Household energy conservation with reality-enhanced serious games

Studies on effects in the real-world

Jan Dirk Fijnheer

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Household energy conservation with reality-enhanced serious games
Studies on effects in the real-world

Thuis energie besparen met door de realiteit verrijkte serious games
Studies naar effecten in de echte wereld

(met een samenvatting in het Nederlands)

Proefschrift

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te Lutjewinkel

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Co-promotor

Dr. H. van Oostendorp

Preface

The first ideas for this research project arose when I was a research-fellow within the research group Digital World of professor Frans Van Der Reep at Inholland University of Applied Sciences in Rotterdam, The Netherlands. The research project was elaborated more in concrete terms when the research group of professor Remco Veltkamp at Utrecht University became involved, and with the support of Herre Van Oostendorp a research plan was written.

In order to make the project possible, Utrecht University provided guidance and practical support. To make time available, I received funding from Inholland University of Applied Sciences for parttime PhD research of higher education teachers and invested private time. Next, for the development of the research tool, the *Powersaver Game*, a grant has been awarded by K.F. Heinfonds Utrecht, and funding was also raised through sponsoring and crowdfunding.

Powersaver Game was built by students of the Game Software Project, a bachelor thesis project of the department Information and Computing Sciences, and then the experiments were performed. This project has resulted in 23 media expressions (local and national), 7 peer review publications (6 academic papers and a book chapter), lectures, public presentations, a best paper award at a science conference and this thesis.

Acknowledgements

Gamification and sustainability are the main topics of my interest and many years ago the starting point of a journey that ends with this thesis. Frans Van Der Reep inspired and supported me to take a step forward in research, for the joy of it. So much has happened since then, this journey alone will fill a book. Herre Van Oostendorp and Remco Veltkamp, have supported me in every possible way over the years. I feel blessed with their involvement. I am also grateful for the colleagues in the department Information & Computing Sciences at Utrecht University, who supported and helped me time and again. I would especially like to mention Geert-Jan Giezeman for his technical expertise, support, and interesting conversations.

Ultimately, this thesis would not have been possible without my love Dieuwertje. You have shown a lot of patience and understanding, and you have been a great support to me and our children as I had to overcome every challenge. I am so proud of our family. You and our children Brem and Dorus are the best prizes I have won in my life.

I dedicate this thesis to my male family line. Starting with my grandfather Jan Fijnheer (1911-1991†), who was always present in my childhood and is an inspiration for self-development. My father Henk Fijnheer (1947-2010†), who has always and unconditionally supported me in my professional development. He is missed in life. My eldest son Brem Fijnheer (2013), who always surprised me with his tremendous insights, and my youngest son Dorus Fijnheer (2015), who inspired me with his rare talent to empower others.

Jan Dirk Fijnheer
Hilversum, June 2022

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Chapter 1

General Introduction

1. General Introduction

1.1 Game-Based Learning, Serious Games & Gamification

Interest in Digital Game-Based Learning (DGBL), using games as instructional media, keeps growing in a wide array of contexts (All et al., 2021). DGBL generally aims to leverage the entertaining nature of games to pursue educational outcomes (Bellotti et al., 2013). The effectiveness of DGBL can be defined as the successful attainment of its intended goals in a real-world context. Consequently, concerning DGBL effectiveness, both learning and player engagement is considered as relevant factors, and research into the effectiveness of digital games as instructional tools is required (All et al., 2015).

The chapter 'Origins of Serious Games' of Djaouti et al. (2011) sets out the history of serious games very well and in detail. They describe that the use of video games for serious matters, other than entertainment purposes, began during the Cold War when U.S. army developed simulation games. Also, in the same period, computer scientists experimented with serious games, especially in the field of artificial intelligence. In a way, some might say that serious computer games came before popular entertainment video games of the early nineteen eighties. From 2002 an enormous growth in serious games started. Before 2002, the majority of serious games, 66%, were used for educational purposes. Today this is only 26% and the use of serious games for advertising purposes, in particular, is large, 31%. It can be concluded that the growth of available and affordable technology stimulates the use of serious games in a wider range of topics for a larger population.

The term gamification has been conceived and named in 2008 and there is no consensus from the academic community on the concept. Two categories of definitions are proposed by Sanchez et al. (2019). The first category of definitions is based on the etymology of the term. Gamification consists of 'making or fabricating a game', i.e., applying game mechanics and using game elements such as badges, points, bonuses, and leaderboard in order to convert a non-game context into a game-like activity. In this approach the functions of a game result from a set of attributes. The second category of definitions is currently emerging. This category of definitions considers gamification to be 'a process focused on the player experience'. This process consists of the implementation of motivational affordances grounded in game-design principles and aiming at fostering 'gamefullness' or 'gamefull experience' (Sanchez et al., 2019).

Gamification results in (internal) psychological and (external) behavioral outcomes, because the focus of gamification is on influencing learning performance, attitude and/or behavior. From a learning perspective, gamification is considered to provide positive effects by fostering engagement in epistemic activities. However, potential negative outcomes, such as increased competition, are also reported (Sanchez et al., 2019). Due to new techniques, it is possible to play games and at the same time solve real-life problems. These kinds of games have the potential to appeal to diverse groups of people. Current technology has created the possibility to play games anytime and anywhere and to use them to tackle issues of great societal importance such as sustainability. Devices as smartphones and tablets have created a wide range of new possibilities, like developing attractive games and collecting huge amounts of data. Douglas and Brauer (2021) have categorized four broad topics in the field of gamification for sustainability to prevent climate change: (1) sustainability education, (2) energy reduction, (3) transportation/air quality, and (4) waste management/water conservation. This thesis focuses on the topic of energy reduction. In this field, as the other fields that are reviewed by Douglas and Brauer (2021), only a limited number of empirical studies have been conducted. Although the results of these studies are promising, it is still unclear why certain attempts are more effective at promoting behavior change than others. It can be concluded that up until now the potential of gamification has not been extensively explored in empirical scientific research and this thesis aims to, at least partly, fill this gap.

1.2 Reality-enhanced games

In a normal gamification process, game features such as levels, narrative, competition and badges, are implemented in real-world processes to stimulate desirable behavior. In our research project, a different and novel approach is chosen. As presented in Figure 1, it takes the opposite approach by implementing real-world processes, such as household energy saving activities (e.g., washing clothes on low temperatures), into the game design itself. User's real-world activities are integrated into a digital serious game. Players are immersed in real-life situations that are generated by user interaction with a virtual environment.

As explained in Chapter 4, the game we have developed for this research has a narrative in which household appliances, depicted in cartoonish style, are in a bad situation. Activities in the real-world, with corresponding real appliances, must be performed to bring these cartoonish appliances into a normal state. For example, the game presents a cartoonish washing machine that is overheating and therefore sick. The player is instructed to wash clothes on low temperatures in its real household. These real-world activities are monitored and affect the game narrative, feedback and reward features.

The aim of this 'reality-enhanced games' approach is to stimulate the transfer of information between the game world and the real-world (Massoud, et al., 2018). When the transfer is optimized, the game is expected to be more effective in change of behavior (Kors et al., 2015). Players experience a game in which real-life situations are integrated.

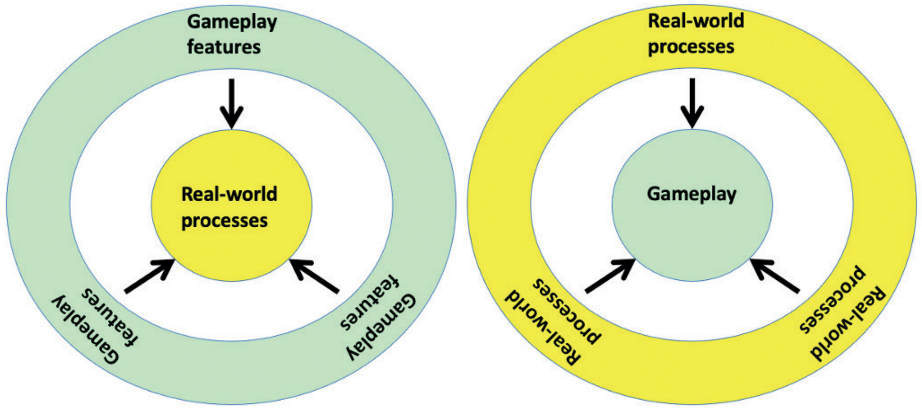


Figure 1. Gamification approach (on the left) and reality-enhanced games approach (on the right).

1.3 Experiments in serious games

Since the beginning of the millennium, there is an increase in empirical studies investigating the effectiveness of games that has been designed and used for learning, training and instruction. These games are often referred to as serious games or game-based learning (Wouters & Van Oostendorp, 2013). These studies, as well as the studies reported in this thesis, are inspired by the cognitive constructivist learning theory, which focuses on assumptions regarding teaching and meaningful learning (e.g., understanding: knowledge is integrated into the knowledge structure) at-a-distance (Garrison, 1993). Constructivism means that knowledge is constructed based on experience and previous knowledge structures. Teaching and learning at-a-distance are (in this thesis) aimed at the effects of serious games. In our case an instrument for teaching and learning at home, on learning processes, e.g., gain of knowledge. In particular, games can stimulate learning to be an active and evolving process. By using a serious game, the learner takes responsibility to construct meaning actively, through dialogue with oneself as well as others (e.g., household members). Garrison (1993) points out five subjects to examine in relation to cognitive constructivist learning theory that are still relevant in current research on serious games: (1) design of the medium (e.g., game features), (2) instructional strategies (e.g., game versus other computer based medium), (3) type of learning goals (complexity:

lower-/higher-level), (4) feedback (corrective/explanatory) and (5) prior knowledge structures. Until 2008 many claims about the effectiveness of serious games are supported by anecdotal arguments, because there was a lack of empirical evidence. From then on, more well-designed empirical studies have been published. See for reviews: Boyle et al. (2016), Clark et al. (2016), Ke (2009), Wouters et al. (2013) and Wouters and Van Oostendorp (2017).

