.856** | **.756** | **.535** | **1** | **.791** | **.544** | **.546** | .305 | **.650** | .236 | **.671** | **.605** | .351 | .247 | **.709** | **.731** | .084 | .273 | **.489** | **.833** | **.713** | **.759** | **.680** | **.480** | .373 |
| **PressedZone** | .182 | **.586** | .224 | **.584** | **.625** | **.721** | **.669** | **.502** | **.791** | **1** | .422 | .424 | .184 | .419 | .179 | **.506** | .427 | .410 | .427 | **.555** | **.578** | .308 | .177 | **.468** | **.656** | **.843** | **.521** | **.470** | **.606** | **.555** |
| **PressedProfile** | .382 | **.609** | .361 | .404 | .397 | **.520** | **.533** | .405 | **.544** | .422 | **1** | .273 | **.602** | **.450** | **.529** | .443 | .137 | .373 | .319 | .399 | **.518** | -.133 | -.066 | .142 | **.547** | **.534** | **.604** | **.497** | .381 | .250 |
| **PressedChecklist** | **.636** | **.813** | .428 | **.687** | **.733** | **.753** | **.808** | **.520** | **.546** | .424 | .273 | **1** | **.475** | **.774** | **.526** | **.689** | .175 | .286 | -.117 | **.663** | **.865** | -.114 | -.042 | .104 | **.820** | **.480** | **.744** | **.903** | **.679** | .361 |
| **PressedResources** | **.683** | **.498** | **.580** | .106 | .155 | .334 | **.502** | **.563** | .305 | .184 | **.602** | **.475** | **1** | **.579** | **.470** | .433 | -.158 | .433 | **.475** | .312 | **.562** | .052 | -.230 | -.106 | **.473** | .319 | **.679** | **.592** | .132 | -.137 |
| **PressedQuests** | **.681** | **.776** | .356 | **.653** | **.726** | **.728** | **.750** | **.583** | **.650** | .419 | **.450** | **.774** | **.579** | **1** | **.460** | **.588** | .125 | .372 | .021 | **.680** | **.804** | .027 | .106 | .259 | **.815** | **.556** | **.738** | **.821** | **.529** | .290 |
| **PressedMenu** | .326 | **.476** | **.536** | .347 | .390 | .405 | .427 | **.462** | .236 | .179 | **.529** | **.526** | **.470** | **.460** | **1** | .181 | -.106 | .086 | -.014 | .404 | **.482** | -.100 | -.020 | .104 | **.479** | .321 | .386 | **.523** | **.493** | .320 |
| **BaseRewardGiven** | **.554** | **.843** | **.445** | **.689** | **.676** | **.802** | **.858** | .404 | **.671** | **.506** | .443 | **.689** | .433 | **.588** | .181 | **1** | .423 | **.716** | .153 | **.528** | **.871** | -.108 | -.039 | -.056 | **.792** | **.623** | **.874** | **.858** | **.574** | .230 |
| **BonusRewardGiven** | .016 | .361 | -.096 | **.476** | **.459** | .436 | .319 | .047 | **.605** | .427 | .137 | .175 | -.158 | .125 | -.106 | .423 | **1** | .108 | -.053 | .008 | .285 | -.154 | -.076 | -.070 | .266 | .236 | .262 | .201 | .178 | .120 |
| **BonusRewardMissed** | .244 | **.464** | **.453** | .316 | .287 | **.444** | **.521** | .424 | .351 | .410 | .373 | .286 | .433 | .372 | .086 | **.716** | .108 | **1** | .407 | .308 | **.529** | .297 | .113 | -.043 | **.479** | **.548** | **.582** | **.539** | .387 | .136 |
| **UsedGetOutOfJailFree Card** | .098 | .123 | **.546** | -.167 | -.160 | .113 | .220 | .281 | .247 | .427 | .319 | -.117 | **.475** | .021 | -.014 | .153 | -.053 | .407 | **1** | .045 | .161 | **.532** | -.076 | .047 | .116 | .395 | .262 | .071 | -.017 | -.035 |

| | Login | EnterWorld | RunOutOfEnergy | BeganQuestStage | CompleteQuest | CompleteChecklist | ReachedLevel | PressedHelp | PressedMap | PressedZone | PressedProfile | PressedChecklist | PressedResources | PressedQuests | PressedMenu | BaseRewardGiven | BonusRewardGiven | BonusRewardMissed | UsedGetOutOfJail FreeCard | ChoppedDownTree | XPBubbleClicked | AverageRewardMissed | NotificiationClicked | NotificiationReceived | Total Action Count | Total Types of Actions | Session Count | Total Session Length | Average Session Length | Average Actions Per Session |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ChoppedDownTree** | **.611** | **.733** | .348 | **.791** | **.827** | **.803** | **.678** | **.561** | **.709** | **.555** | .399 | **.663** | .312 | **.680** | .404 | **.528** | .008 | .308 | .045 | **1** | **.704** | .098 | .415 | **.690** | **.894** | **.606** | **.704** | **.752** | **.575** | **.539** |
| **XPBubbleClicked** | **.698** | **.946** | **.597** | **.776** | **.807** | **.913** | **.983** | **.523** | **.731** | **.578** | **.518** | **.865** | **.562** | **.804** | **.482** | **.871** | .285 | **.529** | .161 | **.704** | **1** | -.093 | -.036 | .084 | **.934** | **.668** | **.895** | **.957** | **.697** | .411 |
| **AverageRewardMissed** | -.152 | -.122 | .136 | -.141 | -.133 | -.066 | -.066 | .137 | .084 | .308 | -.133 | -.114 | .052 | .027 | -.100 | -.108 | -.154 | .297 | **.532** | .098 | -.093 | **1** | **.523** | .290 | -.008 | .191 | -.085 | -.099 | .022 | .159 |
| **NotificiationClicked** | -.036 | .005 | -.140 | .162 | .217 | .086 | -.041 | .068 | .273 | .177 | -.066 | -.042 | -.230 | .106 | -.020 | -.039 | -.076 | .113 | -.076 | .415 | -.036 | **.523** | **1** | **.663** | .177 | .073 | .011 | .008 | -.015 | .146 |
| **NotificiationReceived** | .127 | .151 | -.057 | .342 | .418 | .306 | .106 | .349 | **.489** | **.468** | .142 | .104 | -.106 | .259 | .104 | -.056 | -.070 | -.043 | .047 | **.690** | .084 | .290 | **.663** | **1** | .388 | .391 | .188 | .125 | .141 | .314 |
| **Total Action Count** | **.693** | **.942** | **.479** | **.885** | **.914** | **.960** | **.913** | **.610** | **.833** | **.656** | **.547** | **.820** | **.473** | **.815** | **.479** | **.792** | .266 | **.479** | .116 | **.894** | **.934** | -.008 | .177 | .388 | **1** | **.721** | **.882** | **.932** | **.707** | **.523** |
| **Total Types of Actions** | .238 | **.661** | .432 | **.608** | **.633** | **.763** | **.739** | **.556** | **.713** | **.843** | **.534** | **.480** | .319 | **.556** | .321 | **.623** | .236 | **.548** | .395 | **.606** | **.668** | .191 | .073 | .391 | **.721** | **1** | **.614** | **.603** | **.747** | **.590** |
| **Session Count** | **.809** | **.864** | **.524** | **.653** | **.696** | **.809** | **.858** | **.592** | **.759** | **.521** | **.604** | **.744** | **.679** | **.738** | .386 | **.874** | .262 | **.582** | .262 | **.704** | **.895** | -.085 | .011 | .188 | **.882** | **.614** | **1** | **.909** | .435 | .119 |
| **Total Session Length** | **.733** | **.935** | **.557** | **.768** | **.790** | **.862** | **.898** | **.625** | **.680** | **.470** | **.497** | **.903** | **.592** | **.821** | **.523** | **.858** | .201 | **.539** | .071 | **.752** | **.957** | -.099 | .008 | .125 | **.932** | **.603** | **.909** | **1** | **.679** | .340 |
| **Average Session Length** | .124 | **.721** | .394 | **.745** | **.706** | **.760** | **.726** | .397 | **.480** | **.606** | .381 | **.679** | .132 | **.529** | **.493** | **.574** | .178 | .387 | -.017 | **.575** | **.697** | .022 | -.015 | .141 | **.707** | **.747** | .435 | **.679** | **1** | **.840** |
| **Avg Actions / Session** | -.071 | **.475** | .197 | **.681** | **.619** | **.618** | **.476** | .145 | .373 | **.555** | .250 | .361 | -.137 | .290 | .320 | .230 | .120 | .136 | -.035 | **.539** | .411 | .159 | .146 | .314 | **.523** | **.590** | .119 | .340 | **.840** | **1** |

**Table 37. Correlation matrix for the game metrics recorded in *Energy Explorer*.**

## Appendix H Exit Survey Results

This appendix lists the questions used in the exit survey, as well as summary statistics for each question. Note that questions listed here begin at 4, since questions 1, 2, and 3 were related to household information (number of people in household, number of bedrooms, and air conditioner presence).

Descriptive statistics are provided in Table 38, and a correlation table of all questions (including the first three questions) is shown in Table 39.

| Question | Min | Max | Mean | SD |
|---|---|---|---|---|
| 4. Having the amount of energy I got in-game being linked to my real-world energy usage gave more meaning to my real-world actions. | 1.0 | 4.0 | 1.8 | 1.035 |
| 5. I felt accomplished when I received extra energy in-game. | 1.0 | 4.0 | 2.4 | 1.188 |
| 6. I felt like the changing weather conditions in-game because of my real-world energy usage gave more meaning to real world actions. | 1.0 | 3.0 | 1.8 | 0.886 |
| 7. I felt accomplished when the weather in-game improved. | 1.0 | 3.0 | 1.8 | 0.886 |
| 8. Improving my level and getting experience points made me feel a sense of accomplishment. | 1.0 | 4.0 | 1.9 | 1.126 |
| 9. My friend's progress in the game influenced my actions. | 1.0 | 3.0 | 1.4 | 0.744 |
| 10. My behaviour was influenced by seeing the energy usages statistics of other players. | 1.0 | 3.0 | 1.5 | 0.756 |
| 11. I felt like I owned my game avatar in Energy Explorer. | 1.0 | 4.0 | 1.6 | 1.061 |
| 12. I felt accomplished when I saw that I had better energy usage than other players. | 1.0 | 3.0 | 1.6 | 0.916 |
| 13. The comparison of my energy usage to that of other players influenced my behaviour. | 1.0 | 3.0 | 1.5 | 0.756 |
| 14. When I got rewarded for having better energy usage than other players, I felt I had achieved something. | 1.0 | 3.0 | 1.6 | 0.916 |
| 15. I felt accomplished when I received rewards for completing a quest in the game. | 1.0 | 4.0 | 2.0 | 1.069 |
| 16. I felt like I had achieved something when completing a checklist item. | 1.0 | 4.0 | 2.3 | 1.035 |
| 17. The Energy resource in Energy Explorer was scarce. | 1.0 | 5.0 | 2.4 | 1.408 |
| 18. The treasure chest rewards in the game were unpredictable. | 1.0 | 5.0 | 3.0 | 1.414 |
| 19. I wanted to avoid missing out on quest rewards. | 1.0 | 4.0 | 2.1 | 1.126 |
| 20. I wanted to avoid missing out on bonus energy given for improving my energy behaviour. | 1.0 | 4.0 | 2.3 | 1.035 |
| 21. Bad in-game weather was something I wanted to avoid having happen. | 1.0 | 4.0 | 2.1 | 1.126 |
| 22. In-game energy being linked to my real-world energy usage provided me with feedback on my behaviour. | 1.0 | 4.0 | 2.4 | 1.302 |
| 23. The weather changing in-game based upon my actual energy usage was a form of feedback for my behaviour. | 1.0 | 3.0 | 2.0 | 0.926 |
| 24. I received feedback on my behaviour through the experience points I earned in-game. | 1.0 | 3.0 | 1.8 | 0.886 |
| 25. The social system in Energy Explorer allowed me to compare my behaviour to others. | 1.0 | 3.0 | 1.8 | 0.886 |

| Question | Min | Max | Mean | SD |
|---|---|---|---|---|
| 26. I compared my behaviour to others by looking at their energy usage using Energy Explorer. | 1.0 | 3.0 | 1.5 | 0.756 |
| 27. My game avatar helped me associate my identity with my changed energy behaviour. | 1.0 | 4.0 | 1.8 | 1.035 |
| 28. Having better energy usage than other players made me feel like a role model to them. | 1.0 | 3.0 | 1.6 | 0.916 |
| 29. I felt like my energy behaviour had consequences because it was linked to my progress in-game. | 1.0 | 3.0 | 1.8 | 0.886 |
| 30. The change in weather in-game made me feel like my energy behaviour had consequences. | 1.0 | 4.0 | 2.1 | 1.126 |
| 31. My energy behaviour's impact on in-game resources helped me think about the environmental consequences of my behaviour. | 1.0 | 4.0 | 2.0 | 1.069 |
| 32. I thought about the environmental impact of my behaviour as a result of seeing the consequences my behaviour had on the in-game weather. | 1.0 | 4.0 | 1.9 | 1.126 |
| 33. Having better energy usage than other players was a social reward. | 1.0 | 3.0 | 1.6 | 0.916 |
| 34. Quest rewards were an incentive to reduce my energy usage. | 1.0 | 3.0 | 1.9 | 0.835 |
| 35. I was incentivized to reduce my energy usage by the promise of reward for having better energy usage than other players. | 1.0 | 3.0 | 1.8 | 0.886 |
| 36. Rewards for completing a checklist item were an incentive to reduce my energy usage. | 1.0 | 4.0 | 2.0 | 1.069 |
| 37. The promise of a base energy reward was an incentive to return to the game. | 1.0 | 3.0 | 2.0 | 0.926 |
| 38. Being given less in-game energy when I did not improve my real-world energy usage felt punishing. | 1.0 | 4.0 | 2.0 | 1.069 |
| 39. I felt punished when the weather in an area became worse. | 1.0 | 4.0 | 2.0 | 1.069 |
| 40. I felt like there was a cost to my real-world behaviour when I was given less energy. | 1.0 | 4.0 | 2.0 | 1.069 |
| 41. The weather becoming worse in an area made me feel like there was a cost to my actions. | 1.0 | 4.0 | 2.0 | 1.069 |