De Freitas and Liarokapis (2011) envision a future where all learning in education will include game-based features that incorporate immersive, social and interactive elements. In these learning environments, e-learning resources and learning materials are brought together in an interface that can be traversed and engaged through games, narratives and missions. In such a system, virtual agents can provide customized and personalized information when needed and adapted to the user's requirements to enhance the learning process.

Currently, one of the main challenges related to serious games is to optimize both learning and motivation, as there is a negative correlation between learning and enjoyment when the material is difficult and the students have little knowledge of the subject (Graesser, 2017). Serious games can optimize learning and motivation, but one has to take it into account that game features can also impair learning when they divert attention from the subject. The difficulty of the learning material, the skills of the learner and the characteristics of the game tasks must be taken into account in order to optimize learning and motivation.

Mayer (2011, 2014) has divided game research into three categories: (1) a 'media comparison' approach, which investigates whether people learn better from serious games than from conventional media, (2) a 'value-added' approach, which questions how *specific* game features foster learning and motivation, and (3) a 'cognitive consequences' approach, which investigates what people learn from serious games. In particular, this thesis focuses on a media comparison approach and a value-added approach.

A meta-analysis of Wouters et al. (2013) that is based on a media comparison approach, showed that serious games were found to be more effective in learning and retention, but they were not more motivating than conventional instruction methods such as lectures, reading, drill, and practice, or hypertext learning environments. Learners in serious games learned more, relative to those taught with conventional instruction methods when: (1) the game is supplemented with other instruction methods, (2) multiple training sessions are involved, and (3) players work in groups.

Some argue that learners are more likely to learn to play the game, i.e., directed on in-game performance, rather than learn domain-specific skills (Ke, 2009; Leutner, 1993). However, when instructional support was taken into account serious games with instructional support foster domain-specific skills more than in-game performance (Wouters, 2017).

A later publication of Wouters and Van Oostendorp (2017) presents a meta-analysis that is based on a value-added approach, examining which game features can improve learning and/or increase motivation. They indicate the following nine proven effective or promising instructional techniques in terms of learning and/or motivation: content integration, context integration, assessment and adaptivity, level of realism, narration-based techniques, feedback, self-explanation and reflection, collaboration and competition, and modeling.

Both meta-analyses, with results of empirical studies based on a media comparison approach and value-added approach, show that serious games are effective, but that the effectiveness can be improved (Wouters & Van Oostendorp, 2017; Wouters et al., 2013). There are research gaps and learning gains for serious games in both comparison conditions, as well as in the added value of several game features (Boyle, et al., 2016; Wouters & Van Oostendorp, 2017).

In general, more research is needed into investigating the long-term effects of the different instructional techniques and unravel under what conditions learning is persistent (Jacobs & Jansz, 2021). From both a research - and practical perspective it is relevant to focus on long-term interventions (from about one week and longer) and long-term effects (in the weeks immediately following the intervention). Also, a broader landscape of serious games on different subject matters with different populations and game features is needed. Preferably, researchers should at least be part of the design process when building serious games to make an appropriate research tool for empirical randomized controlled trials (Graesser, 2017).

1.4 Stimulate energy conservation behavior

Social relevance

A central topic in this thesis is the stimulation of efficient energy use of households. It is about enhancing further energy-saving measures. This topic is socially relevant because of three issues in the current energy transition. The first issue is European Union (EU) and national political policy on the energy transition. European policy states that EU countries must empower their citizens in the energy transition. This means that citizens are allowed to participate actively in the energy transition and thereby enjoy benefits, by advancing energy efficiency and lowering their electricity bills (European Commission, 2021). Dutch local governments, provinces, and municipalities, face the challenge of implementing this policy and are diligently seeking ways to do so. A serious game is a potential tool to implement this policy to empower citizens in the energy transition (Raessens, 2018). Results presented in this thesis can be used to support the design of institutional support, regulatory framework, and policy instruments to empower citizens, a central aim of the EU for the energy transition. The second issue is the need for institutions, e.g., energy suppliers and energy dashboard providers, to gain more insight into how a serious game can be used as a service to households. The third issue is the need for citizens to be involved and empowered in the energy transition.

Empowerment

There are social and behavioral barriers that need to be overcome in order to propel energy transition by empowering citizens. This requires technological solutions and new ways of collaboration, decision-making, and mobilizing society (Hoppe & De Vries, 2018). When people are empowered to increase their involvement and are motivated for individual behavioral change, people experience a perceived risk on the one hand and a perceived benefit on the other (Bronfman et al., 2012). A serious game can stimulate the engagement of citizens by providing relevant information that will decrease the perceived risk and more important make benefits insightful. Habits are formed through repetition and reinforcement and are a crucial component in environmental activities that are relatively stable. To shape a new habit, new information and feedback (e.g., presented in a serious game) are processed in relation to a particular choice or action (e.g., household energy consumption). The attitudinal response to this information can ultimately change behavior (e.g., household energy conservation) (Andersen, 1982). People are changing continuously in response to societal and technological changes (e.g., smartphones) (Jackson, 2005). Important in this research project is having available the right information about household energy consumption, for which information and feedback could be important, and how this is related to attitudes in changing behavior regarding household energy conservation. Attitude can be defined as a position towards an item and makes a person do something (e.g., energy consumption). Attitude drives motivation and makes processes efficient and effective (Eagly & Chaiken, 1993; Petty & Cacioppo, 1981). Attitudes can be changed through persuasion. A game can act as an instrument to persuade and motivate. That is the reason that these (serious) games are sometimes called 'persuasive games' (Fogg, 2002).

Motivation

Sustainable behavior is citizens' behaviors that improve social and environmental performance as well as meet their needs. Despite the increase in environmental awareness, many citizens have actually not made any concrete changes in their personal consumption choices and behavior. This can be due to three factors (Belz & Peattie, 2009). First, citizens' selfishness: they don't want to give up or change the way they live. In its design, a serious game stimulates intrinsic motivators to change selfish behavior. Intrinsic motivation is an outcome of interest, enjoyment, inherent satisfaction (Ryan & Deci, 2000a) and can be influenced by playing a serious game. Second, the lack of knowledge about the costs of the environmental impacts of consumption. A feedback system in a serious game provides this knowledge and stimulates new behavior. Third, citizens are locked into unsustainable behavior, due to social and institutional contexts, despite having good intentions. A serious game that is played in competition with peer groups can create a new social context and present tips for sustainable actions in the participant's home situation. As described and explained further in this thesis, research suggests that a game can be highly effective in motivating and engaging players to change their daily energy-consumption patterns during playing. To be motivated means to be stimulated to do something. People have a level of motivation and orientation of that motivation. Orientation of motivation concerns the underlying attitudes and goals that give rise to action (Ryan & Deci, 2000b). The two sources of motivation are intrinsic rewards and extrinsic rewards. Intrinsic rewards drive us to do things that make us feel good just by doing them. Four issues are essential for intrinsic motivation (Fullan, 2011): First, a strong sense of purpose, value, and meaningfulness. This suggests that personal relevance and feedback are important features in a serious game. We discuss this in more detail in Section 3.1.7. Second, increased capacity to get better at something important. Relevant feedback from a serious game will facilitate this. Third, degree of autonomy in the gameplay of a serious game. Fourth, connecting to others in the pursuit of significant goals. This suggests that playing together and competing with others is important for a serious game. The importance of social interactions for shaping the player experience is demonstrated in the overwhelming participation in massively multiplayer online games, and the personal relevance of these communities to those intensely involved in such games (De Kort & Ijsselsteijn, 2008). Some even argue that it is the social interaction and participation that, to a large extent, explain game enjoyment (Bryce & Rutter, 2003; Carr et al., 2004). Several studies demonstrate that games involving social interaction elicit beneficial effects on cognitive skills, but also in affective and social terms (Calvert, 2005; Gunter, 2005).

1.5 Publications

This thesis incorporates peer-reviewed publications. These are presented in Table 1, and briefly introduced below. Table 1 also presents in which chapters each publication is incorporated.

Table 1. Publications.

Paper	Chapter
Fijnheer, J. D., & Van Oostendorp, H. (2016a). Steps to Design a Household Energy Game. In A. De Gloria, & R. C. Veltkamp (eds), *Games and Learning Alliance 4th International Conference: GALA 2015. Lecture Notes in Computer Science* (Vol. 9599, pp. 12-22). Cham: Springer.	3, 4
Fijnheer, J. D., & Van Oostendorp, H. (2016b). Steps to Design a Household Energy Game. *International Journal of Serious Games*, Volume 3(3), 16 p.	3, 4
Fijnheer, J. D., Van Oostendorp, H., & Veltkamp, R. C. (2016). Gamification in a Prototype Household Energy Game. In T. Connolly, & L. Boyle (eds), *Proceedings of the 10th European Conference on Game Based Learning, ECGBL 2016* (pp. 192-201). Paisley, Scotland: ACPI.	3, 4
Fijnheer, J. D., Van Oostendorp, H., & Veltkamp, R. C. (2019). Enhancing Energy Conservation by a Household Energy Game. In M. Gentile, M. Allegra, & H. Söbke (eds), *Proceedings of the 7th International Conference, Games and Learning Alliance (GALA) 2018* (Vol. 11385, pp. 257-266). Palermo, Italy: Springer.	5
Fijnheer, J. D., Van Oostendorp, H., & Veltkamp, R. C. (2019). Household Energy Conservation Intervention: a Game versus Dashboard Comparison. *International Journal of Serious Games, Volume 6*(3), 23-36.	5, 7
Sanchez, E., Van Oostendorp, H., Fijnheer, J. D., & Lavoué, E. (2019). Gamification. In A. Tatnall (Ed.), *Encyclopedia of Education and Information Technologies*. Springer, Cham.	1, 2
Fijnheer, J. D., Van Oostendorp, H., Giezeman, G. J., & Veltkamp, R. C. (2021). Competition in a Household Energy Conservation Game. *Sustainability, Volume 13*(21), 1-25.	6, 7

The first publication 'Steps to Design a Household Energy Game' is published in 'Games and Learning Alliance 4th International Conference: GALA 2015. Lecture Notes in Computer Science' (Fijnheer & Van Oostendorp, 2016a), and presented at this conference in Rome, Italy. A more extended version of this paper is published in the 'International Journal of Serious Games' in 2016 (Fijnheer & Van Oostendorp, 2016b). In that year also 'Gamification in a Prototype Household Energy Game' in T. Connolly, & L. Boyle (eds.) 'Proceedings of the 10th European Conference on Game Based Learning: ECGBL 2016' (Fijnheer et al., 2016) was published and presented at this conference in Paisley, Scotland. These papers are about the theoretical background of this research and iterations in the development of the research instrument *Powersaver Game*. In 2019 two papers were published about the first experiment with *Powersaver Game*. This experiment is part of a media comparison study (Mayer, 2014). The first paper, 'Enhancing Energy Conservation by a Household Energy Game' in 'Proceedings Games and Learning Alliance 8th International Conference: GALA 2018' (Fijnheer et al., 2019), was presented at this conference in Palermo, Italy, and was awarded 'the best paper award'. A much more extended paper about the first experiment is published in the 'International Journal of Serious Games' in 2019: 'Household Energy Conservation Intervention: A Game versus Dashboard Comparison' (Fijnheer et al., 2019). Next, in 2019 the chapter 'Gamification', in 'Encyclopedia of Education and Information Technologies' (Sanchez et al., 2019) was published. In this chapter, together with other researchers, more depth is given to the definition of 'Gamification'. The last publication 'Competition in a Household Energy Conservation Game' (Fijnheer et al., 2021) is published in 2021 and is about the last experiment, which is part of a value-added study (Mayer, 2014).

Chapter 2

Research Outline

2. Research Outline

Gamification by applying reality-enhanced games has a great potential for behavior change and attitude change in novel and engaging ways. However, little empirical research has been done on the effectiveness of reality-enhanced games and, although recent findings do point to a moderately positive direction, even less is known about why some games succeed in effectively behavior change (Fijnheer et al., 2016). Therefore, in this thesis we propose to empirically test a number of (design-) guidelines/principles for reality-enhanced games, in this case, to influence household energy conservation. The purpose is to come to a set of (design-) guidelines/principles through empirical studies that enhance the instructional design of reality-enhanced games and can be used in the development of effective, future games, especially in the field of household energy conservation. This chapter provides an explanation of the perspective on how to influence sustainable household energy consumption through reality-enhanced games. A description is given of the research questions that need to be answered to bring the field a step further. Also, this chapter outlines the rest of this thesis, and introduces some of the key concepts that the research is based on.

2.1 Conceptual framework

The target of current research is to contribute to the stimulation of individual sustainable behavior by studying how gamification can be a positive means for people to change their behavior on energy use at home. The decision to focus on energy use has been made because it is an important topic in the field of sustainability, both from a social perspective (European Commission, 2021; Vringer et al., 2021) and a scientific perspective (Douglas & Brauer, 2021; Gustafsson et al., 2009), and because it will lead, within the confines of this research, to instantly measurable results. Before presenting the conceptual model, the topic of 'optimizing knowledge transfer from the game world to the real-world' and why this is relevant for engagement, behavior change and attitude change, is discussed.

2.1.1 Optimizing transfer from the game world to the real-world

Wouters et al. (2013) conclude that serious games can have strong effects on learning and retention. It can be assumed that implementing real-world processes, instead of simulated/fictive processes, in a serious game will have similar effects. A situated learning experience is provided if a serious game and gamification principles are combined. The player/learner applies his/her knowledge directly to solve real-world problems (Gustafsson et al., 2009). Such as setting the real thermostat to a lower temperature in a household energy game. Some gamification research suggests that the integration of serious games into real-life could have positive effects on both attitudes and behavior (Hamari, et al., 2016; Gustafsson et al., 2009). Therefore, the inclusion of reality by using gamification principles in a serious game will stimulate the transfer of knowledge from the game to reality. When in this way the transfer is optimized, it is expected that the game will be more effective in the change of attitudes and behavior (Kors et al., 2015).

2.1.2 Engagement, knowledge transfer, attitude change and behavior change

Gamification by incorporation of game features can be a valuable strategy for making non-game products, services, or applications more motivating and/or engaging the user (Deterding et al., 2011). Likewise, serious games and gamification can be an effective means to change people's energy-related attitudes (Fijnheer & Van Oostendorp, 2016). When people are highly engaged in the game, they are apt to adopt the attitude that is promoted in the game (Ruggiero, 2013). This can lead to a higher awareness of relevant factors involved in, for instance, energy-saving. In effect, attitudes may positively change and as such, subsequently trigger a change in energy-saving behavior itself. The assumed chain of events, *awareness (knowledge) - attitude change - behavior change*, is what serious games try to influence (Aronson et al., 2013; Chen & Chaiken, 1999; Soekarjo & Van Oostendorp, 2015), and is presented in Figure 2.

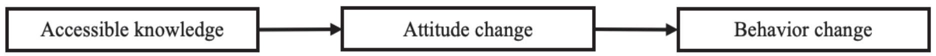


Figure 2. Assumed chain of events in behavior change.

Player-Oriented Persuasive Game Elaboration model

Jacobs (2017) developed the Player-Oriented Persuasive Game Elaboration model (POPGE-model) to study the influence of persuasive games on attitudes and behavior. This model has been used as inspiration for the conceptual model in this thesis. Jacobs (2017) argues that a persuasive game is a serious game that is primary aimed at attitude change. His model theorizes the mechanism through which a serious game can influence an attitude and behavior of an individual player. It should be noted here that his focus is on a single game session and short-term effects. In this thesis, the focus is on multiple game sessions over time (from about one week and longer) and long-term effects (in the weeks immediately following the intervention). Figure 3 is a simplified version of POPGE-model and shows the main factors that are considered.

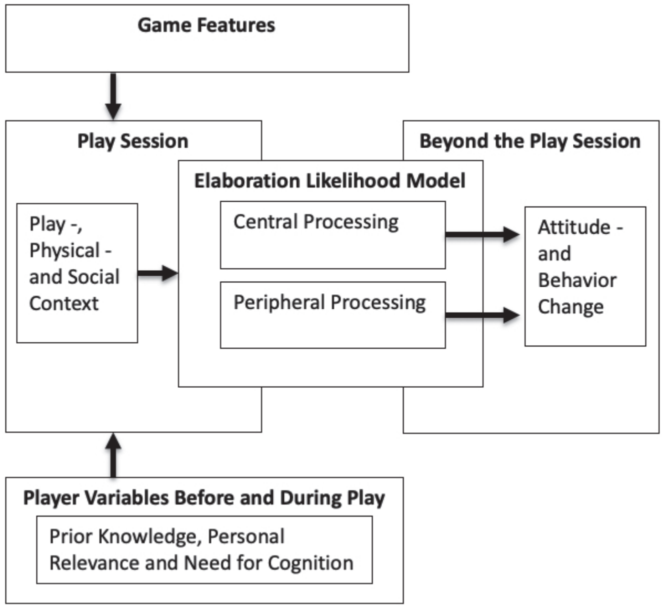


Figure 3. Simplified version of the Player-Oriented Persuasive Game Elaboration model (Jacobs, 2017).

The five elements (1- Game Features, 2- Player Variables Before and During Play, 3- Play Session, 4- Elaboration Likelihood Model and 5- Beyond the Play Session) of the POPGE-model and their interrelationships are discussed below.

Game features are important for a persuasive effect, however there are many ways to look at game designs in terms of how they can affect players (Jacobs, 2017). In the POPGE-model game features theoretically affect both play context as well as the elaboration process. Depending on whether and how game features are deployed, they can affect all factors in the elaboration process.

Jacobs (2017) emphasizes three *player variables* related to involvement with a topic of a serious game, for example, household energy conservation, that affect player's likelihood to elaborate information presented in the game. First, prior knowledge mainly affects the ability to elaborate, because the more knowledge someone has about a subject, the more involvement there is at a cognitive level for the arguments presented (O'Keefe, 2002). Second, personal relevance / issue involvement (Johnson & Eagly, 1989) mainly affects the motivation/engagement to elaborate (Jacobs, 2017). If the topic dealt with in the game is more relevant, it will cause considerations of arguments more actively (O'Keefe, 2002). Personal relevance in serious games can be stimulated using the instructional technique 'adaptation' as described by Wouters and Van Oostendorp (2017). For example, an energy conservation game that incorporates the player's real household energy consumption instead of general simulations is probably more personal-relevant. Another example often applied in games to stimulate personal relevance, and thus motivation, is the possibility to personalize avatars (Blumberg et al., 2013; Lee & Youn, 2008). Third, the need for cognition defined as the intrinsic need and pleasure of considering and thinking about certain topics. Individuals with a high need for cognition elaborate more (Petty & Cacioppo, 1986a, 1986b). In summary, it can be assumed that players with higher need for cognition, more personal knowledge, and for whom the topic is personally more relevant are more likely to elaborate.