**Table 38. Descriptive statistics of responses to the game experience question on the exit survey.**

| | q1 | q2 | q4 | q5 | q6 | q7 | q8 | q9 | q10 | q11 | q12 | q13 | q14 | q15 | q16 | q17 | q18 | q19 | q20 | q21 | q22 | q23 | q24 | q25 | q26 | q27 | q28 | q29 | q30 | q31 | q32 | q33 | q34 | q35 | q36 | q37 | q38 | q39 | q40 | q41 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| q1 | 1 | 0.853 | -0.389 | 0.034 | -0.091 | -0.091 | -0.250 | -0.596 | -0.426 | -0.494 | -0.220 | -0.426 | -0.220 | -0.302 | -0.078 | -0.544 | -0.570 | -0.036 | -0.234 | -0.036 | 0.155 | 0.174 | -0.091 | -0.091 | -0.426 | -0.389 | -0.220 | -0.091 | -0.036 | -0.151 | -0.250 | -0.220 | 0.048 | -0.091 | -0.151 | 0.174 | -0.151 | -0.151 | -0.151 | -0.151 |
| q2 | 0.853 | 1 | -0.548 | -0.159 | -0.426 | -0.426 | -0.504 | -0.508 | -0.500 | -0.535 | -0.413 | -0.500 | -0.413 | -0.530 | -0.183 | -0.537 | -0.535 | -0.168 | -0.183 | -0.168 | -0.145 | 0.000 | -0.426 | 0.000 | -0.500 | -0.548 | 0.000 | 0.000 | -0.168 | -0.177 | -0.168 | 0.000 | 0.000 | 0.000 | -0.177 | 0.000 | -0.177 | -0.177 | -0.177 | -0.177 |
| q4 | -0.389 | -0.548 | 1 | 0.784 | 0.856 | 0.856 | 0.950 | 0.881 | 0.913 | 0.943 | 0.791 | 0.913 | 0.791 | 0.904 | 0.733 | 0.074 | -0.195 | 0.766 | 0.600 | 0.766 | 0.715 | 0.596 | 0.856 | 0.545 | 0.913 | 1.000 | 0.490 | 0.545 | 0.766 | 0.775 | 0.705 | 0.490 | 0.620 | 0.545 | 0.775 | 0.596 | 0.775 | 0.775 | 0.775 | 0.775 |
| q5 | 0.034 | -0.159 | 0.784 | 1 | 0.780 | 0.780 | 0.788 | 0.626 | 0.716 | 0.695 | 0.673 | 0.716 | 0.673 | 0.675 | 0.842 | 0.075 | -0.340 | 0.921 | 0.610 | 0.921 | 0.912 | 0.909 | 0.780 | 0.780 | 0.716 | 0.784 | 0.673 | 0.780 | 0.921 | 0.900 | 0.788 | 0.673 | 0.919 | 0.780 | 0.900 | 0.909 | 0.900 | 0.900 | 0.900 | 0.900 |
| q6 | -0.091 | -0.426 | 0.856 | 0.780 | 1 | 1.000 | 0.823 | 0.596 | 0.853 | 0.798 | 0.924 | 0.853 | 0.924 | 0.754 | 0.545 | 0.086 | -0.228 | 0.608 | 0.389 | 0.751 | 0.711 | 0.696 | 0.818 | 0.455 | 0.853 | 0.856 | 0.220 | 0.455 | 0.608 | 0.603 | 0.537 | 0.220 | 0.531 | 0.455 | 0.603 | 0.522 | 0.603 | 0.603 | 0.603 | 0.603 |
| q7 | -0.091 | -0.426 | 0.856 | 0.780 | 1.000 | 1 | 0.823 | 0.596 | 0.853 | 0.798 | 0.924 | 0.853 | 0.924 | 0.754 | 0.545 | 0.086 | -0.228 | 0.608 | 0.389 | 0.751 | 0.711 | 0.696 | 0.818 | 0.455 | 0.853 | 0.856 | 0.220 | 0.455 | 0.608 | 0.603 | 0.537 | 0.220 | 0.531 | 0.455 | 0.603 | 0.522 | 0.603 | 0.603 | 0.603 | 0.603 |
| q8 | -0.250 | -0.504 | 0.950 | 0.788 | 0.823 | 0.823 | 1 | 0.746 | 0.755 | 0.792 | 0.641 | 0.755 | 0.641 | 0.949 | 0.766 | -0.056 | -0.269 | 0.803 | 0.521 | 0.690 | 0.816 | 0.548 | 0.966 | 0.394 | 0.755 | 0.950 | 0.364 | 0.394 | 0.803 | 0.712 | 0.549 | 0.364 | 0.589 | 0.394 | 0.712 | 0.685 | 0.712 | 0.712 | 0.712 | 0.712 |
| q9 | -0.596 | -0.508 | 0.881 | 0.626 | 0.596 | 0.596 | 0.746 | 1 | 0.889 | 0.928 | 0.655 | 0.889 | 0.655 | 0.718 | 0.603 | 0.119 | -0.136 | 0.618 | 0.603 | 0.618 | 0.424 | 0.415 | 0.596 | 0.596 | 0.889 | 0.881 | 0.655 | 0.596 | 0.618 | 0.718 | 0.746 | 0.655 | 0.546 | 0.596 | 0.718 | 0.415 | 0.718 | 0.718 | 0.718 | 0.718 |
| q10 | -0.426 | -0.500 | 0.913 | 0.716 | 0.853 | 0.853 | 0.755 | 0.889 | 1 | 0.980 | 0.928 | 1.000 | 0.928 | 0.707 | 0.548 | 0.201 | -0.134 | 0.587 | 0.548 | 0.755 | 0.508 | 0.612 | 0.640 | 0.640 | 1.000 | 0.913 | 0.516 | 0.640 | 0.587 | 0.707 | 0.755 | 0.516 | 0.566 | 0.640 | 0.707 | 0.408 | 0.707 | 0.707 | 0.707 | 0.707 |
| q11 | -0.494 | -0.535 | 0.943 | 0.695 | 0.798 | 0.798 | 0.792 | 0.928 | 0.980 | 1 | 0.864 | 0.980 | 0.864 | 0.756 | 0.618 | 0.203 | -0.095 | 0.643 | 0.618 | 0.763 | 0.530 | 0.582 | 0.646 | 0.646 | 0.980 | 0.943 | 0.570 | 0.646 | 0.643 | 0.756 | 0.792 | 0.570 | 0.585 | 0.646 | 0.756 | 0.436 | 0.756 | 0.756 | 0.756 | 0.756 |
| q12 | -0.220 | -0.413 | 0.791 | 0.673 | 0.924 | 0.924 | 0.641 | 0.655 | 0.928 | 0.864 | 1 | 0.928 | 1.000 | 0.583 | 0.414 | 0.235 | -0.110 | 0.467 | 0.414 | 0.744 | 0.494 | 0.674 | 0.572 | 0.572 | 0.928 | 0.791 | 0.319 | 0.572 | 0.467 | 0.583 | 0.641 | 0.319 | 0.490 | 0.572 | 0.583 | 0.337 | 0.583 | 0.583 | 0.583 | 0.583 |
| q13 | -0.426 | -0.500 | 0.913 | 0.716 | 0.853 | 0.853 | 0.755 | 0.889 | 1.000 | 0.980 | 0.928 | 1 | 0.928 | 0.707 | 0.548 | 0.201 | -0.134 | 0.587 | 0.548 | 0.755 | 0.508 | 0.612 | 0.640 | 0.640 | 1.000 | 0.913 | 0.516 | 0.640 | 0.587 | 0.707 | 0.755 | 0.516 | 0.566 | 0.640 | 0.707 | 0.408 | 0.707 | 0.707 | 0.707 | 0.707 |
| q14 | -0.220 | -0.413 | 0.791 | 0.673 | 0.924 | 0.924 | 0.641 | 0.655 | 0.928 | 0.864 | 1.000 | 0.928 | 1 | 0.583 | 0.414 | 0.235 | -0.110 | 0.467 | 0.414 | 0.744 | 0.494 | 0.674 | 0.572 | 0.572 | 0.928 | 0.791 | 0.319 | 0.572 | 0.467 | 0.583 | 0.641 | 0.319 | 0.490 | 0.572 | 0.583 | 0.337 | 0.583 | 0.583 | 0.583 | 0.583 |
| q15 | -0.302 | -0.530 | 0.904 | 0.675 | 0.754 | 0.754 | 0.949 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 1 | 0.775 | -0.190 | -0.094 | 0.712 | 0.645 | 0.593 | 0.718 | 0.433 | 0.905 | 0.302 | 0.707 | 0.904 | 0.292 | 0.302 | 0.712 | 0.625 | 0.475 | 0.292 | 0.480 | 0.302 | 0.625 | 0.577 | 0.625 | 0.625 | 0.625 | 0.625 |
| q16 | -0.078 | -0.183 | 0.733 | 0.842 | 0.545 | 0.545 | 0.766 | 0.603 | 0.548 | 0.618 | 0.414 | 0.548 | 0.414 | 0.775 | 1 | -0.074 | -0.098 | 0.950 | 0.867 | 0.827 | 0.874 | 0.745 | 0.701 | 0.701 | 0.548 | 0.733 | 0.716 | 0.701 | 0.950 | 0.904 | 0.766 | 0.716 | 0.868 | 0.701 | 0.904 | 0.894 | 0.904 | 0.904 | 0.904 | 0.904 |
| q17 | -0.544 | -0.537 | 0.074 | 0.075 | 0.086 | 0.086 | -0.056 | 0.119 | 0.201 | 0.203 | 0.235 | 0.201 | 0.235 | -0.190 | -0.074 | 1 | 0.502 | 0.056 | -0.074 | 0.237 | -0.010 | 0.219 | -0.143 | 0.315 | 0.201 | 0.074 | 0.235 | 0.315 | 0.056 | 0.190 | 0.304 | 0.235 | 0.167 | 0.315 | 0.190 | 0.000 | 0.190 | 0.190 | 0.190 | 0.190 |
| q18 | -0.570 | -0.535 | -0.195 | -0.340 | -0.228 | -0.228 | -0.269 | -0.136 | -0.134 | -0.095 | -0.110 | -0.134 | -0.110 | -0.094 | -0.098 | 0.502 | 1 | -0.269 | 0.195 | -0.179 | -0.310 | -0.218 | -0.342 | -0.114 | -0.134 | -0.195 | -0.110 | -0.114 | -0.269 | -0.189 | -0.090 | -0.110 | -0.242 | -0.114 | -0.189 | -0.327 | -0.189 | -0.189 | -0.189 | -0.189 |
| q19 | -0.036 | -0.168 | 0.766 | 0.921 | 0.608 | 0.608 | 0.803 | 0.618 | 0.587 | 0.643 | 0.467 | 0.587 | 0.467 | 0.712 | 0.950 | 0.056 | -0.269 | 1 | 0.705 | 0.887 | 0.938 | 0.822 | 0.751 | 0.751 | 0.587 | 0.766 | 0.744 | 0.751 | 1.000 | 0.949 | 0.803 | 0.744 | 0.931 | 0.751 | 0.949 | 0.959 | 0.949 | 0.949 | 0.949 | 0.949 |
| q20 | -0.234 | -0.183 | 0.600 | 0.610 | 0.389 | 0.389 | 0.521 | 0.603 | 0.548 | 0.618 | 0.414 | 0.548 | 0.414 | 0.645 | 0.867 | -0.074 | 0.195 | 0.705 | 1 | 0.705 | 0.556 | 0.596 | 0.389 | 0.701 | 0.548 | 0.600 | 0.716 | 0.701 | 0.705 | 0.775 | 0.766 | 0.716 | 0.703 | 0.701 | 0.775 | 0.596 | 0.775 | 0.775 | 0.775 | 0.775 |
| q21 | -0.036 | -0.168 | 0.766 | 0.921 | 0.751 | 0.751 | 0.690 | 0.618 | 0.755 | 0.763 | 0.744 | 0.755 | 0.744 | 0.593 | 0.827 | 0.237 | -0.179 | 0.887 | 0.705 | 1 | 0.840 | 0.959 | 0.608 | 0.895 | 0.755 | 0.766 | 0.744 | 0.895 | 0.887 | 0.949 | 0.915 | 0.744 | 0.931 | 0.895 | 0.949 | 0.822 | 0.949 | 0.949 | 0.949 | 0.949 |
| q22 | 0.155 | -0.145 | 0.715 | 0.912 | 0.711 | 0.711 | 0.816 | 0.424 | 0.508 | 0.530 | 0.494 | 0.508 | 0.494 | 0.718 | 0.874 | -0.010 | -0.310 | 0.938 | 0.556 | 0.840 | 1 | 0.829 | 0.835 | 0.588 | 0.508 | 0.715 | 0.494 | 0.588 | 0.938 | 0.821 | 0.621 | 0.494 | 0.838 | 0.588 | 0.821 | 0.948 | 0.821 | 0.821 | 0.821 | 0.821 |
| q23 | 0.174 | 0.000 | 0.596 | 0.909 | 0.696 | 0.696 | 0.548 | 0.415 | 0.612 | 0.582 | 0.674 | 0.612 | 0.674 | 0.433 | 0.745 | 0.219 | -0.218 | 0.822 | 0.596 | 0.959 | 0.829 | 1 | 0.522 | 0.870 | 0.612 | 0.596 | 0.674 | 0.870 | 0.822 | 0.866 | 0.822 | 0.674 | 0.925 | 0.870 | 0.866 | 0.833 | 0.866 | 0.866 | 0.866 | 0.866 |
| q24 | -0.091 | -0.426 | 0.856 | 0.780 | 0.818 | 0.818 | 0.966 | 0.596 | 0.640 | 0.646 | 0.572 | 0.640 | 0.572 | 0.905 | 0.701 | -0.143 | -0.342 | 0.751 | 0.389 | 0.608 | 0.835 | 0.522 | 1 | 0.273 | 0.640 | 0.856 | 0.220 | 0.273 | 0.751 | 0.603 | 0.394 | 0.220 | 0.531 | 0.273 | 0.603 | 0.696 | 0.603 | 0.603 | 0.603 | 0.603 |
| q25 | -0.091 | 0.000 | 0.545 | 0.780 | 0.455 | 0.455 | 0.394 | 0.596 | 0.640 | 0.646 | 0.572 | 0.640 | 0.572 | 0.302 | 0.701 | 0.315 | -0.114 | 0.751 | 0.701 | 0.895 | 0.588 | 0.870 | 0.273 | 1 | 0.640 | 0.545 | 0.924 | 1.000 | 0.751 | 0.905 | 0.966 | 0.924 | 0.917 | 1.000 | 0.905 | 0.696 | 0.905 | 0.905 | 0.905 | 0.905 |
| q26 | -0.426 | -0.500 | 0.913 | 0.716 | 0.853 | 0.853 | 0.755 | 0.889 | 1.000 | 0.980 | 0.928 | 1.000 | 0.928 | 0.707 | 0.548 | 0.201 | -0.134 | 0.587 | 0.548 | 0.755 | 0.508 | 0.612 | 0.640 | 0.640 | 1 | 0.913 | 0.516 | 0.640 | 0.587 | 0.707 | 0.755 | 0.516 | 0.566 | 0.640 | 0.707 | 0.408 | 0.707 | 0.707 | 0.707 | 0.707 |
| q27 | -0.389 | -0.548 | 1.000 | 0.784 | 0.856 | 0.856 | 0.950 | 0.881 | 0.913 | 0.943 | 0.791 | 0.913 | 0.791 | 0.904 | 0.733 | 0.074 | -0.195 | 0.766 | 0.600 | 0.766 | 0.715 | 0.596 | 0.856 | 0.545 | 0.913 | 1 | 0.490 | 0.545 | 0.766 | 0.775 | 0.705 | 0.490 | 0.620 | 0.545 | 0.775 | 0.596 | 0.775 | 0.775 | 0.775 | 0.775 |
| q28 | -0.220 | 0.000 | 0.490 | 0.673 | 0.220 | 0.220 | 0.364 | 0.655 | 0.516 | 0.570 | 0.319 | 0.516 | 0.319 | 0.292 | 0.716 | 0.235 | -0.110 | 0.744 | 0.716 | 0.744 | 0.494 | 0.674 | 0.220 | 0.924 | 0.516 | 0.490 | 1 | 0.924 | 0.744 | 0.875 | 0.917 | 1.000 | 0.864 | 0.924 | 0.875 | 0.674 | 0.875 | 0.875 | 0.875 | 0.875 |
| q29 | -0.091 | 0.000 | 0.545 | 0.780 | 0.455 | 0.455 | 0.394 | 0.596 | 0.640 | 0.646 | 0.572 | 0.640 | 0.572 | 0.302 | 0.701 | 0.315 | -0.114 | 0.751 | 0.701 | 0.895 | 0.588 | 0.870 | 0.273 | 1.000 | 0.640 | 0.545 | 0.924 | 1 | 0.751 | 0.905 | 0.966 | 0.924 | 0.917 | 1.000 | 0.905 | 0.696 | 0.905 | 0.905 | 0.905 | 0.905 |
| q30 | -0.036 | -0.168 | 0.766 | 0.921 | 0.608 | 0.608 | 0.803 | 0.618 | 0.587 | 0.643 | 0.467 | 0.587 | 0.467 | 0.712 | 0.950 | 0.056 | -0.269 | 1.000 | 0.705 | 0.887 | 0.938 | 0.822 | 0.751 | 0.751 | 0.587 | 0.766 | 0.744 | 0.751 | 1 | 0.949 | 0.803 | 0.744 | 0.931 | 0.751 | 0.949 | 0.959 | 0.949 | 0.949 | 0.949 | 0.949 |
| q31 | -0.151 | -0.177 | 0.775 | 0.900 | 0.603 | 0.603 | 0.712 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 0.625 | 0.904 | 0.190 | -0.189 | 0.949 | 0.775 | 0.949 | 0.821 | 0.866 | 0.603 | 0.905 | 0.707 | 0.775 | 0.875 | 0.905 | 0.949 | 1 | 0.949 | 0.875 | 0.961 | 0.905 | 1.000 | 0.866 | 1.000 | 1.000 | 1.000 | 1.000 |
| q32 | -0.250 | -0.168 | 0.705 | 0.788 | 0.537 | 0.537 | 0.549 | 0.746 | 0.755 | 0.792 | 0.641 | 0.755 | 0.641 | 0.475 | 0.766 | 0.304 | -0.090 | 0.803 | 0.766 | 0.915 | 0.621 | 0.822 | 0.394 | 0.966 | 0.755 | 0.705 | 0.917 | 0.966 | 0.803 | 0.949 | 1 | 0.917 | 0.893 | 0.966 | 0.949 | 0.685 | 0.949 | 0.949 | 0.949 | 0.949 |
| q33 | -0.220 | 0.000 | 0.490 | 0.673 | 0.220 | 0.220 | 0.364 | 0.655 | 0.516 | 0.570 | 0.319 | 0.516 | 0.319 | 0.292 | 0.716 | 0.235 | -0.110 | 0.744 | 0.716 | 0.744 | 0.494 | 0.674 | 0.220 | 0.924 | 0.516 | 0.490 | 1.000 | 0.924 | 0.744 | 0.875 | 0.917 | 1 | 0.864 | 0.924 | 0.875 | 0.674 | 0.875 | 0.875 | 0.875 | 0.875 |
| q34 | 0.048 | 0.000 | 0.620 | 0.919 | 0.531 | 0.531 | 0.589 | 0.546 | 0.566 | 0.585 | 0.490 | 0.566 | 0.490 | 0.480 | 0.868 | 0.167 | -0.242 | 0.931 | 0.703 | 0.931 | 0.838 | 0.925 | 0.531 | 0.917 | 0.566 | 0.620 | 0.864 | 0.917 | 0.931 | 0.961 | 0.893 | 0.864 | 1 | 0.917 | 0.961 | 0.925 | 0.961 | 0.961 | 0.961 | 0.961 |
| q35 | -0.091 | 0.000 | 0.545 | 0.780 | 0.455 | 0.455 | 0.394 | 0.596 | 0.640 | 0.646 | 0.572 | 0.640 | 0.572 | 0.302 | 0.701 | 0.315 | -0.114 | 0.751 | 0.701 | 0.895 | 0.588 | 0.870 | 0.273 | 1.000 | 0.640 | 0.545 | 0.924 | 1.000 | 0.751 | 0.905 | 0.966 | 0.924 | 0.917 | 1 | 0.905 | 0.696 | 0.905 | 0.905 | 0.905 | 0.905 |
| q36 | -0.151 | -0.177 | 0.775 | 0.900 | 0.603 | 0.603 | 0.712 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 0.625 | 0.904 | 0.190 | -0.189 | 0.949 | 0.775 | 0.949 | 0.821 | 0.866 | 0.603 | 0.905 | 0.707 | 0.775 | 0.875 | 0.905 | 0.949 | 1.000 | 0.949 | 0.875 | 0.961 | 0.905 | 1 | 0.866 | 1.000 | 1.000 | 1.000 | 1.000 |
| q37 | 0.174 | 0.000 | 0.596 | 0.909 | 0.522 | 0.522 | 0.685 | 0.415 | 0.408 | 0.436 | 0.337 | 0.408 | 0.337 | 0.577 | 0.894 | 0.000 | -0.327 | 0.959 | 0.596 | 0.822 | 0.948 | 0.833 | 0.696 | 0.696 | 0.408 | 0.596 | 0.674 | 0.696 | 0.959 | 0.866 | 0.685 | 0.674 | 0.925 | 0.696 | 0.866 | 1 | 0.866 | 0.866 | 0.866 | 0.866 |
| q38 | -0.151 | -0.177 | 0.775 | 0.900 | 0.603 | 0.603 | 0.712 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 0.625 | 0.904 | 0.190 | -0.189 | 0.949 | 0.775 | 0.949 | 0.821 | 0.866 | 0.603 | 0.905 | 0.707 | 0.775 | 0.875 | 0.905 | 0.949 | 1.000 | 0.949 | 0.875 | 0.961 | 0.905 | 1.000 | 0.866 | 1 | 1.000 | 1.000 | 1.000 |
| q39 | -0.151 | -0.177 | 0.775 | 0.900 | 0.603 | 0.603 | 0.712 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 0.625 | 0.904 | 0.190 | -0.189 | 0.949 | 0.775 | 0.949 | 0.821 | 0.866 | 0.603 | 0.905 | 0.707 | 0.775 | 0.875 | 0.905 | 0.949 | 1.000 | 0.949 | 0.875 | 0.961 | 0.905 | 1.000 | 0.866 | 1.000 | 1 | 1.000 | 1.000 |
| q40 | -0.151 | -0.177 | 0.775 | 0.900 | 0.603 | 0.603 | 0.712 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 0.625 | 0.904 | 0.190 | -0.189 | 0.949 | 0.775 | 0.949 | 0.821 | 0.866 | 0.603 | 0.905 | 0.707 | 0.775 | 0.875 | 0.905 | 0.949 | 1.000 | 0.949 | 0.875 | 0.961 | 0.905 | 1.000 | 0.866 | 1.000 | 1.000 | 1 | 1.000 |
| q41 | -0.151 | -0.177 | 0.775 | 0.900 | 0.603 | 0.603 | 0.712 | 0.718 | 0.707 | 0.756 | 0.583 | 0.707 | 0.583 | 0.625 | 0.904 | 0.190 | -0.189 | 0.949 | 0.775 | 0.949 | 0.821 | 0.866 | 0.603 | 0.905 | 0.707 | 0.775 | 0.875 | 0.905 | 0.949 | 1.000 | 0.949 | 0.875 | 0.961 | 0.905 | 1.000 | 0.866 | 1.000 | 1.000 | 1.000 | 1 |