In a context where the player and game meet, a *play session* emerges. This element describes the individual experiences of players during play sessions. These include affective reactions toward the game including presented knowledge. The context in a play session can be divided in three parts: 1- The play context in which game features are presented in the game design. Chapter 4 discusses both the design process and the incorporation of effective features into game design. 2- The physical context in which the game is played. Game research on the topic of the physical context mostly refers to playing at home versus playing in a classroom. More enjoyment and better learning outcomes are reported when playing at home than in a classroom. This is caused by differences in playing time (longer playing time at home) and technical issues (more technical issues in the classroom) (De Grove et al., 2012; Jacobs, 2017). This outcome is in a way positive for reality-enhanced games that incorporate real-world processes from the physical world in the gameplay itself, especially when they take place in the household. Researchers should consider research environments other than classrooms or labs. Activities from the physical world feed the gameplay of reality-enhanced games and are therefore relevant to the player. Activities are preferably monitored continuously and objectively so that good feedback, and possibly also instructions, can be provided at relevant moments to stimulate desired behavior. This is possible due to new technologies such as smart-energy meters in the case of household energy conservation, or activity trackers in the case of exergames. 3- Social context relates to collaboration in digital game-based learning, which involves problem-solving and constructing knowledge together as a team. This takes mutual engagement and coordinated efforts (Sanchez, 2017; Van Der Meij et al., 2011). Participants extend their knowledge and must make it explicit to others. This makes interaction in a collaborative setting highly engaging (Ter Vrugte & De Jong, 2017). Its effectiveness depends on the quality of dialogues in acquiring knowledge from each other by questioning, answering and discussing (Sanchez, 2017; Van Der Meij et al., 2011). These discussions, often about conflicting information, lead to opportunities for reflection on the offered content and existing knowledge (Chen & Law, 2016), and thus stimulate information exchange and constructive communication (Dindar et al., 2020). To be more specific: when asking questions, participants outline what they know and/or identify what they need to know, which helps to become aware of their knowledge and to generate knowledge. In this way both learning processes and outcomes benefit from collaboration (Ter Vrugte & De Jong, 2017) and, through these social interactions, also positive motivational experiences are facilitated and feelings of relatedness generated (Rigby & Ryan, 2011). Furthermore, when team members face emotional challenges such as frustration or demotivation, collaboration stimulates mutual cognitive, motivational and emotional support (Dindar et al., 2020; Hadwin et al., 2017).

Jacobs (2017) has adapted the *Elaboration Likelihood model* of Petty and Cacioppo (1986a, 1986b) to link the game session, where player and game meet and interact, to the persuasive effects of attitude change and behavior change. The Elaboration Likelihood Model posits two general ways of processing stimuli: the central processing route and peripheral processing route. To elaborate on stimuli means to think about them consciously and actively. For example, to save energy during various activities in the household. This includes previous experience, retrieving relevant existing knowledge, logically testing arguments and coming to conclusions. If a person is elaborating more, he/she is probably using the central processing route. The person takes then careful and thoughtful considerations of the information presented. For example, studying energy consumption charts provided by the energy supplier. The results of attitude and behavior change will be in this case relatively enduring. However, if a person is using the peripheral route, probably merely associations with positive or negative cues are used which are generally unrelated to logical thinking. Using the peripheral route can be influenced by the credibility or attractiveness of the message (game design) and medium (computer tablet). A serious game that is played for a longer time can probably trigger both routes. Informative feedback can trigger the central route, while an attractive design and presentation of the gameplay can target the peripheral route. Unfortunately, Jacobs (2017) was unable to demonstrate in his experiments which route, the central processing route or peripheral processing route, had an effect on attitude change.

The right side of the model, *Beyond the Play Session* (see Figure 3), presents in a sense the earlier proposed assumed chain of events, in which higher awareness (more accessible knowledge) for a longer period leads to attitude change which in turn results in behavior change in the long term (Aronson et al., 2013; Chen & Chaiken, 1999; Soekarjo & Van Oostendorp, 2015). In this thesis a distinction is made between micro-level attitude and macro-level attitude. Macro-level attitude involves more general and important aspects of a topic, such as sustainable energy, than micro-level attitude. This approach allows specific hierarchical attributes to be measured, on macro-level and micro-level, of the object of, in this case, sustainable energy attitude. It can be assumed that micro-level attitude topics are nested within macro-level attitude topics (Watt et al., 2008). It is not clear in advance to what extent both influence each other and influence behavior change when interventions take place.

Basic conceptual model

The hypothesis of Jacobs (2017) is that (1) the game, (2) the context in which a game is played and (3) the individual player, together can predict short-term effects on attitudes and behaviors. From both a research and practical perspective it is more relevant to focus on long-term interventions (the duration is a week and longer) and long-term effects (in the weeks after the intervention). This is when a game is played for a longer time so that more constructive behavior change and related attitude formation can take place. Both change processes need time to take effect (Krosnick & Petty, 1995; Lally et al., 2010). Also, this thesis focuses on adding reality in the gameplay as a way to stimulate the transfer of knowledge from the game to the player (Kors et al., 2015). Although the POPGE-model offers a novel position to the wider perspective on the effects of persuasive games, the major and probably most important issue that the model did not clarify is the assumed chain of events. Nevertheless, it is a useful starting point for the conceptual model in this thesis, because it offers a relatively simple overview in which various research gaps are present and their mutual connections become visible.

Figure 4 presents the basic conceptual model, which is inspired by the POPGE-model and the assumed chain of events regarding attitudes and behavior change. The basic conceptual model includes the elements 'Reality-Enhanced Game Features', 'Player Variables', 'Play Sessions', 'Elaboration of Information Transfer', and 'Assumed Chain of Events'. Reality-enhanced game features are incorporated into an application, with which players interact. They do this in several play sessions in the long term. Information that is presented by the reality-enhanced game features is processed by the player and triggers the assumed chain of events regarding attitudes and behavior change.

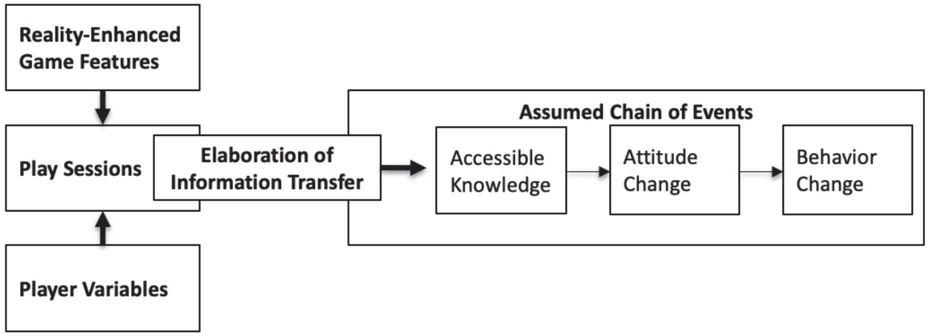


Figure 4. Basic conceptual model.

The basic conceptual model focuses on the research issues that are addressed in this thesis, such as the reality-enhanced gamification approach and effects of long-term interventions (the duration is a week and longer) and long-term effects (in the weeks after the intervention). It provides an overview of how to study elements and relationships of reality-enhanced games that stimulate household energy conservation in the long term and includes a more refined method to measure the effect on the assumed chain of events regarding attitudes and behavior change. An extended version of the conceptual model is presented in the next section. This version is based on the research gaps and research questions addressed in this thesis.

2.2 Research gaps & Research questions

The aim of this research is to contribute to the stimulation of individual sustainable behavior by studying how gamification, using a reality-enhanced game, can be a positive means for people to change their behavior on energy use at home.

The decision to focus on energy use at home has been made because it is an important topic in the field of sustainability in general and, more specific, the energy transition (see Section 1.4). Also, because it will lead, within the confines of this research, to results that are instantly measurable.

In chapters 1 and 2 several theoretical topics are introduced and discussed that are in line with the central research question:

'How can gamification, by means of reality-enhanced games, be used effectively to stimulate long-term sustainable energy use at home?'

There are several research gaps in this area of research. First, it is not clear how reality-enhanced games are related to gamification process principles. Second, not much is known about the effectiveness of reality-enhanced games in the long term, both in general and specifically in the case of household energy conservation. Also interesting are the empirical effects of game features of household energy conservation games on player's engagement, knowledge, attitudes and behavior. Third, a description of a design strategy for reality-enhanced games is still not available. In this case which steps must be taken to design a household energy conservation game. It is not known what the characteristics for evaluating a game design are, and how to implement these as features in a new game design, especially in the case of a household energy conservation game. Also, it is not clear which features are key, and what their effects are.

The basic conceptual model presented earlier (see Figure 4) provides an overview of where both the research gaps and the central research question can be located. Because this area of research is new, the focus is on the basic effects of a reality-enhanced game and its features. The scope of this research is primarily limited to the assumed chain of events, by conducting a media comparison approach and a value-added approach (Mayer, 2014). To clarify this, Figure 5 presents an extended version of the conceptual model.

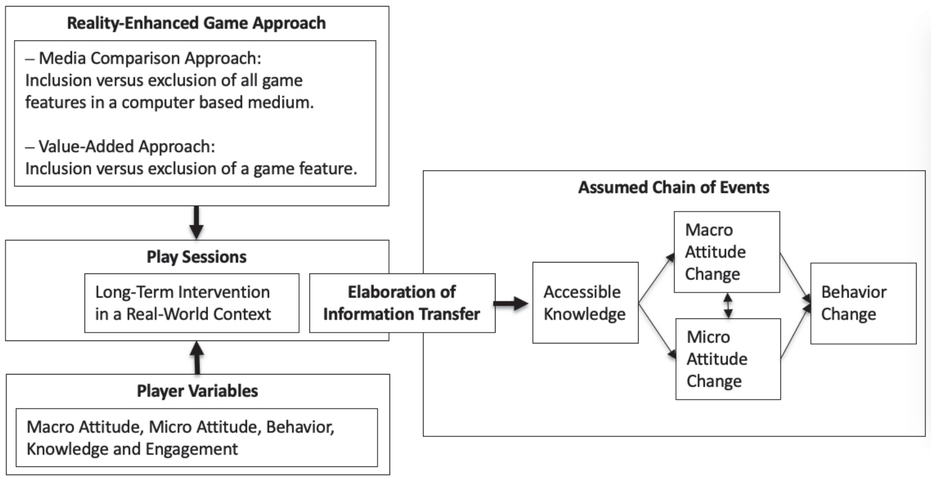


Figure 5. Extended display of conceptual model.