**Table 39. Correlation table of all exit survey questions. Strong positive correlation was found for most game experience questions.**

# Appendix I Energy Explorer Resources

This appendix lists the resources that players can collect in *Energy Explorer* (Table 40). Main resources can be obtained as quest rewards, in addition to the ways mentioned in the notes below. The table also lists the quest items the player collects. These items are collectable in the game world or from other quests, and only a finite number of these items exist the game world (in some cases only one is available, from a specific quest). Quest items are used to complete other quests and checklist items—they do not serve an actual purpose in the game; however future iterations of the game could include the ability to use some items (e.g. throw the frisbee item).

| **Resource** | **Notes** |
|---|---|
| Energy | Main resource, all actions in game deplete this. |
| XP | Main resource, determines player level, obtained from all actions. |
| Wood | Core resource, obtained from chop down tree action, and specialized quests. |
| Water | Core resource, obtained from specialized quests. |
| Food | Core resource, obtained from specialized quests. |
| Money | Core resource, obtained from specialized quests. |
| Stone | Obtained from rockfalls. |
| Sapphire | Least-rare gem in Energy Explorer. |
| Ruby | Rarer than sapphire. |
| Emerald | Rarer than ruby. |
| Diamond | Rarer than emerald. |

| **Quest Items** | | | |
|---|---|---|---|
| Zoo Map | Tiffany's Breakfast Basket | Sam's Clock | Chocolate Banana |
| Jam Jar | Tiffany's Fork | Sam's Coffee Mug | Microphone |
| Earl the Eagle | Tiffany's Wine Glass | Coffee Mug | Cat Food |
| Cracker | Terrence's Letter | Bird Handling Glove | Party Golf Game |
| Shovel | Tiffany's Note | Larry's Frisbee | Vuvuzela |
| Saxophone | Badminton Shuttle | Yellow Frisbee | Tennis Ball |
| Whistle | Sam's Jam Jar (filled) | Blue Frisbee | Soccer Ball |
| Gold Watch | Stolen Jam Jar | Frisbee Club Reference | Boxing Glove |
| Water Gun | Fish Bowl | Frisbee | Bowling Ball |
| Fish | Fish Food | Super Frisbee | Dolphin Ring |
| Large Dolphin Ring | | Necklace of Jam Making | |

**Table 40.** ***Energy Explorer*** **resources.**

# Appendix J Energy Explorer Quest Examples

*Energy* Explorer featured in total 43 quests. This appendix presents three examples of quests implemented in *Energy Explorer.* The character (see Section 5.2.6) who must be spoken to to start the quest is given, as well as the requirements for the quest to become available (specifically which quests must be completed first). Following this, the dialog for the quest is presented.

## J.1 Welcome to Energy Explorer

**Quest Giver:** Bob (Introduction Zone)

**Available:** Starts automatically at the start of the game.

**Dialog:**

- Bob
  - <name>! I'm so glad you are here! There's been a terrible accident and I could really use help from someone with your skills!
- Player
  - An accident? What happened?
- Bob
  - I'll get to that in a minute, I need to show you how to get around.
- Player
  - You're right, I do not even know how to walk yet.
- Bob
  - Yes, that is very strange. Are you a baby?
- Player
  - Just show me how to walk, ok?
- Bob (Repeated if the player talks again, or looks at quest log)
  - To walk around, simply DRAG a path from your character on the screen, then TAP the "Walk here" button to confirm.
  - If you want to change your path, just DRAG from any point on the path to redraw.
  - Try it now, and I will talk to you again.
- Requirements
  - Walk 15 steps
- Rewards
  - None
- Bob
  - Looks like you have worked out this walking thing pretty quick!
  - <name>, you may have noticed the ENERGY cost of walking.
    - Player Response: I did, what's that about?
  - Everything you do in the game costs you ENERGY.
  - Once you RUN OUT of ENERGY, you have to WAIT to get some more, so use it carefully!

    - In this starting out area it does not cost any energy to move so you can learn.
        - Player Response: Convenient!
    - Did you also see you completed a checklist item?
    - COMPLETE items on the CHECKLIST to get XP
- Player
    - What is XP?
- Bob
    - XP means Experience. Gathering XP will increase your LEVEL.
    - Your LEVEL determines what awesome things you will discover in the game.
    - <name>, why do not you have a look at the CHECKLIST now to see what sort of things you can do to get XP?
- Requirements
    - Open Checklist
- Rewards
    - Small XP
- Bob
    - You really have a lot to do, <name>!
    - One of the items on that list was to COMPLETE 1 QUEST.
- Player
    - What is a quest?
- Bob
    - Well <name>, you're on your very first QUEST right now!
    - TALK to CHARACTERS in the WORLD to start and finish QUESTS.
    - Characters will ask you to FIND items or other characters to COMPLETE their QUESTS.
- Player
    - What's in it for me?
- Bob
    - COMPLETEING QUESTS will earn you REWARDS to complete other quests, and XP.
    - <name>, I need your help to collect some wood.
    - Good thing we are in a forest!
    - To collect wood, simply DRAG a path from your character to any TREE, and click the ACTION button to chop it down. (repeated)
    - When you have collected the wood, DRAG a path back to me to TALK to me again.
    - Come back to me with some WOOD, and I will reward you with some GEMS!
- Requirements
    - 10 Wood
- Rewards
    - 5 Emeralds
    - Small XP
- Bob
    - Thank you, <name>! Here are the GEMS I promised you!
    - Congratulations, you have completed your very first QUEST, <name>!
    - Now about that terrible accident. <name>, my good friend DANIEL over at the ZOO will tell you more about it.
    - You should WALK over to her and TALK to her.

## J.2 Breakfast at Tiffany's

**Quest Giver:** Tiffany (Introduction Zone)

**Available:** After completing Welcome to Energy Explorer

**Dialog:**

- Tiffany
  - Hey, you must be <name>! Bob told me you were on your way to see me.
  - I'm really hungry. Are you hungry? I'm hungry. I really want to eat. Did I mention I am hungry?
- Player
  - Seems you are hungry!
- Tiffany
  - I left some food in a TREASURE CHEST near here.
  - It's too muddy over there for me to go though. I'm too hungry to go as well. I do not want to walk in the mud. Also, I'M TOO HUNGRY!
  - Can you go and collect my BREAKFAST for me, <name>?
- Player
  - Well, if you really are that hungry…
- Tiffany
  - Oh THANK YOU, <name>!
  - It's just over to the left there, but be careful, the MUD will cost you more energy to walk through!
  - I'll wait here for you to bring my breakfast.
- Requirements
  - Tiffany's Breakfast Basket
- Rewards
  - 10 Sapphires
  - Small XP
- Tiffany
  - Thanks, <name>! You collected my breakfast for me.
  - Let's see if it is all there.
  - Eggs. Check.
  - Bacon. Check.
  - Toast. Check.
  - Toaster. Check.
  - Frying Pan. Check.
  - Knife. Check.
  - Fork…
  - Fork?!
  - Where is my fork?
  - <name>, my fork isn't here!
  - Are you sure you collected everything from the treasure chest?
- Player
  - Yes!
  - But I did see someone lurking around in the trees behind the chest!
- Tiffany
  - Oh no…
  - I bet it was that silly Terrence!

- Player
  - Terrence?
- Tiffany
  - Yes, he is always stealing things from my treasure chests!
  - I usually just give him some STONES for his pet rock collection and he gives me my things back
  - I do not have any STONES though! Can you go and collect them and give them to TERRENCE?
  - Bring me back my FORK and I will give you something that I think will come in handy for you!
  - Just head over there and…
    - The weather in Tiffany's treasure chest zone changes to poor
  - Oh dear, it looks like the WEATHER has gotten even worse over there!
- Player
  - So, it's just a bit of rain!
- Tiffany
  - Oh no, <name>, bad WEATHER makes things cost MORE ENERGY
  - <name>, the WEATHER is controlled by your SMART METER data!
  - Do well with your REAL WORLD ENERGY USAGE, to keep the WEATHER good.
  - You can check a zone's WEATHER by looking at the WEATHER BAR on the BOTTOM of the SCREEN.
  - Now go get me my fork!
  - I'm HUNGRYYYYYY!!!
- Requirements
  - Tiffany's Fork
    - Player can get this by completing the "Pet Rock Showdown" quest.
- Rewards
  - Jam Jar
- Tiffany
  - Finally! I can eat my breakfast!

## J.3 That's a Birdie

**Quest Giver**: Daniel (Zoo Zone)

**Available**: After completing the "Getting the Elephant in the Room" quest (starts automatically).

**Dialog**:

- Eloise the Elephant
  - But Dan, where are all the other animals?
- Daniel
  - They're all just as lost as you were.
- Eloise the Elephant
  - Oh! That must be why I saw Earl flying around in circles on the Golf Course near where <name> found me.
- Daniel

  - <name> - Earl the Eagle should be somewhere near you. Can you have a look around and see if you can find him?
- Requirements
  - Talk to Earl the Eagle
- Rewards
  - Small XP
- Player
  - Earl! I've come to help you make it back to the Zoo. I have a map here that might help you!
- Earl the Eagle
  - <name> - I've been able to see you slowly making your way here this whole time. I can even see the zoo, but I'm afraid it is no use. I can't fly straight because my wing is injured!
  - (repeated if return unfinished) I'm going to need your help getting back, but you're going to need a LEATHER GLOVE because my claws are too sharp.
  - I think that there is a lady near Frisbee Forest that looks after birds, so she should have one!
- Requirements
  - 1 Bird Handling Glove
    - Player can obtain this by completing the "Bear-ly Awake" quest.
- Rewards
  - Medium XP
- Earl the Eagle
  - Ah <name>, you found a glove!
  - I'm going to need you to carry me back to the Zoo.
    - Player gains 1 Earl the Eagle
    - Earl the Eagle disappears from area
- Requirements
  - Talk to Daniel
  - 1 Earl the Eagle
- Daniel
  - Earl! I'm so glad you have returned. I've missed you a lot.
- Eloise the Elephant
  - Yay!
- Earl the Eagle
  - It's good to be back. My wing is feeling a little bit better now…
    - Earl the Eagle now spawns in Zoo Zone

# Appendix K Energy Explorer Checklist Items

Quest-related checklist items:

- Find and Rescue Fred the Fish
- Find and Rescue Timmy the Tiger
- Find and Rescue Eloise the Elephant
- Find and Rescue Dee the Dog
- Find and Rescue Manuel the Monkey
- Find and Rescue John Mallard
- Find and Rescue Chloe Cat
- Find and Rescue Dennis the Dolphin
- Find and Rescue Carl the Chicken
- Find and Rescue Polly the Parrot

Item-specific checklist items (often required a quest to complete):

- Find a Vuvuzela
- Find a Water Gun
- Find the Super Frisbee
- Find Saxophone
- Find Shovel
- Find Gold Watch
- Receive the Necklace of Jam Making
- Collect 100 Wood
- Earn 10,000 Money

Progress-related checklist items:

- Travel [N] Steps (10, 100, 250, 500, 1000, 2000, 5000, 10000)
- Complete a Quest
- Complete [N] Quests (5, 10, 15, 20, 25, 30)
- Collect [N] Diamonds (10, 20, 30, 40, 50)
- Collect [N] Emeralds (25, 50, 75)
- Collect [N] Rubies (25, 50, 75, 100)
- Reach Level [N] (2, 5, 8, 10, 15, 20)

# Appendix L Energy Explorer Database and Web API

*Energy Explorer* uses a *MySQL* database for storing data about the players. The schema for the database is provided in Figure 93, and the following sub-sections describe the contents of the tables in the database. The final sub-section describes the Web API commands exposed for the server.

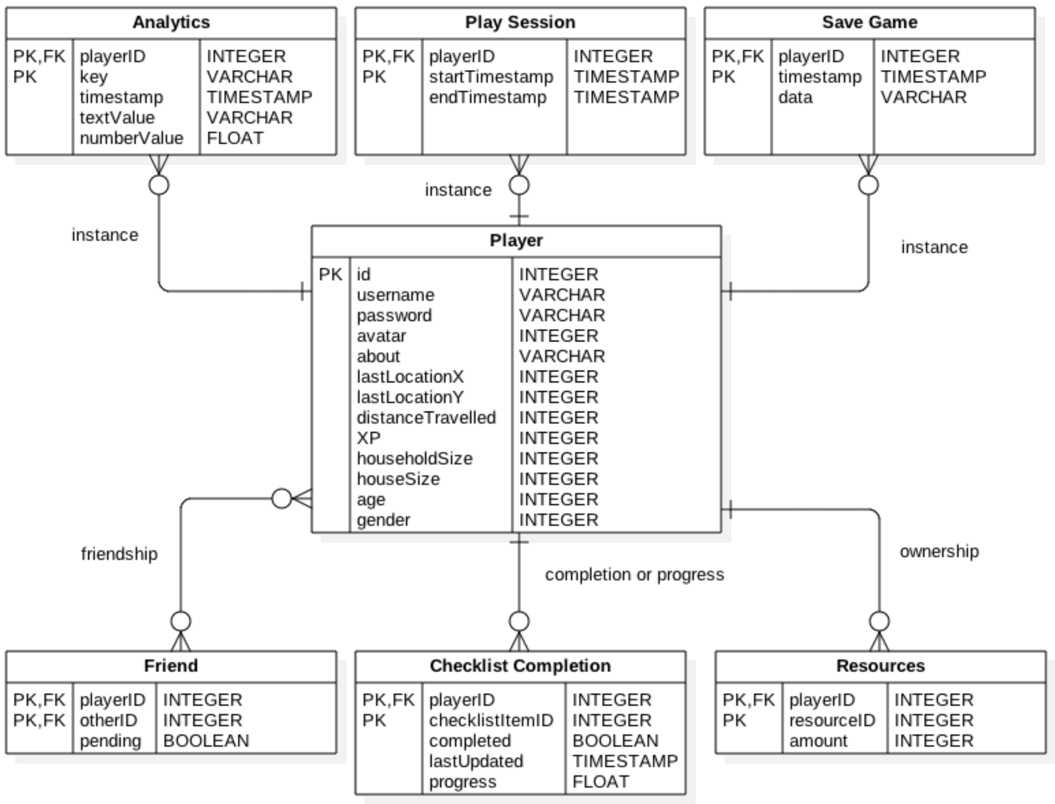


**Figure 93. Relational diagram of tables within the MySQL database used for storing *Energy Explorer* data.**

## L.1 Player

The *player* table contains the following fields:

- *id*: numerical, used throughout the database to uniquely identify a player (automatically generated);
- *RBBES_ID*: the corresponding identifier in the *RBEES* database for this player, used by the system to obtain the appropriate smart meter data for this player;
- *username*: used by players in the client application to uniquely identify players;
- *password*: an MD5 hashed password string, used by the system for authentication;

- *avatar*: numerical identifier for which of the avatar images the player has chosen for their profile;
- *about*: string message that appears on the player's profile;
- *lastLocation*: a vector value representing the $x$ and $y$ coordinates of the space the player was last on;
- *distanceTravelled*: numerical value representing the number of spaces the player has visited in the game;
- *XP*: numerical value representing the amount of *XP resource* the player has obtained (note that this is not stored in the *resources* table as the Unity client code does not treat *XP* as a normal resource, but instead as an attribute of the player);
- *householdSize*: numerical value representing the number of people in that player's household (sentinel value of -1 if not provided);
- *houseSize*: numerical value representing the size of the player's house in square feet (sentinel value of -1 if not provided);
- *age*: numerical value representing the player's age; and
- *gender*: the player's gender preference (stored as number where 0 = male, 1 = female, and 2 = other/undisclosed).