Regarding *play sessions*, the game application including or excluding reality-enhanced game features, presents information that the player takes note of. The transfer of information takes place in a real-world context during several gaming sessions over time, and is likely to affect the player's level of knowledge, attitudes and behavior regarding the information presented by reality-enhanced game features. Game design should contribute to keep the player engaged over a long period of time. Therefore, the focus is on game features and their effect on people's knowledge, attitudes and behavior.

Regarding the *player variables* section of the conceptual model, this research focuses on people's attitudes, behavior and knowledge-level, because of the assumed chain of events. In this section, the status of variables at the beginning of play sessions is presented, while in the section *assumed chain of events*, the change in the status of the same variables after the play sessions is presented. Engagement during the intervention is also monitored, because of the long-term duration of the intervention period.

Regarding *elaboration of information transfer*, it has been decided not to pay attention to the elaboration processes as Jacobs (2017) did. Here, through interaction with the game, the elaboration of information takes place, resulting in more accessible knowledge and probably a change in attitude and behavior.

Regarding the *assumed chain of event*, which is based on theoretical reasoning, as expressed in Figure 2, that more accessible knowledge (higher awareness) leads to more attitude change which subsequently leads to greater behavior change (energy conservation change), a split is made between macro-attitude and micro-attitude. Macro-attitude involves more general and important aspects of a topic and micro-attitude involves more specific aspects of the same topic. This approach allows specific hierarchical attributes to be measured, because it can be assumed that micro-level attitude topics are nested within macro-level attitude topics (Watt et al., 2008). This section presents the change after the play sessions of the same variables, which are also in the *player variables* section.

In order to answer the research question and the mentioned research gaps, the following sub-questions are studied:

1. ***'What are effective design principles for reality-enhanced household energy conservation games?'***

2. ***'What is the long-term effectiveness of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players?'***

3. ***'What is the long-term effectiveness of specific game features of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players?'***

2.3 Proposed experiments

To find out more about the effectiveness, both a media comparison approach and a value-added approach by Mayer (2014) are chosen. In the first experiment, a media comparison study, answering the question whether people learn better from a game or from conventional media, households played a reality-enhanced household energy conservation game or used an energy conservation dashboard version in the control condition. The form, timing and content of the information received by the control condition are as similar as possible as in the game condition, but excluded game elements. Next, in a value-added approach, answering the question which features of a game promote learning, the effects of the features, personal relevance using personalized avatars and social interaction through competition are examined, on engagement, knowledge, attitudes and behavior concerning energy consumption.

2.4 Outline of the thesis

In the next chapter, Chapter 3, an overview of related work and a novel approach are presented. It addresses the first sub-question of this thesis, which is about effective design principles for reality-enhanced household energy conservation games. The chapter starts with a comparative literature review of eight games developed for related research purposes. Special attention is given to the empirical effect of the evaluated energy games and their effective game features. Suggestions for the design of a new game that is used in this project have been identified. Next, a taxonomy of gamification approaches is presented to explain and clarify the novel gamification process to develop a reality-enhanced game, in which real-world activities are implemented in a game design. Finally, our approach to both media comparison study and value-added study (Mayer, 2014) is explained, with special attention to both game features personalization of avatars and competition.

In Chapter 4 the user-centered design process and iterations of the development of *Powersaver Game*, which is the instrument of research, is elaborated. Also, the design of *Powersaver Dashboard*, which involves the design of the control condition, is presented. As in the previous chapter, the first sub-question of this thesis is addressed, which is about effective design principles for reality-enhanced household energy conservation games. *Powersaver Game* is described and special attention is paid to the results of two evaluations. For an effective transfer of information, the match between the game world and real-world was examined in the first evaluation. In the second evaluation, end-users reviewed design features.

Chapter 5 presents the results of a media comparison study (Mayer, 2014), comparing a game versus a dashboard condition concerning energy conservation in the household. It addresses the second sub-question of this thesis, which is about the long-term effectiveness (in the weeks after the intervention) of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players. In a pretest-posttest design, an empirical study tested whether change in attitudes, knowledge, engagement and behavior concerning energy conservation in the household was different for participants playing *Powersaver Game* compared to a control condition where participants used an energy dashboard with similar content, but excluding game features.

Chapter 6 presents the results of two value-added studies (Mayer, 2014) regarding the personalization of avatars and competition. It addresses the third sub-question of this thesis, which is about the long-term effectiveness (in the weeks after the intervention) of *specific* game features of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players. First, a pilot experiment is presented in which the effects of standard avatars and personalized avatars are examined in a small group of households. Next, we tested whether change in engagement, attitudes, knowledge and behavior concerning energy conservation in the household was different for participants playing the *Powersaver Game* with or without competition.

Finally, in Chapter 7 a reflection on the experiments is given, how they relate to the theory, and it provides a general conclusion to the thesis, as well as a discussion of limitations and recommendations for future research. It addresses the central question of this thesis, which is about how gamification, by means of reality-enhanced games, can be used effectively to stimulate long-term sustainable energy use at home, and the final conceptual model is presented.

Chapter 3

Related Work and a Novel Approach

3. Related Work and a Novel Approach

In this chapter an overview of related work and a novel approach is presented. First, in Section 3.1 design goals, or demands, are formulated with which games are selected that provide input for the design of our game. Eight games developed for related research purposes provided first suggestions for the design of our game. Next, in Section 3.2 a taxonomy of gamification approaches is presented to explain and clarify a novel gamification process to develop a reality-enhanced game, in which real-world activities are implemented in a game design. Finally, in Section 3.3 our approach for both media comparison study and a value-added study (Mayer, 2014) is explained, with special attention to both game features personalization of avatars and competition.

3.1 Overview of method to analyze energy games

Based on design goals, games are identified that have similar, or at least partially similar, goals to the game developed here (see Chapter 4). The design of these games is analyzed with the dimensions/characteristics identified. The optimal implementation of characteristics, and what might be lacking, will become clear from the thoughtful analysis. Also, the effect of the games is analyzed to conclude whether the designs are sufficiently effective. Based on this, suggestions are made for the design of the game consistent with the research objectives. It should be noted that the analysis in this chapter was done in 2015 to develop *Powersaver Game*. Since then, other research groups worked on projects that have similarities with our project, and occasionally refer to *Powersaver Game*. Although there are many similarities, only one project, the EU funded project EnerGAware (Casals, et al., 2020), meets the same design goals (see Table 2) as *Powersaver Game*. This project is further discussed in Section 3.1.8.

3.1.1 Design goals

Six goals are formulated based on the requirements of the design of the game (see Table 2). The first goal is that the game makes players aware of sustainability issues concerning energy use at home. The game raises awareness. The second goal is the transfer of information about energy consumption so that players acquire more knowledge. The third goal is that players will be influenced by the game to change their behavior concerning energy consumption in real-life. The fourth goal is that behavior in real-life is integrated into the game by monitoring behavior in real-life and using this information in the game progression. The fifth goal is that the game is played over a relatively long period of time and has several sessions. The sixth and final goal is that the game has a compelling and complex storyline that can engage players. A storyline in a game can be engaging because it stimulates our emotions

(Prensky, 2007). A complex storyline includes a setting where game characters must achieve goals and face multiple obstacles in reaching these goals (Stein & Glenn, 1979).

Table 2. Goals game design.

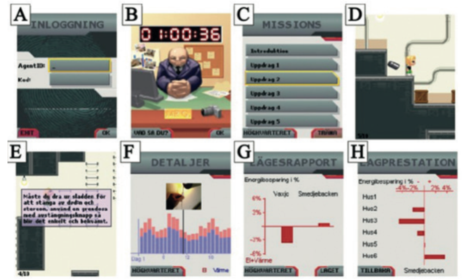
1. Awareness Sustainable Energy Use at Home
2. Information Transfer Energy Consumption
3. Influencing Energy Consumption at Home
4. Integrating Real-Life Behavior
5. Playing a Longer Period
6. Compelling and Complex Storyline

3.1.2 Energy games

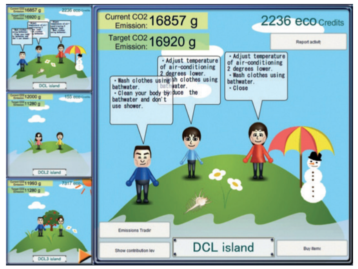
The game design we want to realize is focused on energy use at home, specifically where personal behavior is involved. Games that also have this focus were chosen based on the above six goals. Searches were performed in scientific databases and with the aid of public search engines. In these databases eight games were found that had been used as a research instrument with similarities to this research. These eight games are analyzed in this section. The output of public search engines also suggested many games that are used for education and entertainment purposes, but not for research. Unfortunately, they bear little resemblance to the design goals. Most games that came out of the search are not useful because they do not have a connection with real-life energy consumption behavior and/or are too simple. The eight selected games are presented in the Table 3.

Table 3. Selected energy games.

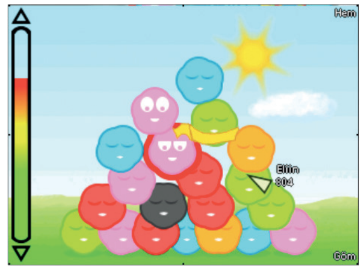
1. The Power House
(Bang et al., 2006)



2. Power Agent
(Bang et al., 2007; Gustafsson et al., 2009b)

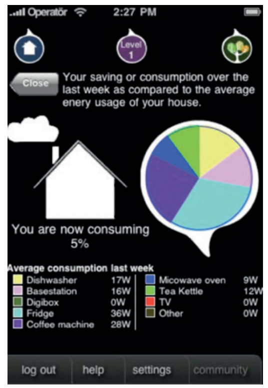


3. EcoIsland
(Kimura & Nakajima, 2011)

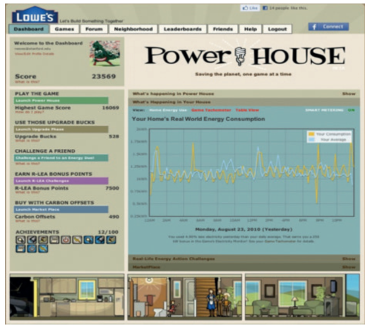


4. Power Explorer
(Bang et al., 2009; Gustafsson et al., 2009a)

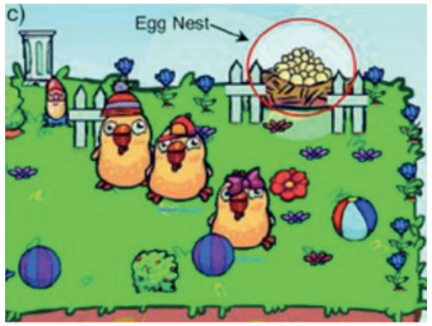
5. Agents Against Power Waste
(Svahn, 2014)



6. EnergyLife
(Gamberini, et al., 2011, 2012)



7. Power House
(Reeves et al., 2012, 2013)



8. Energy Chickens
(Orland, et al., 2014)

3.1.3 Characteristics of game design evaluation

Nineteen characteristics that are inspired by Prensky (2007), Adams (2014), Schell (2008) and Arnab et al. (2015) are distinguished to evaluate these eight games. For this evaluation the published papers, additional documents and corresponding websites are used. It has been analyzed whether these characteristics are present and to what extent they are applied. These characteristics are mentioned in Table 4. The characteristics are clustered into five topics. The first topic is identification. A game is introduced by mentioning four general characteristics: (1) the year the game was released, (2) the research group/owner, (3) the purpose of the game (research, education or entertainment) and (4) the profile of the players. The second topic is Gameplay. The game itself is described by mentioning (5) the description of the game type, (6) quality of the storyline, (7) the levels and progression (chronologic stages in difficulty) and (8) the representation of game characters. The third topic is Game Design. The presentation of the game and features are discussed by describing (9) the world (real-life and/or in-game) where missions are accomplished, (10) the quantity of missions, (11) the possibility to personalize, (12) feedback and rewards, (13) competition (high scores by oneself and/or competing against other players), (14) the quality of the graphic design, (15) real-world effect (effect of behavior in the real-world on progression in the game), (16) monitoring the electricity meter and (17) the duration of the game. The fourth topic is (18) the Technical Architecture that explains the technical design of the system. The fifth and final topic is Measurements. In this topic the kind of measurements that are used (19) is mentioned.

Table 4. Overview eight energy games.

Topic	**Game** / **Characteristic**	1 The Power House (Bang et al., 2006)	2 Power Agent (Bang et al., 2007; Gustafsson et al., 2009b)	3 EcoIsland (Kimura & Nakajima, 2011)	4 Power Explorer (Bang et al., 2009; Gustafsson et al., 2009a)
Identification	1. Year	2006	2007	2008	2008
	2. Research group / Owner	Bang et al.	Bang et al.	Kimura et al.	Bang et al.
	3. Purpose	Research	Research	Research	Research
	4. Player's profile	Teenagers	Teenagers in households	Households incl. teenagers	Teenagers in households
Gameplay	5. Game type	Simulation & Role-playing	Adventure & Role-playing	FarmVille like	Multiplayer
	6. Storyline*	+	+	--	+
	7. Levels & Progress*	+	+	--	++
	8. Game Characters *	+	+	+	+
Game Design	9. Mission world	In-game	Real-life	Real-life	Real-life
	10. Mission quantity	?	7	?	2 duels
	11. Personalization	No	No	Yes	No
	12. Feedback and Rewards**	Combi.	Combi.	Combi.	Combi.
	13. Competition (Oneself / Other)	O/O	O/O	O/O	O/O
	14. Graphic Design*	-	+	-	++
	15. Real-world effect*	--	++	++	++
	16. Monitoring energy meter	No	Yes	Yes	Yes
	17. Duration	1 Session	1W	3W	1W

Table 4. Overview eight energy games. *Continued*

Topic	Game / Characteristic	1 The Power House (Bang et al., 2006)	2 Power Agent (Bang et al., 2007; Gustafsson et al., 2009b)	3 EcoIsland (Kimura & Nakajima, 2011)	4 Power Explorer (Bang et al., 2009; Gustafsson et al., 2009a)
18. Technical Architecture*		-	++	+	++
Measurements	19. Measurements:				
	- Knowledge	?	Yes	No	Yes
	- Attitude	Yes	Yes	Yes	Yes
	- Energy usage	No	Yes	Yes	Yes
	- Engagement	Yes	Yes	No	Yes
Topic	**Game / Characteristic**	5 Agents Against Power Waste (Svahn, 2014)	6 EnergyLife (Gamberini, et al., 2011, 2012)	7 Power House (Reeves et al., 2012, 2013)	8 Energy Chickens (Orland, et al., 2014)
Identification	1. Year	2010	2011	2011	2014
	2. Research group / Owner	Svahn, M.	Gamberine et al.	Reeves et al.	Orlanda et al.
	3. Purpose	Research	Research	Research	Research
	4. Player's profile	Households incl. teenagers	Adults in households	Adults in households	Office workers
Gameplay	5. Game type	Adventure & Role-playing	Eco-feedback	Multiplayer	FarmVille like
	6. Storyline*	+	--	+	--
	7. Levels & Progress*	?	++	+	-
	8. Game Characters *	--	--	+	+

Table 4. Overview eight energy games. *Continued*

Topic	Game / Characteristic	5 Agents Against Power Waste (Svahn, 2014)	6 EnergyLife (Gamberini, et al., 2011, 2012)	7 Power House (Reeves et al., 2012, 2013)	8 Energy Chickens (Orland, et al., 2014)
Game Design	9. Mission world	Real-life	Real-life	In-game & Real-life	Real-life
	10. Mission quantity	?	?	10 sessions	?
	11. Personalization	No	Yes	No	No
	12. Feedback and Rewards**	?	Combi.	Combi.	Combi.
	13. Competition (Oneself / Other)	O/O	O/O	O/O	O/O
	14. Graphic Design*	-	+	++	+
	15. Real-world effect*	++	++	-	++
	16. Monitoring energy meter	Yes	Yes	Yes	Yes
	17. Duration	4W	16W	2,5W	27W
18. Technical Architecture*		++	++	++	++
Measurements	19. Measurements:				
	- Knowledge	Yes	Yes	Yes	Yes
	- Attitude	Yes	Yes	?	Yes
	- Energy usage	Yes	Yes	Yes	Yes
	- Engagement	Yes	Yes	?	Yes

* --/-/+/++

** Points, Badges/Achievements, Energy use/savings or a Combination (Combi.)

Table 5. Meeting the goals game design.

Game / **Goal**	1 The Power House (Bang et al., 2006)	2 Power Agent (Bang et al., 2007; Gustafsson et al., 2009b)	3 EcoIsland (Kimura & Nakajima, 2011)	4 Power Explorer (Bang et al., 2009; Gustafsson et al., 2009a)
1. Awareness Sustainable Energy Use at Home	+	+	+	+
2. Information Transfer Energy Consumption	+	+	+	+
3. Influencing Energy Consumption at Home	+	+	+	+
4. Integrating Real-Life Behavior	-	+	+	+
5. Playing a Longer Period	-	+	+	+
6. Compelling and Complex Storyline	-	-	-	-
% Attained	50%	83%	83%	83%
Game / **Goal**	5 Agents Against Power Waste (Svahn, 2014)	6 EnergyLife (Gamberini, et al., 2011, 2012)	7 Power House (Reeves et al., 2012, 2013)	8 Energy Chickens (Orland, et al., 2014)
1. Awareness Sustainable Energy Use at Home	+	+	+	-
2. Information Transfer Energy Consumption	+	+	+	+
3. Influencing Energy Consumption at Home	+	+	+	+
4. Integrating Real-Life Behavior	+	+	+	+
5. Playing a Longer Period	+	+	+	+
6. Compelling and Complex Storyline	-	-	-	-
% Attained	83%	83%	83%	67%

3.1.4 Meeting the goals

First, it is indicated to what extent the analyzed games have met the goals that are presented in Table 2, the outcome of this calculation is a percentage of the goals that are met. As presented in Table 5, most goals are incorporated in the games (based on the high scores). Only the game *The Power House* meets the relatively low fifty percent of goals. We conclude that most games have similarities with the game design goals that we want to achieve with our game. The first goal is to make players aware of sustainability issues concerning energy use at home. To some degree almost all analyzed games, except *Energy Chickens*, do this. The game *EcoIsland* also focuses on energy use out of home. *Energy Chickens* is played in a work environment instead of a home, but it is very likely that these players will also be more aware of energy use at home. The second goal is the transfer of information about energy consumption so that players acquire more knowledge. All analyzed games do this. The third goal is that players will be influenced by the game to change their behavior concerning energy consumption in real-life. All analyzed games do this. This effect seems to be more likely when the electricity meter is part of the technical architecture. Because of this, the game *The Power House* will only have indirect influence, as the energy usage is not measured. The game *The Power House* does not meet the fourth goal because the electricity meter is not connected to the game, and does not meet the fifth goal that the game is played over a long period of time and has several sessions. The sixth goal is to have a compelling and complex storyline. Six games have a storyline, but unfortunately it is in all cases a very simple one. None of the games has strong storylines. Storylines appear to be an aspect that needs to be considered and implemented in our game.

3.1.5 Evaluation of the implementation of game characteristics

The eight games that are selected have been analyzed and compared to each other by means of these nineteen characteristics. An overview of the results of this analysis is presented in Table 4. In the order of the five topics, the a-priori best implementations of characteristics and what is overall lacking are discussed. At the same time suggestions for the design of our game are made.

Topic 1. Identification Characteristics Year (Characteristic 1), Research group/Owner (Characteristic 2) and Purpose (Characteristic 3) are not discussed because they are only used to identify games. It is interesting to look closer at Player's profile (Characteristic 4). In six games the game is played in family households, which include teenagers. There are good arguments to use family households as a study population. Family members all consume energy that can only be measured from an electricity meter, so it is reasonable and preferable that the whole family is involved in playing.