The *id* field is used by the database for a number of foreign key relationships (i.e. where another table needs to reference this user). Records in this table were indexed by the *id* field. The fields for *householdSize, houseSize, age,* and *gender* are not visible to other players within the game, and are used only on the server-side for calculating user similarity.

## L.2 Friend

The *friend* table represents a relationship between pairs of players, and contains the following fields:

- *playerID*: the *id* of one of the players in the pair;
- *otherID:* the *id* of the other player in the pair; and
- *pending*: a binary value representing whether or not this relationship is still at the request stage (0), or if the process has been completed by the other player accepting the request (1).

Both *playerID* and *otherID* reference *id*s in the *player* table using a foreign key constraint. The *friend* table does not contain duplicate entries where *playerID* and *otherID* are in reverse order. Records in this table were indexed by a pair index the two fields, *playerID* and *otherID.*

## L.3 Resources

The purpose of the *resources* table is to store the player's data about the number of in-game resources they possess (see Section 5.2.2). This is stored in its own table rather than the *save game* table so that other players can easily obtain this information without needing to download the entire save game (including world layout) from the server. Each record in the table represents a player's ownership of a resource, using the following fields:

- *playerID*: the *id* of the player who owns the resource;
- *resourceID*: the id of the resource (as defined by the Unity client enumeration) that the player owns; and
- *amount*: an integer value representing the amount of that resource the player owns.

The *ownerID* references the *id* of a player in the *player* table using a foreign key constraint. It should be noted that the *resourceID* does not have a foreign key constraint, and instead references the integer value of casting the *ResourceType* enumeration in the *Unity* client. Additionally, it should be noted that the resources table does not store the *XP* resource, as this is handled differently by the *Unity* client (i.e. it is not part of the *ResourceType* enumeration).

Records in this table were indexed by a pair index of *playerID* and *resourceID.*

## L.4 Checklist Completion

The purpose of the *accomplishments* table is to store the player's data about their completion of items in the checklist (see Section 5.2.8). This is stored in its own table rather than the *save game* table so that other players can easily obtain this information without needing to download the entire save game (including world layout) from the server. The records in this table contain the following fields:

- *playerID*: the *id* of the player who has completed or progressed the item on the checklist;
- *checklistItemID*: the id of the checklist item (as defined by the Unity client array index) that the player has completed or progressed in;
- *completed*: a binary value indicating if the player has completed the item (1), or has stored some progress toward completing the item (0);
- *lastUpdated:* a UNIX timestamp representing when the checklist item was completed or if the item has not yet been completed, the time it was last given a new progress value; and

- *progress*: a numerical value representing the player's progression toward the checklist item (e.g. if the item is to "Complete 5 Quests" and the player has completed 3 quests, the value stored here would be 3).

The *playerID* references the *id* of a player in the *player* table using a foreign key constraint. It should be noted that the *checklistItemID* does not have a foreign key constraint, and instead references the integer value of the relevant index in the Unity client for the checklist item array. Records in this table were indexed by a pair index of *playerID* and *checklistItemID.*

The checklist table provides one form of analytics to determine what players have done but it does not provide comprehensive statistics. Instead, a table for providing analytics data was added, and this is described in the next section.

## L.5 Analytics

The *analytics* table provides a generic way to examine what actions players took in the game. Any time players in the game completed an action, it was stored in this table. Records in this table included the following fields:

- *playerID*: the *id* of the player for whom this piece of analytics was recorded;
- *key*: a string key indicating the type of analytics data that was recorded;
- *timestamp*: a UNIX timestamp value indicating the time when this action occurred;
- *textValue*: an optional value for providing extra data associated with this piece of analytics data; and
- *numberValue*: an optional value for providing extra data associated with this piece of analytics data;

The *playerID* references the *id* of a player in the *player* table using a foreign key constraint. Records in this table were indexed by a pair index of *playerID* and *key.*

Analytics data was also separated into sessions by recording when a game play session began and ended. The table for recording this is described in the next section.

## L.6 Play Session

Each record in the *play session* table represents a single play session by a player of the *Energy Explorer* game. This data gives an indication of how much each of the players played the game, and provided extra context for the analytics data described in the previous section. The fields recorded in this table included:

- *playerID*: the *id* of the player who participated in this play session;

- *startTimestamp*: a UNIX timestamp value indicating the when this play session was initiated; and
- *endTimestamp*: a UNIX timestamp value indicating the when this play session was finished;

The *playerID* references the *id* of a player in the *player* table using a foreign key constraint. Records in this table were indexed by a pair index of *playerID* and *startTimestamp.*

## L.7 Save Game

This table served as a backup source for players' save game data in the event that an older save needed to be recovered. Each record in the table represents an instance of when the player's game was backed up (this is done when the player closes the client application). The fields for this table included:

- *playerID*: the *id* of the player whom this save game belongs to;
- *timestamp*: a UNIX timestamp value representing when this save game was uploaded to the server (automatically updated); and
- *data*: XML data representing the player's save game.

The *playerID* references the *id* of a player in the *player* table using a foreign key constraint. Records in this table were indexed by a pair index of *playerID* and *startTimestamp.* The data is stored in XML format in order to allow manual editing of the data to remove errors.

## L.8 Web API

Commands were issued to the *Energy Explorer* server in the form of HTTP POST requests with a number of parameters. Responses returned were in JSON format. Table 41 presents the commands used, the parameters required, and the response type of each command.

| Command (PHP) | Parameters | Response | Description |
|---|---|---|---|
| addChecklistItem | UserID<br>ItemID | Success or failure (boolean) | Record on the server that a checklist item <ItemID> has been completed by <UserID>. |
| addFriend | UserID<br>OtherUserID | Success or failure (boolean) | Create a new friendship relationship between <UserID> and <OtherUserID>. |
| addMetric | UserID<br>ActionID<br>Value (Optional) | Success or failure (boolean) | Record usage of a given game element <ActionID> by <UserID> with optional <Value> (e.g. for "level up" action, Value is the level the user has reached). |
| currentVersion | None | Version number (integer) | Returns the most recent version number of the Android version of Energy Explorer. Used to facilitate updates. |
| deleteFriend | UserID<br>OtherUserID | Success or failure (boolean) | Deletes the friendship relationship between <UserID> and <OtherUserID>. |
| getAverageAll | StartDate<br>EndDate | Energy data structure (see below) | Gets the average energy consumption of all users in the trial for time period between <StartDate> and <EndDate>. |
| getSmartData | UserID<br>StartDate<br>EndDate | Energy data structure (List of Tuple <Timestamp, Channel, Unit, Value>) | Gets the smart meter data for <UserID>, for time period between <StartDate> and <EndDate>. |
| getUserData | UserID | Save game data (XML) | Returns the XML formatted save game for <UserID>. |
| handleFriendRequest | UserID<br>ID<br>Action | Success or failure (boolean) | Transitions the friendship relationship defined by <ID> to either an accepted state, or deletes it, based upon <Action>. |

| **Command (PHP)** | **Parameters** | **Response** | **Description** |
|---|---|---|---|
| listChecklistItems | UserID | List of Tuple <ItemID, Complete> | Returns all the checklist items, and their completion state for <UserID>. |
| listFriends | UserID | List of UserIDs | Returns the UserIDs of all the friends of <UserID>. |
| listUsers | UserID (optional) | List of User Tuple <UserID, Username, Level, StepsTaken, Gender> | Returns the user profile information of all users, or if <UserID> is specified, only the data for that user. |
| login | Username<br>Password (hashed) | Success or failure (boolean), and User tuple (see above) | Used to facilitate the login process. |
| saveUserData | UserID<br>UserData (XML) | Success or failure (boolean) | Saves the XML formatted save game <UserData> for <UserID> to the server. |
| similarUsers | UserID | List of UserIDs | Returns the UserIDs of the most similar registered users. Ordered by most similar to least similar. |

**Table 41. The commands available through the Web API that allow *Energy Explorer* to function.**

# Appendix M Participant Characteristics

For all categorical questions in the original RBEES survey, a two-proportion z-test was conducted on all possible survey responses between the *original* participants and those who *played the game*, and between the *original* participants and those who completed the *exit survey*. For the majority of questions, there was no significant difference in proportions between the three groups, however there were a few minor exceptions. Table 42 below shows the data examined for this task. It should be noted that significance was found for the group of players who completed the exit survey, however given the small number of participants in this sample ($n$ = 8) these are not discussed at length.

| | **Non-Game Group** | **Played Game Group** | **Played Game Group *p*-value[103]** | **Completed Exit Survey Group** | **Completed Exit Survey Group *p*-value[104]** |
|---|---|---|---|---|---|
| **Q2 Occupancy** | | | | | |
| Nobody at home all day | 19.9% | 10.0% | 0.277 | 25.0% | 1.430 |
| Nobody at home during school hours | 15.9% | 25.0% | 1.719 | 25.0% | 1.719 |
| Nobody at home in the afternoon | 3.5% | 5.0% | 1.281 | 0.0% | 0.412 |
| Nobody at home in the mornings | 10.2% | 5.0% | 0.450 | 0.0% | 0.138 |
| Someone is home all day | 50.6% | 55.0% | 1.298 | 50.0% | 0.957 |
| **Q4 Electricity Sources** | | | | | |
| Electricity | 97.3% | 100.0% | 1.546 | 100.0% | 1.546 |
| Mains Gas (Natural Gas) | 60.8% | 65.0% | 1.293 | 62.5% | 1.121 |
| Solar PV Electricity | 32.0% | 60.0% | 1.990 | 37.5% | 1.389 |
| Solar Pool Heating | 4.2% | 5.0% | 1.134 | 0.0% | 0.362 |
| Solar Water Heating | 19.1% | 25.0% | 1.485 | 37.5% | 1.958 |
| Wood | 2.2% | 0.0% | 0.499 | 0.0% | 0.499 |
| LPG/Bottled Gas | 12.2% | 10.0% | 0.772 | 12.5% | 1.036 |
| **Q5 On average, how much does your household spend on electricity per year?** | | | | | |
| <$500 | 14.4% | 0.0% | 0.068 | 0.0% | 0.068 |
| $500-$1500 | 45.2% | 25.0% | 0.076 | 12.5% | **0.004** |
| $1500-$2500 | 25.8% | 45.0% | 1.942 | 62.5% | 2.000 |
| $2500-$3500 | 8.7% | 15.0% | 1.665 | 0.0% | 0.185 |
| >$3500 | 4.0% | 15.0% | 1.993 | 25.0% | 2.000 |

[103] *p*-value is stated for a two-proportion z-test where sample one is the non-game group ($n$ = 398) and the second sample is the group of participants who played the game ($n$ = 20).

[104] *p*-value is stated for a two-proportion z-test where sample one is the non-game group ($n$ = 398) and the second sample is the group of participants who completed the exit survey ($n$ = 8).

| | Non-Game Group | Played Game Group | Played Game Group *p*-value[103] | Completed Exit Survey Group | Completed Exit Survey Group *p*-value[104] |
|---|---|---|---|---|---|
| N/A | 2.7% | 0.0% | 0.454 | 0.0% | 0.454 |
| **Q6 Do you pay extra to your energy retailer for Green Power?** | | | | | |
| Yes | 14.1% | 20.0% | 1.533 | 37.5% | 1.996 |
| No | 85.9% | 80.0% | 0.467 | 62.5% | **0.004** |
| **Q7 What percentage of GreenPower do you subscribe to?** | | | | | |
| None | 85.9% | 80.0% | 0.467 | 62.5% | **0.004** |
| 10% | 6.2% | 5.0% | 0.827 | 12.5% | 1.748 |
| 25% | 3.5% | 0.0% | 0.397 | 0.0% | 0.397 |
| 50% | 0.2% | 5.0% | 1.998 | 12.5% | 2.000 |
| 75% | 0.0% | 0.0% | | 0.0% | |
| 100% | 4.2% | 10.0% | 1.777 | 12.5% | 1.919 |
| **Q8 On average, how much does your household spend on mains gas per year?** | | | | | |
| <$300 | 5.7% | 0.0% | 0.272 | 0.0% | 0.272 |
| $300-$1000 | 46.7% | 15.0% | 0.005 | 12.5% | **0.003** |
| $1000-$1600 | 7.7% | 30.0% | 1.999 | 25.0% | 1.993 |
| >$1600 | 0.7% | 20.0% | 2.000 | 25.0% | 2.000 |
| na | 39.2% | 35.0% | 0.707 | 37.5% | 0.879 |
| **Q9 On average, how much does your household spend on LPG/bottled gas per year?** | | | | | |
| N/A | 100.0% | 100.0% | | 100.0% | |
| **Q10 Features** | | | | | |
| Ceiling insulation | 95.3% | 100.0% | 1.680 | 100.0% | 1.680 |
| Wall insulation | 73.2% | 85.0% | 1.758 | 87.5% | 1.844 |
| Floor insulation | 6.0% | 5.0% | 0.860 | 0.0% | 0.270 |
| Tinted glass/windows | 19.6% | 30.0% | 1.743 | 37.5% | 1.949 |
| Energy efficient lights | 73.4% | 80.0% | 1.484 | 87.5% | 1.837 |
| Double glazed windows | 9.7% | 25.0% | 1.972 | 37.5% | 2.000 |
| Box pelmets | 0.0% | 0.0% | | 0.0% | |
| Glass doors/large windows | 92.1% | 95.0% | 1.368 | 100.0% | 1.804 |
| Passive design | 17.9% | 25.0% | 1.580 | 25.0% | 1.580 |
| Outside awnings/shutters | 21.6% | 30.0% | 1.625 | 50.0% | 1.997 |
| Louvre windows | 0.0% | 0.0% | | 0.0% | |
| Do not know | 0.0% | 0.0% | | 0.0% | |
| **Q14 What type of cooking appliances does your house have?** | | | | | |
| **Cooktop** | | | | | |
| Gas | 73.2% | 85.0% | 1.758 | 75.0% | 1.142 |
| Electric | 26.8% | 15.0% | 0.242 | 25.0% | 0.858 |
| **Oven** | | | | | |
| Gas | 7.7% | 10.0% | 1.293 | 0.0% | 0.211 |
| Electric | 92.3% | 90.0% | 0.707 | 100.0% | 1.789 |

| | Non-Game Group | Played Game Group | Played Game Group *p*-value[103] | Completed Exit Survey Group | Completed Exit Survey Group *p*-value[104] |
|---|---|---|---|---|---|
| **Q15 How frequently is each of the following appliances used by this household?** | | | | | |
| **Dishwasher** | | | | | |
| Multiple times each day | 3.0% | 0.0% | 0.434 | 0.0% | 0.434 |
| Once a day | 25.1% | 35.0% | 1.680 | 25.0% | 0.995 |
| Most days | 20.6% | 25.0% | 1.364 | 12.5% | 0.384 |
| Once a week | 22.6% | 30.0% | 1.559 | 50.0% | 1.996 |
| Once a month | 8.2% | 5.0% | 0.609 | 12.5% | 1.511 |
| Never | 3.5% | 0.0% | 0.397 | 0.0% | 0.397 |
| Do not have one | 17.1% | 5.0% | 0.154 | 0.0% | **0.044** |
| **Washing Machine** | | | | | |
| Multiple times each day | 8.4% | 15.0% | 1.689 | 25.0% | 1.990 |
| Once a day | 12.2% | 15.0% | 1.294 | 12.5% | 1.036 |
| Most days | 37.5% | 25.0% | 0.259 | 0.0% | **< 0.001** |
| Once a week | 41.2% | 45.0% | 1.264 | 62.5% | 1.941 |
| Once a month | 0.5% | 0.0% | 0.752 | 0.0% | 0.752 |
| Never | 0.0% | 0.0% | | 0.0% | |
| Dont have one | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |
| **Clothes Dryer** | | | | | |
| Multiple times each day | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |
| Once a day | 1.5% | 0.0% | 0.583 | 0.0% | 0.583 |
| Most days | 6.0% | 0.0% | 0.261 | 0.0% | 0.261 |
| Once a week | 22.3% | 5.0% | 0.066 | 12.5% | 0.296 |
| Once a month | 32.3% | 55.0% | 1.965 | 37.5% | 1.373 |
| Never | 5.2% | 5.0% | 0.967 | 0.0% | 0.306 |
| Do not have one | 32.5% | 35.0% | 1.184 | 50.0% | 1.897 |
| **Q16 If you have a washing machine, what water temperature do you use?** | | | | | |
| Cold Water | 44.2% | 0.0% | **< 0.001** | 0.0% | **< 0.001** |
| Warm Water | 15.6% | 20.0% | 1.398 | 0.0% | 0.062 |
| Hot Water | 0.2% | 15.0% | 2.000 | 25.0% | 2.000 |
| N/A | 40.0% | 65.0% | 1.974 | 75.0% | 1.998 |
| **Q17 How frequently is each of the following appliances used by this household?** | | | | | |
| **Television** | | | | | |
| Continuously | 9.7% | 0.0% | 0.144 | 0.0% | 0.144 |
| Few hours a day | 75.4% | 90.0% | 1.864 | 100.0% | 1.988 |
| Most days | 12.9% | 10.0% | 0.704 | 0.0% | 0.091 |
| Once a week | 1.2% | 0.0% | 0.616 | 0.0% | 0.616 |
| Once a month | 0.5% | 0.0% | 0.752 | 0.0% | 0.752 |
| Never | 0.0% | 0.0% | | 0.0% | |
| Do not have one | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |

| | Non-Game Group | Played Game Group | Played Game Group *p*-value[103] | Completed Exit Survey Group | Completed Exit Survey Group *p*-value[104] |
|---|---|---|---|---|---|
| **Computers** | | | | | |
| Continuously | 22.3% | 25.0% | 1.220 | 50.0% | 1.996 |
| Few hours a day | 54.8% | 60.0% | 1.349 | 37.5% | 0.128 |
| Most days | 14.9% | 15.0% | 1.011 | 12.5% | 0.770 |
| Once a week | 5.2% | 0.0% | 0.295 | 0.0% | 0.295 |
| Once a month | 0.7% | 0.0% | 0.699 | 0.0% | 0.699 |
| Never | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |
| Do not have one | 1.7% | 0.0% | 0.552 | 0.0% | 0.552 |
| **Air Conditioner (in summer)** | | | | | |
| Continuously | 2.5% | 0.0% | 0.476 | 0.0% | 0.476 |
| Few hours a day | 25.3% | 30.0% | 1.361 | 25.0% | 0.975 |
| Most days | 13.6% | 10.0% | 0.641 | 12.5% | 0.883 |
| Once a week | 31.3% | 45.0% | 1.802 | 50.0% | 1.921 |
| Once a month | 13.9% | 10.0% | 0.621 | 0.0% | 0.078 |
| Never | 1.7% | 0.0% | 0.552 | 0.0% | 0.552 |
| Do not have one | 11.7% | 5.0% | 0.359 | 12.5% | 1.092 |
| **Heater (in winter)** | | | | | |
| Continuously | 6.2% | 10.0% | 1.502 | 25.0% | 1.999 |
| Few hours a day | 33.5% | 25.0% | 0.430 | 12.5% | 0.051 |
| Most days | 20.8% | 20.0% | 0.928 | 25.0% | 1.345 |
| Once a week | 22.3% | 20.0% | 0.807 | 25.0% | 1.221 |
| Once a month | 11.2% | 20.0% | 1.772 | 12.5% | 1.144 |
| Never | 3.7% | 5.0% | 1.230 | 0.0% | 0.394 |
| Do not have one | 2.2% | 0.0% | 0.499 | 0.0% | 0.499 |
| **Q18 If you have an air conditioner, when was it last serviced?** | | | | | |
| Do not have one | 1.0% | 0.0% | 0.654 | 0.0% | 0.654 |
| Less than 2 years ago | 39.0% | 35.0% | 0.723 | 12.5% | **0.018** |
| 2-4 years ago | 10.9% | 20.0% | 1.789 | 37.5% | 2.000 |
| 4-6 years ago | 4.0% | 5.0% | 1.181 | 0.0% | 0.378 |
| 6-8 years ago | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |
| 8-10 years ago | 17.4% | 30.0% | 1.849 | 37.5% | 1.978 |
| Never | 14.1% | 5.0% | 0.246 | 0.0% | 0.073 |
| Do not know | 13.4% | 5.0% | 0.276 | 12.5% | 0.907 |
| **Q19 What is the average temperature in your home over winter?** | | | | | |
| Cold | 9.2% | 0.0% | 0.156 | 0.0% | 0.156 |
| Cool | 33.5% | 30.0% | 0.746 | 25.0% | 0.431 |
| Comfortable | 53.6% | 65.0% | 1.682 | 75.0% | 1.939 |
| Warm | 3.7% | 5.0% | 1.230 | 0.0% | 0.394 |
| Hot | 0.0% | 0.0% | | 0.0% | |

| | Non-Game Group | Played Game Group | Played Game Group *p*-value[103] | Completed Exit Survey Group | Completed Exit Survey Group *p*-value[104] |
|---|---|---|---|---|---|
| **Q20 What is the average temperature in your home over winter?** | | | | | |
| Cold | 0.0% | 0.0% | | 0.0% | |
| Cool | 9.2% | 10.0% | 1.098 | 12.5% | 1.383 |
| Comfortable | 56.1% | 70.0% | 1.780 | 75.0% | 1.904 |
| Warm | 29.5% | 15.0% | 0.162 | 12.5% | 0.101 |
| Hot | 5.2% | 5.0% | 0.967 | 0.0% | 0.306 |
| **Q21 Do you take any steps to limit your household use of energy?** | | | | | |
| Yes | 90.1% | 95.0% | 1.533 | 87.5% | 0.704 |
| No | 9.9% | 5.0% | 0.467 | 12.5% | 1.296 |
| **Q23 What are the main reasons for you to reduce your energy use at home? (Please tick all that apply)** | | | | | |
| Economic benefits | 87.1% | 95.0% | 1.703 | 87.5% | 1.042 |
| Concern about the environment | 69.2% | 75.0% | 1.416 | 62.5% | 0.523 |
| Maintaining comfort | 28.8% | 40.0% | 1.718 | 37.5% | 1.597 |
| Convenient | 10.7% | 0.0% | 0.123 | 0.0% | 0.123 |
| Others are doing it | 1.5% | 0.0% | 0.583 | 0.0% | 0.583 |
| Making a positive contribution | 54.6% | 60.0% | 1.380 | 75.0% | 2.000 |
| **Q24 What are the main reasons you do not to take steps to limit your personal use of energy at home? (Please tick all that apply)** | | | | | |
| Our energy consumption is already low enough | 1.7% | 0.0% | 0.552 | 0.0% | 0.552 |
| Comfort | 7.9% | 5.0% | 0.632 | 12.5% | 1.542 |
| Limiting energy consumption is not a priority | 0.0% | 0.0% | | 0.0% | |
| Time consuming | 1.2% | 5.0% | 1.835 | 12.5% | 2.000 |
| Do not care how much energy is used | 0.5% | 0.0% | 0.752 | 0.0% | 0.752 |
| Inconvenient | 1.7% | 0.0% | 0.552 | 0.0% | 0.552 |
| I have not thought about saving energy | 0.7% | 0.0% | 0.699 | 0.0% | 0.699 |
| Do not know what to do | 2.2% | 0.0% | 0.499 | 0.0% | 0.499 |
| Other | 0.0% | 0.0% | | 0.0% | |
| **Q25 In the past twelve months, would you say that your household's energy use has:** | | | | | |
| Increased | 25.3% | 25.0% | 0.975 | 37.5% | 1.779 |
| Decreased | 29.5% | 30.0% | 1.036 | 37.5% | 1.554 |
| Stayed the same | 40.9% | 40.0% | 0.933 | 25.0% | 0.157 |
| Do not know | 4.2% | 5.0% | 1.134 | 0.0% | 0.362 |
| **Q26 What are the reasons your household's energy use has increased? (Please tick all that apply)** | | | | | |
| Weather conditions (e.g. longer summer or winter) | 9.7% | 0.0% | 0.144 | 0.0% | 0.144 |
| Acquired additional appliances (e.g. heaters, cooling devices, TV, etc…) | 0.0% | 0.0% | | 0.0% | |
| Lifestyle changes | 11.2% | 5.0% | 0.387 | 12.5% | 1.148 |
| Health reasons | 1.5% | 0.0% | 0.583 | 0.0% | 0.583 |
| Do not know | 2.2% | 5.0% | 1.573 | 0.0% | 0.521 |