Topic 2. Gameplay Six different game types (Characteristic 5) are mentioned. One game is a Simulation & Role-playing game, two games are Adventure & Role-playing games, two games are FarmVille like games and two games are Multiplayer games. *EnergyLife* is the only Eco-feedback game. Implementing simulations can help players to prepare for real-life missions. Role-playing can engage players more and adventure elements can be used for the storyline. Altogether, the games mainly focus on providing feedback on energy consumption. There are no games with a compelling and complex storyline (Characteristic 6). In general, the games are not story-focused and miss opportunities to enhance gameplay (Schell, 2008). The games *Power Explorer* and *EnergyLife* have the best level and progression structure (Characteristic 7). The strength of the game *Power Explorer* is the combination of normal gameplay and duels. *EnergyLife* has three levels with different activities. None of the games has levels that become more difficult during playing, and no game has the alignment of a compelling storyline and difficulty in playing. For our game it is preferable that a storyline will be implemented and missions become more complex when progression in the game is made. In six games, game characters (Characteristic 8) are used in the design. In the games *The Power House*, *EcoIsland* and *Powerhouse* the characters are family members that have some similarities with the characteristics of the players. Only in *EcoIsland* it is possible to "personalize" the player's avatar. This feature should be implemented in the design of our game because it establishes a stronger connection between the game and reality (Schell, 2008).

Topic 3. Game Design Seven games have real-life (Characteristic 9) energy-saving missions. The game *Power House* has a strong combination by using both real-life and in-game missions. It is preferable that in the design of our game missions have to be carried out in real-life. Using in-game missions to prepare players for real-life missions is an option that should be considered. From five games no information about the quantity of missions (Characteristic 10) is available. The game *Power House* has, with ten missions, the most. In the games *EcoIsland* and *EnergyLife* personalization (Characteristic 11) is to some extent possible. In *EcoIsland* the avatars can be personalized, and in *EnergyLife* a player can add two electrical devices to the five that are standard monitored. The personalization of avatars and the addition of electrical appliances in the game are preferable, because it can have a positive influence on the involvement of the players. Seven of the eight games provide extensive feedback (Characteristic 12) by means of points, badges/achievements and overviews of energy used or saved. All items should be implemented in our game design. In all games players compete (Characteristic 13) against themselves and others. Both should be implemented in our game. Two games have high quality graphics (Characteristic 14). The game *Power House* has the best graphics and can be

used as an example for the development of the game for this research project. In six games the player's behavior in the real-world has a very strong effect on the game (Characteristic 15). In our game it should be strong because real-life missions will be implemented. In seven games the energy consumption is monitored (Characteristic 16). This should be implemented in our game. Information that is obtained from continuously monitoring the energy consumption can be used to make progression in the gameplay. In the games *EnergyLife* and *Energy Chickens* electrical devices are monitored separately. This could be considered for implementation in our game if more specific feedback from individual appliances has to be provided. The duration of the games (Characteristic 17) varies between one session to twenty-seven weeks. Three games are played for a month or more. Because this research focuses on the long-term effects on behavior and attitude, right after playing the game, it is plausible that the duration of our game should be extensive.

Topic 4. Technical Architecture (Characteristic 18) In six games the Technical Architecture is very advanced. The energy consumption is monitored and sometimes directly used in the game. For the game design in this project, it is preferable that a real time connection between the household smart energy meter and game server is accomplished by (1) using a datalogger with an Internet connection that is connected to the smart energy meter in a household that has a Wi-Fi network, or (2) direct from the smart energy meter via a service provider. The data of energy consumption will be sent to a database of a server. The data transfer from a service provider is delayed by a day compared to using a datalogger. It is preferable that the game is basically an Internet page that is uploaded by a device (e.g., tablet) when the player logs in via an Internet browser.

Topic 5. Measurements (Characteristic 19) Knowledge, Attitude and Engagement are measured by means of questionnaires outside the gameplay. These questionnaires should be filled in before and after playing. Knowledge is also often measured with in-game quizzes and engagement can be measured by monitoring player's behavior during playing. These two options should be considered in our game design. Energy usage is measured by monitoring the energy meter. To set a good baseline for giving feedback about average energy consumption during playing, the energy consumption should be monitored before the game starts.

3.1.6 Empirical effect of energy games

The next step is to evaluate the effects each game has on acquired knowledge, attitude towards saving energy, actual energy usage and engagement with respect to continuing playing the game. Insight in these effects can possibly give direction for implementation of design features in our game. Because the reported effects are all positive (see Table 6), all design suggestions described in Section 3.1.5 can possibly be implemented. It is not possible to give exact outcomes of the effects, because in most papers they are not fully reported. For example, there is no information available from the game *The Power House*. However, it is sufficient to draw the following preliminary conclusions: (1) all reported effects are positive, (2) the game designs can be improved because not all topics are fully/optimal implemented and (3) not all goals are met. We expect that behavior change can sufficiently be improved, certainly when all topics and goals are met in our game design.

3.1.7 Effective features of energy games

Features in energy games considered effective by authors include competition, collaboration, gameplay and feedback (see Table 7). Competition and collaboration are important features to stimulate energy conservation, because they both influence interaction between players and performance-awareness. In general, authors mention it is important that gameplay is user friendly and directly related to energy conservation measures in the real-world, and that feedback(-loops) are based on real time energy consumption and energy-saving missions.

Table 6. Reported effects of energy games.

Game / **Empirical Effect**	1 The Power House (Bang et al., 2006)	2 Power Agent (Bang et al., 2007; Gustafsson et al., 2009b)	3 EcoIsland (Kimura & Nakajima, 2011)	4 Power Explorer (Bang et al., 2009; Gustafsson et al., 2009a)
Knowledge	N/A*	Positive	N/A	Positive
Attitude	N/A	Positive	Positive	Positive
Energy usage	N/A	Positive	Positive	Positive
Engagement	N/A	Positive	N/A	Positive
Game / **Empirical Effect**	5 Agents Against Power Waste (Svahn, 2014)	6 EnergyLife (Gamberini, et al., 2011, 2012)	7 Power House (Reeves et al., 2012, 2013)	8 Energy Chickens (Orland, et al., 2014)
Knowledge	Positive	Positive	Positive	Positive
Attitude	Positive	Positive	N/A	Positive
Energy usage	Positive	Positive	Positive	Positive
Engagement	Positive	Positive	N/A	Positive

* Not Available

Table 7. Effective game features.

Game	1 The Power House (Bang et al., 2006)	2 Power Agent (Bang et al., 2007; Gustafsson et al., 2009b)	3 EcoIsland (Kimura & Nakajima, 2011)	4 Power Explorer (Bang et al., 2009; Gustafsson et al., 2009a)
Effective Features				
1. Competition		Competition	Competition	
2. Collaboration		Social demand and peer pressure between team and player.	Cooperation	Social component in the household
3. Gameplay	Timing (info. just before a task), Conditioning (info. through points) and Praise	Simulation and enact in the real-world.		Small investments by players
4. Feedback			Positive and Negative feedback	Real time feedbackloop: fast and frequent rewards
Game	5 Agents Against Power Waste (Svahn, 2014)	6 EnergyLife (Gamberini, et al., 2011, 2012)	7 Power House (Reeves et al., 2012, 2013)	8 Energy Chickens (Orland, et al., 2014)
Effective Features				
1. Competition		Competition		
2. Collaboration	Parents and children play together		Teamplay	
3. Gameplay		Progression of challenges and learning, Simple interfaces & Match knowledge and actions	Frequently changing episodes	User Friendly
4. Feedback		Contextualized feedback & Customized saving tips	Rewards & Achievements	Feedback

3.1.8 Recent energy game

As mentioned in the introduction of Section 3.1, the analysis in this chapter was done in 2015 to develop *Powersaver Game*. Since then, other groups worked on projects that have similarities with our project. Such as EU-funded projects that demonstrated efficient, cost-effective and socially acceptable technology solutions that motivate consumers to engage in basic energy-saving behaviors (European Commission, 2022). In most projects, applications are developed that provide information, instruction and feedback about energy consumption. However, no or only basic game features have been implemented, such as points and badges. Although there are similarities between our project and other projects, only one project since our analysis in 2015, the EU funded project EnerGAware (Casals, et al., 2020), meets the same requirements of the game design (see Table 2) as our game (*Powersaver Game*). The project targeted reducing the energy consumption of low-income households through the game '*EnergyCat*'. In a pretest- posttest design, an empirical study tested whether change in attitude, knowledge and behavior with respect to energy conservation the household was different for participants playing *EnergyCat* to a control condition. In this study 82 UK social housing households have been involved for 12 months. The gameplay is based on 'The Sims' simulation video game. In the game, participants build a virtual house, and a game character, a cat, provides tips, information and missions about effective energy consumption (see Figure 6).

Figure 6. EnergyCat.

Results indicated that the intervention did not lead to changes in awareness and behavior concerning energy conservation. Although they have applied our thoughtful user-centered game design methodology (see Chapter 4), there are issues in game design and usability that might explain why the game failed to change behavior. These include game complexity, difficulty in seeing the display features, and a lack of clear instructions and gameplay objectives. These problems could have been foreseen because social housing residents, which was the target audience, have not been involved in the design process. This is a key flaw in this research.