| | Non-Game Group | Played Game Group | Played Game Group *p*-value[103] | Completed Exit Survey Group | Completed Exit Survey Group *p*-value[104] |
|---|---|---|---|---|---|
| Other | 6.7% | 10.0% | 1.431 | 25.0% | 1.998 |
| **Q27 What are the reasons your household's energy use has decreased? (Please tick all that apply)** | | | | | |
| Have been trying to conserve energy | 24.8% | 30.0% | 1.399 | 37.5% | 1.799 |
| Cost saving | 18.9% | 20.0% | 1.101 | 37.5% | 1.962 |
| Replaced outdated appliances with energy efficient ones | 5.2% | 10.0% | 1.643 | 0.0% | 0.316 |
| Reduced the number of appliances | 2.2% | 0.0% | 0.499 | 0.0% | 0.499 |
| Purchased/Use energy efficient appliances | 11.2% | 25.0% | 1.939 | 25.0% | 1.939 |
| Lifestyle changes (e.g. less people in the home) | 8.9% | 15.0% | 1.640 | 37.5% | 2.000 |
| Do not know | 0.0% | 0.0% | | 0.0% | |
| Other | 0.0% | 0.0% | | 0.0% | |
| **Q28 Do you take any steps to limit your household use of energy?** | | | | | |
| Yes | 89.1% | 95.0% | 1.598 | 87.5% | 0.823 |
| No | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |
| Not sure | 0.7% | 0.0% | 0.699 | 0.0% | 0.699 |
| No Response | 9.9% | 5.0% | 0.467 | 12.5% | 1.296 |
| **Q29 In the next twelve months, do you expect to take different or additional actions to reduce your energy?** | | | | | |
| Yes | 61.5% | 55.0% | 0.558 | 62.5% | 1.069 |
| No | 17.6% | 20.0% | 1.215 | 25.0% | 1.601 |
| Not sure | 20.8% | 25.0% | 1.344 | 12.5% | 0.372 |
| **Q30 In the next twelve months, do you expect to install energy efficient appliances in your house?** | | | | | |
| Yes | 33.3% | 20.0% | 0.217 | 0.0% | **0.002** |
| No | 41.2% | 60.0% | 1.904 | 87.5% | 2.000 |
| Not sure | 25.6% | 20.0% | 0.577 | 12.5% | 0.190 |
| **Q31 Do you think your household is a:** | | | | | |
| High energy user | 11.9% | 10.0% | 0.796 | 12.5% | 1.064 |
| Medium energy user | 56.6% | 65.0% | 1.542 | 50.0% | 0.562 |
| Low energy user | 29.5% | 20.0% | 0.360 | 25.0% | 0.663 |
| Do not know | 2.0% | 5.0% | 1.638 | 12.5% | 1.999 |
| **Q32 Overall, how mindful is your household of the amount of energy it uses?** | | | | | |
| Extremely mindful | 16.6% | 15.0% | 0.849 | 25.0% | 1.675 |
| Very mindful | 37.5% | 40.0% | 1.180 | 37.5% | 1.002 |
| Fairly mindful | 40.2% | 45.0% | 1.331 | 37.5% | 0.810 |
| Not very mindful | 4.7% | 0.0% | 0.320 | 0.0% | 0.320 |
| Not mindful at all | 0.2% | 0.0% | 0.824 | 0.0% | 0.824 |
| Not sure | 0.7% | 0.0% | 0.699 | 0.0% | 0.699 |
| **Household Type** | | | | | |
| Family with school children | 19.4% | 30.0% | 1.756 | 0.0% | **0.034** |
| Family with preschool children | 13.4% | 20.0% | 1.598 | 50.0% | 2.000 |

| | **Non-Game Group** | **Played Game Group** | **Played Game Group *p*-value**[103] | **Completed Exit Survey Group** | **Completed Exit Survey Group *p*-value**[104] |
|---|---|---|---|---|---|
| Family with adult children | 6.7% | 10.0% | 1.431 | 12.5% | 1.684 |
| Working single | 3.7% | 10.0% | 1.837 | 12.5% | 1.949 |
| Retired couple | 6.7% | 10.0% | 1.431 | 12.5% | 1.684 |
| Working couple | 13.6% | 20.0% | 1.577 | 12.5% | 0.885 |
| Retired Single | 1.5% | 0.0% | 0.583 | 0.0% | 0.583 |
| No Answer | 30.0% | 0.0% | 0.005 | 0.0% | **0.005** |

**Table 42. Comparison between the RBEES survey responses of those who did not play the game, those played the game, and those who played the game and completed the exit survey.**

# Appendix N Recruitment Materials

This appendix presents the email invitation, information sheet, consent form, and registration pages used for the main trial of *Energy Explorer*. The information sheet was attached to the email invitation as a PDF document, and the registration page was in HTML format. The consent form and information sheet were available in PDF format from the registration page.

## N.1 Email Invitation

**Energy Explorer: A Serious Game for Energy Conservation**

**Invitation to Participate**

Researchers at the CSIRO Energy Flagship in conjunction with the University of Tasmania are investigating the use of a video game for providing feedback on energy consumption in the home. We are inviting you to take part in this study by using your smart meter data to run your copy of our video game, Energy Explorer.

You have been selected to be a part of this study because of your previous participation in the Residential Building Energy Efficiency Standards (RBEES) project run by the CSIRO in 2012.

Participation is voluntary, and there are no consequences should you decide not to participate.

You will be given exclusive access to a unique mobile game that responds to your personal energy usage. Explore your very own generated game world, complete quests, compete with other players, and customise your own in-game character!

More detailed information and consent forms are attached this email, and are also available at the link below.

To sign up to be part of the Energy Explorer game, simply click this unique link http://energyexplorer.it.csiro/?SignUpID=<DEVICE_ID>

You will need an iPhone running iOS version 8 or higher or an Android phone in order to participate.

The results of this study will help inform future versions that can be distributed to the wider community. We really appreciate your help!

## N.2 Information Sheet

**1. Invitation**

Researchers at the CSIRO Energy Flagship in conjunction with the University of Tasmania are looking to investigate the use of a video game for providing feedback on energy consumption in the home. We are inviting you to take part in this study by using your smart meter data to run your copy of our video game, Energy Explorer.

This study is being conducted in partial fulfillment of a PhD for Lindsay Wells under the supervision of Dr Adam Berry of the CSIRO Energy Flagship in Newcastle and Dr Kristy de Salas and Dr Ian Lewis of the School of Engineering and ICT at the University of Tasmania.

**2. What is the purpose of this study?**

We are investigating the effectiveness of a serious video game that responds to your real-world energy usage. This study will result in a proof of concept to allow for future versions of the game that work with different smart meters.

**3. Why have I been invited to participate?**

You have been selected to be a part of this study because of your previous participation in the Residential Building Energy Efficiency Standards (RBEES) project run by the CSIRO in 2012. Your home has a particular model of smart meter with automated data collection by the CSIRO that makes accessing your energy usage to operate the Serious Game easy. We are looking to get at least 25 people to play to play the game.

We have identified you as being part of the RBEES project using the data collected by the CSIRO who are working with us on this project. Initial contact was made by the CSIRO, and we (researchers at the University of Tasmania) do not have access to your contact details.

Participation is voluntary, and there are no consequences should you decide not to participate. This will not affect your relationship with the CSIRO or the University of Tasmania, or your participation in the RBEES project.

You will need an iPhone running iOS version 8 or higher or an Android phone in order to participate.

**4. What will I be asked to do?**

We ask that you download the appropriate version of the game (iPhone or Android), log in to the game and play as much or as little as you like, whenever you like. This is a field test, and as such you can play the game on your phone at any time of day within the two-month period

30th May to 25th July. You can use the application anywhere you have an active internet connection (WiFi, 3G, 4G, etc), as well as offline (the game experience will not be as complete, however).

The game has a number of exciting features, and we encourage you to explore the game as much as you like. Some features are only available after you have progressed a certain amount in the game.

We ask that you connect the game to the internet at least once, and should you choose to stop playing the game, you connect the game to the internet one last time, to allow for any final data to be transferred.

Your actions within the game will be recorded, and at the conclusion of the study period, you will be asked to complete a Game Experience Questionnaire, delivered through the mobile game. We may ask you for use of quotes from this survey, however these will be published in an anonymous manner.

**5. Are there any possible benefits from participation in this study?**

Participating in this study will give you access to an exclusive video game that responds directly to your real world energy usage. Hopefully the game will provide you with a novel approach to looking at your energy usage, and the results of this study will help inform future versions that can be distributed to the wider community. We really appreciate your help!

**6. Are there any possible risks from participation in this study?**

There are no foreseeable risks from participating in this study. Your smart meter data is handled with the upmost of care, and is not identifiable.

**7. What if I change my mind during or after the study?**

You can choose to withdraw from this study at any time, and no explanation is needed. Should you choose to withdraw, you may contact anyone on the research team (details provided on this information sheet, as well as on the “dashboard” page on the Energy Explorer website, and within the Energy Explorer game itself). The primary contact for opting-out is Adam.Berry@csiro.au (02 4960 6123).

Withdrawal from this study will not effect your participation in the RBEES project (i.e. your data will continue to be automatically collected by the CSIRO), and withdrawal from that project should be sought separately. Should you choose to withdraw from the RBEES project then that will implicitly withdraw you from this project as we will no longer have access to your smart meter data.

Withdrawal from this project will ensure that your data is not included in any analysis for this study. Any data collected specifically for this project will be destroyed (game action logs, and survey responses).

Any data collected under the RBEES project however will continue to be collected under the previous terms set out for that project unless you choose to opt-out of that project.

**8. What will happen to the information when this study is over?**

Data collected during this study (game action logs, and survey responses) will be kept for 5 years after the date of the first publication relating to this study. This data will be stored by the CSIRO, with only the research team having access to this data.

The smart meter data collected by the CSIRO remains subject to the previous terms set out in the RBEES project.

Data will be treated in a confidential manner, and will be stored in an un-identifiable form.

**9. How will the results of the study be published?**

The data will be analyzed using statistical methods, and no individual's data will be published. Only aggregate information across all participants will be published.

Results are expected to be published in a PhD thesis authored by Lindsay Wells, and in journal articles and conference publications. Access to these publications will be provided using the "dashboard" section of the Energy Explorer website.

**10. What if I have questions about this study?**

If you have any questions or wish to opt-out of the study, you may contact any of the members of the research team.

## N.3 Consent Form

1. I agree to take part in the research study named above. Submitting the form on the project website hosted at http://energyexplorer.it.csiro.au constitutes consent to participate, and a record of this submission will be recorded with email confirmation.

2. I have read and understood the Information Sheet for this study.

3. The nature and possible effects of the study have been explained to me.

4. I understand that the study involves downloading a mobile game, playing the game as much as I like, completing a survey on my experience, and will involve the use of my smart meter data, and my in-game actions will be recorded.

5. I understand that participation involves the no foreseeable risks.

6. I understand that all research data will be securely stored on the CSRIO and University of Tasmania premises for five years from the publication of the study results, and will then be destroyed.

7. Any questions that I have asked have been answered to my satisfaction.

8. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research.

9. I understand that the results of the study will be published so that I cannot be identified as a participant.

10. I understand that my participation is voluntary and that I may withdraw at any time without any effect. I can do so by contacting any of the research team, and the primary contact for this is Adam.Berry@csiro.au

Further opt-out information is provided on the project website, within the mobile game, and on the information sheet.

11. I understand that the terms of this study are in addition to the terms that I have already agreed to as part of the RBEES project.

If I so wish, I may request that any data I have supplied be withdrawn at any time.

**Statement by Investigator**

I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

The participant has received the Information Sheet where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

## N.4 Registration Pages

Figure 94 shows the website shown to users after they clicked the invitation link in the email. Note that for those without a special invitation link, a "contact" button is provided instead of a "Sign Up" link. Figure 95 shows the registration page presented to users after clicking the "Sign Up" button.

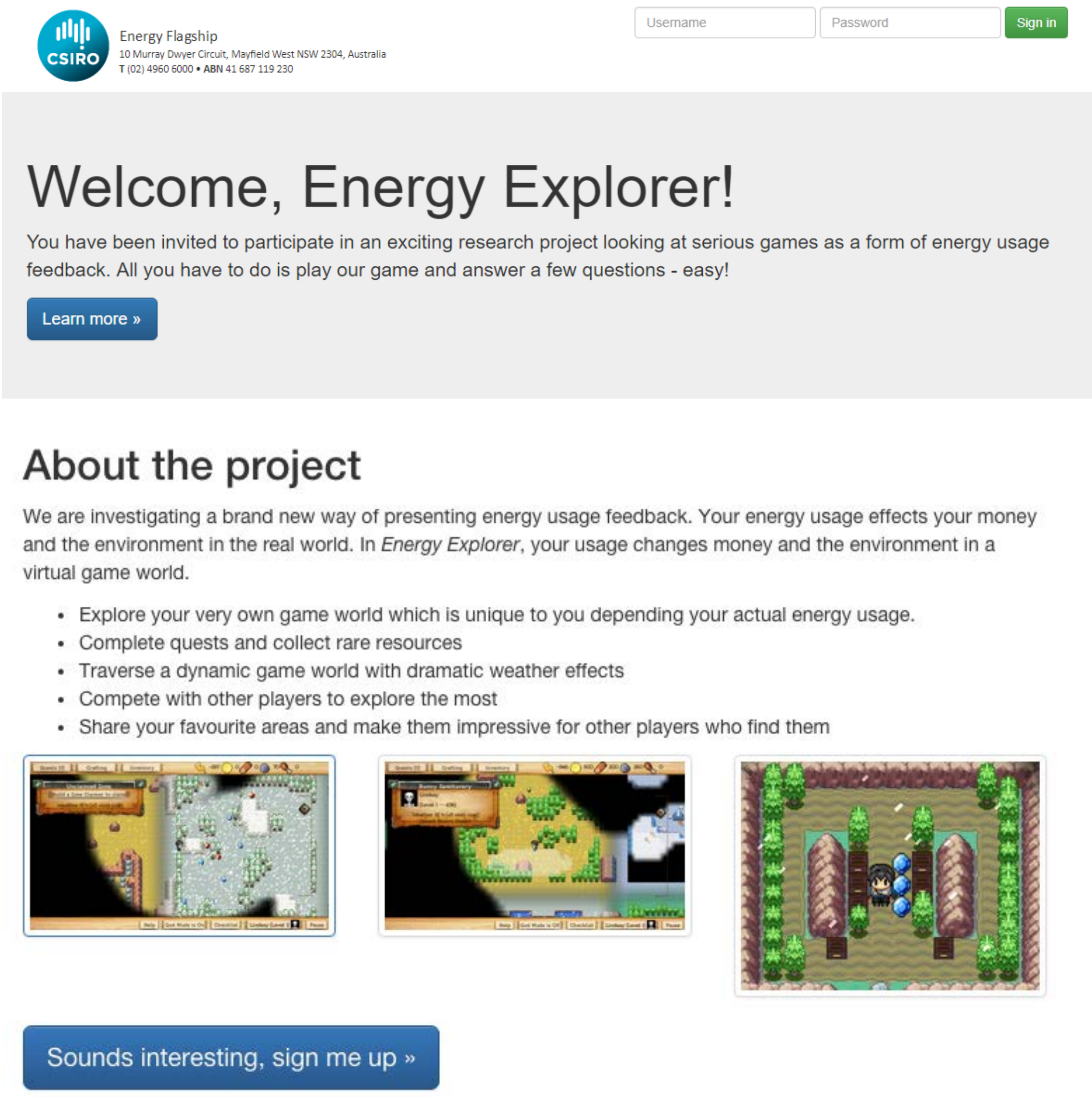


**Figure 94. The project information page presented to participants who clicked the registration link in the invitation email.**

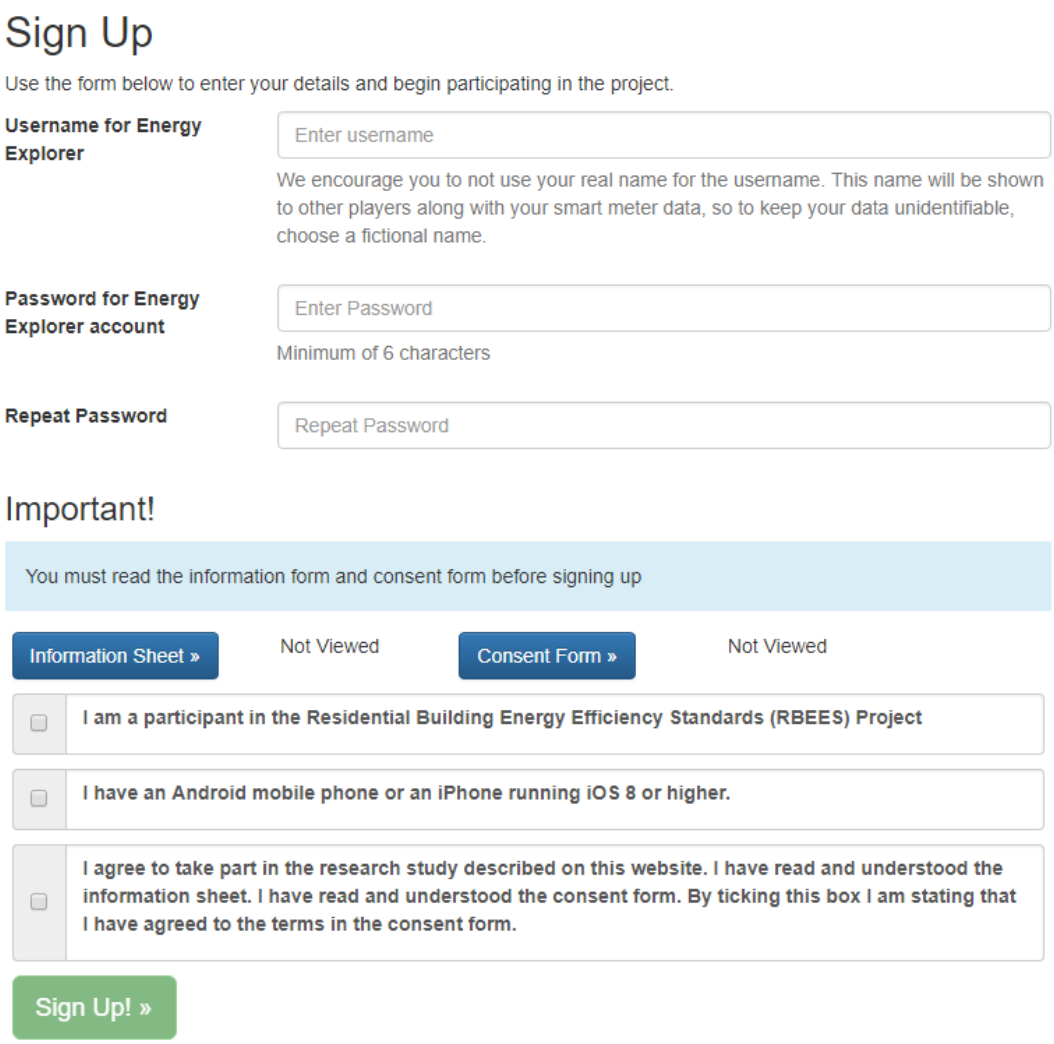


**Figure 95. The registration page presented to participants after clicking the "Sign Up" button on the landing page.**

## N.5 Entry and Exit Survey Display

The entry survey page of the *Energy Explorer* website is shown in Figure 96, and Figure 97 shows the exit survey page. Both surveys were developed using the *Typeform* software which is included in the website as an HTML "iframe". Note that scripting could not access the contents of the iframe, and so the "download" button could not be disabled until the survey was completed, and the ID of the logged in user for data linking purposes could not be injected into the Typeform data, without manual user intervention.

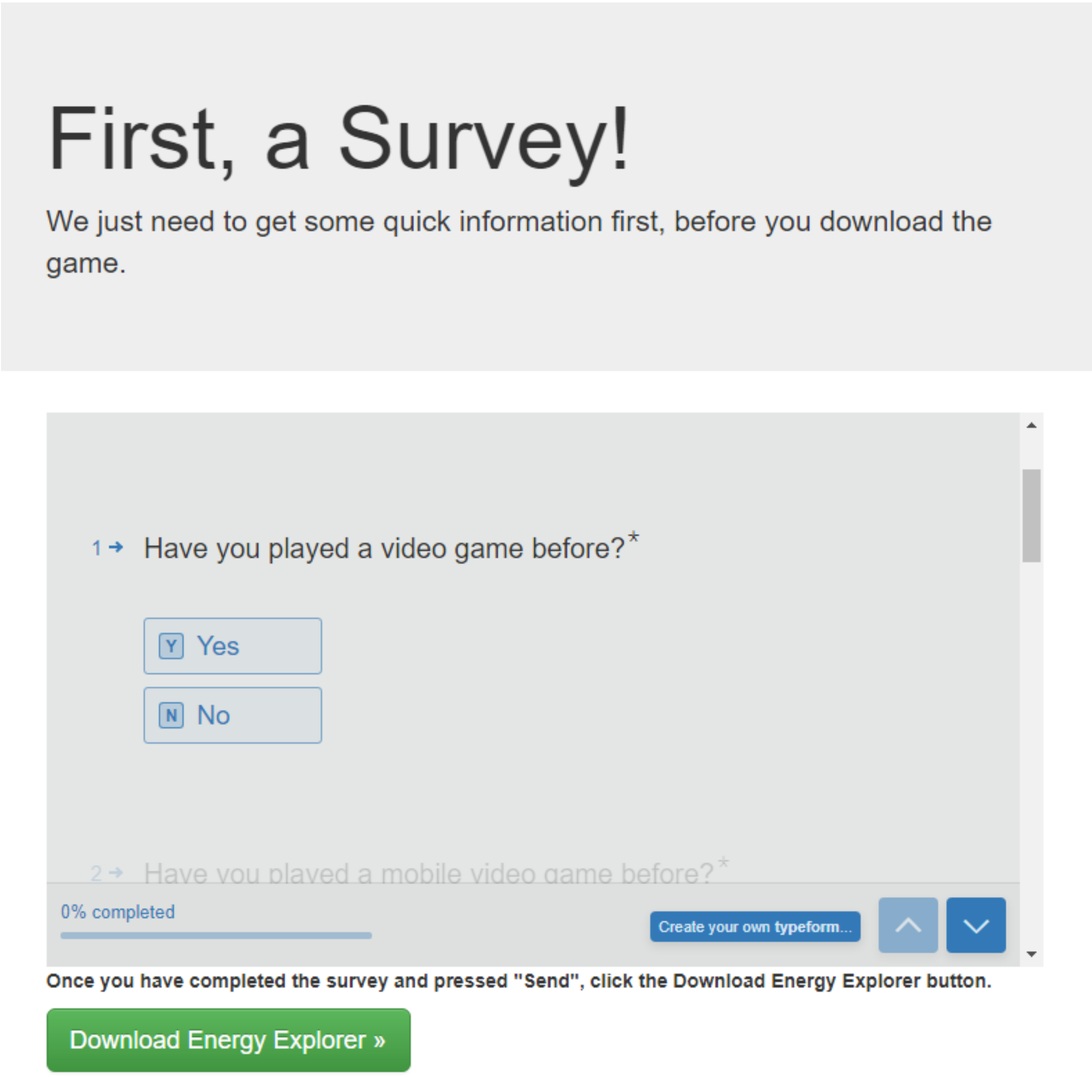


**Figure 96. The entry survey component of the *Energy Explorer* website, created using the *Typeform* software[105]. Note the "download" button used to progress to the next stage of the experiment.**

[105] http://www.typeform.com

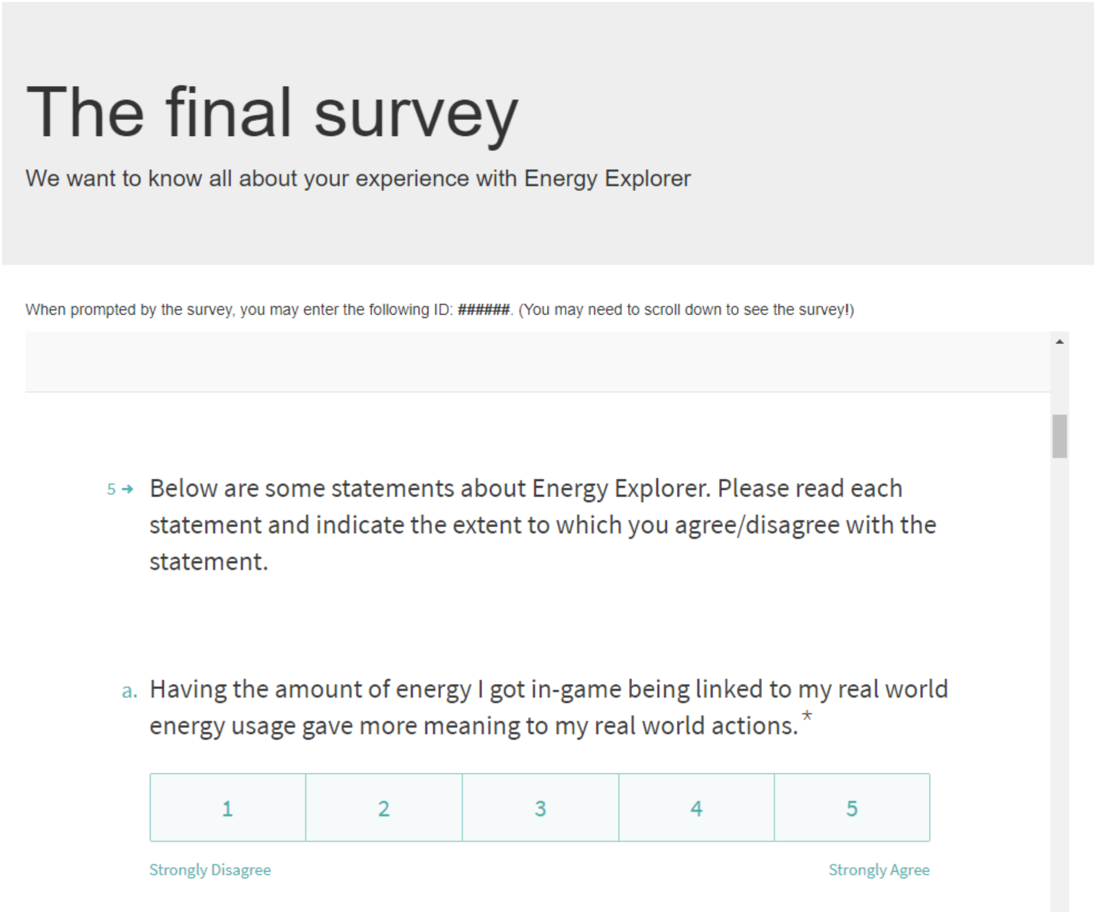


**Figure 97. The exit survey component of the *Energy Explorer* website, created using the *Typeform* software. Note the instruction for entering in an ID, which was used to facilitate data linking**