3.2 Taxonomy of gamification approaches

Gamification by incorporation of game features can be a valuable strategy for making non-game products, services, or applications, more motivating, and/or engaging to the user (Deterding et al., 2011). From this broad view, we have formulated a taxonomy of five approaches of gamification related to digital applications based on main characteristics and game features. This taxonomy of approaches gives more differentiation, depth and scientific relevance to the diverse appearances of gamification. As presented in Table 8, the first is the simplest form where a playful persuasive element in a creative design stimulates simple behavior (Tieben et al., 2014). In the second approach, Feedback systems, actual behavior is measured and results are presented to the user (Mueller et al., 2008). In the third approach, Learning systems, a learning loop is created when first instructions for certain behavior are given after which later feedback is presented (Tuah et al., 2021). From this approach on, applications are considered to belong to Digital Game Based Learning (All et al., 2015, 2021). The fourth approach consists of complex standalone serious (simulations) games with several, more complex, game mechanics (e.g., storylines and competition) included (Djaouti et al., 2011). The fifth approach, Reality-enhanced games, is explained below.

Table 8. Taxonomy of gamification approaches.

Approach	Main characteristic and game features	Example
Playful persuasive element (Tieben et al., 2014)	Stimulate behavior by creative design	Piano stairs to encourage to take the staircase
Feedback systems (Mueller et al., 2008)	Playful feedback	Pedometer to increase physical activity
Learning systems (Tuah et al., 2021)	Learning loop by means of playful instruction and feedback	Mental health apps
Serious (simulations) games (Djaouti et al., 2011)	Standalone game	Military simulations
Reality-enhanced games (Fijnheer et al., 2019; Massoud, et al., 2018)	Gameplay are real-world processes	Household energy conservation

3.2.1 Reality-enhanced games, a novel gamification process

An important aspect of serious (simulations) games is that users normally gain implicit knowledge (improved performance during the game), but this gain does not always translate into a gain in explicit knowledge (e.g., improved performance on knowledge tasks after the game or transfer tasks) (Leemkuil & De Jong, 2012). This problem is mitigated by the last approach of gamification, namely 'Reality-enhanced games' (see Table 8). The aim of this approach is to stimulate the transfer of information between the game world and the real-world. When the transfer is optimized, the game is expected to be more effective in the change of attitude and behavior (Kors et al., 2015). In this approach user's real-world activities, such as household energy saving activities (e.g., washing clothes on low temperatures), are integrated into a digital serious game or gamified application (see Section 1.2). Players are immersed in real-life situations that are generated by user interaction with a virtual environment (Fijnheer et al., 2019; Massoud, et al., 2018). While it has been technically possible to implement real-world processes in a game design for more than a decade, it is still an emerging principle in gamification research. Especially when it comes to the energy conservation of households.

3.3 Approach of comparison study and value-added study

Empirical studies in game research have a particular approach. As explained in Chapter 1 and Chapter 2, in this study two categories, described by Mayer (2014), have been chosen. First, a media comparison approach, which investigates whether people learn better from serious games than from conventional media. Meta-analyses with a media comparison approach reveal that serious games are more effective than traditional learning methods, however the effect size is only low to moderate (Wouters & Van Oostendorp, 2017). Second, a value-added approach with the underlying question how *specific* game features foster learning and motivation.

The approach in this thesis is to conduct a media comparison study first, focusing on comparing a persuasive game and control condition, both within a computer-based medium. This is a somewhat more advanced approach than that of Mayer (2014), because in his research he compares a digital game versus the same (or similar) content from conventional media, therefore also a different medium, such as books and face-to-face slideshow presentations, is present. Second, to conduct a value-added study, focusing on the features personal relevance by means of personalized avatars and social interaction by means of competition. In both studies the effects on knowledge, attitude and behavior with respect to energy consumption are examined.

For the media comparison study, we decided that based on the context of energy conservation at home, both a game (intervention condition) and an energy dashboard version (control condition) are used as research instruments. The form, timing and content of the information that the control condition receives, are as similar as possible as in the game condition.

For the value-added study, we decided that based on the practical possibilities, e.g., technological architecture, financial support, available capacity of personnel and timespan, to focus on two features. These features should be relatively easy to turn on and off in the same game design. Potential features are mentioned by Mayer (2016) and Wouters and Van Oostendorp (2017). Mayer (2016) identified five game features that substantially improved student performance on a test of learning outcome: (1) Personalization by using a specific conversational style, (2) Modality by presenting words in spoken form, (3) Self-explanation by adding prompts to explain, (4) Coaching by adding explanations or advice, and (5) Pretraining by adding pregame descriptions of key components. Also, Mayer (2016) recommends that more research is needed to six game additional features: (6) Competition by adding competitive features based on ongoing game score, (7) Learner control by allowing learners to control the order of game activities, (8) Choice by allowing learners to choose the game format, (9) Narrative theme adding an engaging story line, (10) Image by including a static image of game characters on the screen, and (11) Segmenting by breaking the screen into parts. Wouters and Van Oostendorp (2017) mention twelve features. They do not use the term feature, but instructional techniques instead. These are: (1) Adaptivity of game tasks, (2) Advice to give support for continuation, (3) Collaboration in groups, (4) Content Integration in the game, (5) Context Integration of game, e.g., game combined with class discussion, (6) Feedback loops that are corrective and/or explanatory, (7) Interactivity in making choices, (8) Level of Realism of both audio and visual, (9) Modeling to give explanation or instruction, (10) Narrative elements which provide a cognitive framework ('scaffold'), (11) Personalization for players and (12) Reflection to think about the answers and outcomes. All mentioned features are considered in the game design, but for some it was not possible to implement because of the specific game context. The two features that have been chosen for this study are personalization of avatars and competition. Both features are relatively easy to implement in a game design. Personalization is mentioned by Mayer (2016) and Wouters and Van Oostendorp (2017), and competition, mentioned by Mayer (2016), has a strong connection with collaboration which is mentioned by Wouters and Van Oostendorp (2017).

3.3.1 Game feature personalization of avatars

Personalization is a concept applicable to several game features, such as tasks, narrative, sounds, etc., for the purpose of tailoring the game experience to the individual player, which is beneficial in several gaming domains such as serious games (Bakkes et al., 2012). Personalized avatars in games provide users the possibility of self-presentation and identity expression, by allowing users to manipulate, control and embody a digital self-representation of the self. With customizable options available in the avatar creation interface, users can alter various characteristics, including body components, facial features, outfits etc., to create an online self-representation. An avatar is defined as a representation of the self that serves as a visual embodiment of the user within the game, and individuals tend to create their avatars as their self to identify themselves with. This motivates users to take care in creating and using their own avatar. In general, studies about self-representation in games report positive effects in engagement and, as a consequence, positive effects for information transfer (Kang & Kim, 2020). A study of Ahn et al. (2016) reports that avatars can promote a sense of a theme, in this case nature, as a part of people's self-identity, and as a consequence, stimulate involvement with that theme. The avatar promotes a feeling of interconnectedness between the theme and the self. This may also be applicable in the case of household energy conservation.

Roughly there are two possibilities to personalize avatars. First, the avatar is a pre-created digital representation of the user. Or second, the avatar can be created dynamically and personalized by the user. Pre-created avatars can serve as a strong model for players. This is demonstrated in a set of experiments on exercising and eating behavior. The results of this study indicate that personalized avatars that are pre-created, improve engagement of people participating in health behavior changes (Fox & Bailenson, 2009). When players can create and personalize avatars themselves, they will often make their avatar visually resembling and add more positive features to it (Vasalou et al., 2008). This has positive effects for immersion and interactivity compared to those who have pre-created avatars (Jin, 2009).

3.3.2 Game feature competition

When discussing competition, it is relevant to also discuss the feature collaboration. The game features competition and collaboration are closely related because they are both influential in creating interaction between players (Cagiltay et al., 2015) and on performance-awareness (Sanchez, 2017), and as a result, both have positive effects on motivation, attitudes and behavior (Burguillo, 2010; Chen et al., 2020; Sanchez, 2017). However, research provides limited explanation of how exactly these features influence learning, and there are few guidelines for game designers (Sanchez, 2017). Although in many DGBL studies no difference was found between competition and cooperation in terms of learning achievement (Ke & Grabowski, 2007; Plass, et al., 2013), Ter Vrugte et al. (2015) found that for low achieving students the effectiveness of collaboration was negatively affected by competition. On the other hand, Chen et al. (2018) suggest that effectiveness of collaboration within groups will increase when groups are in competition because players are working toward a common goal. Some studies found differences in motivation in the short and long term and by the complexity of tasks that have to be performed. Dindar et al. (2020) and Katz-Navon and Erez (2005) both suggest that in a DGBL-setting collaboration invokes higher task effort in long-lasting learning activities compared with competition, and Chen (2019) reports that collaboration increases reflective thinking and effective problem-solving. Therefore, collaboration seems to be an effective feature for higher and complex learning tasks that takes a longer time period to carry out. Also, Marker and Staiano (2015) report a similar difference between both features. They found that the competition feature in a fitness game typically stimulates motivation and behavior in a short time period, such as in a game session, while the collaboration feature stimulates motivation for a longer period, such as continuing playing several game sessions over time.

Collaboration

Collaboration in DGBL involves problem-solving and constructing knowledge together as a team. This takes mutual engagement and coordinated efforts (Sanchez, 2017; Van Der Meij et al., 2011). Participants extend their knowledge and have to make it explicit to others. This makes interaction in a collaborative setting highly engaging (Ter Vrugte & De Jong, 2017). Its effectiveness depends on the quality of dialogues in acquiring knowledge from each other by questioning, answering, and discussing (Sanchez, 2017; Van Der Meij et al., 2011). These discussions about conflicting information lead to opportunities for reflection on the offered content and present knowledge (Chen & Law, 2016), and thus stimulate information exchange and constructive communication (Dindar et al., 2020). To be more specific: When asking questions, participants outline what they know and/or identify what they need to know, which helps to become aware of their knowledge and to generate knowledge. In this way both learning processes and outcomes benefit from collaboration (Ter Vrugte & De Jong, 2017) and, through these social interactions, also positive motivational experiences are facilitated and feelings of relatedness generated (Rigby & Ryan, 2011). Furthermore, when team members face emotional challenges such as frustration or demotivation, collaboration stimulates mutual cognitive, motivational and emotional support (Dindar et al., 2020; Hadwin et al., 2017).

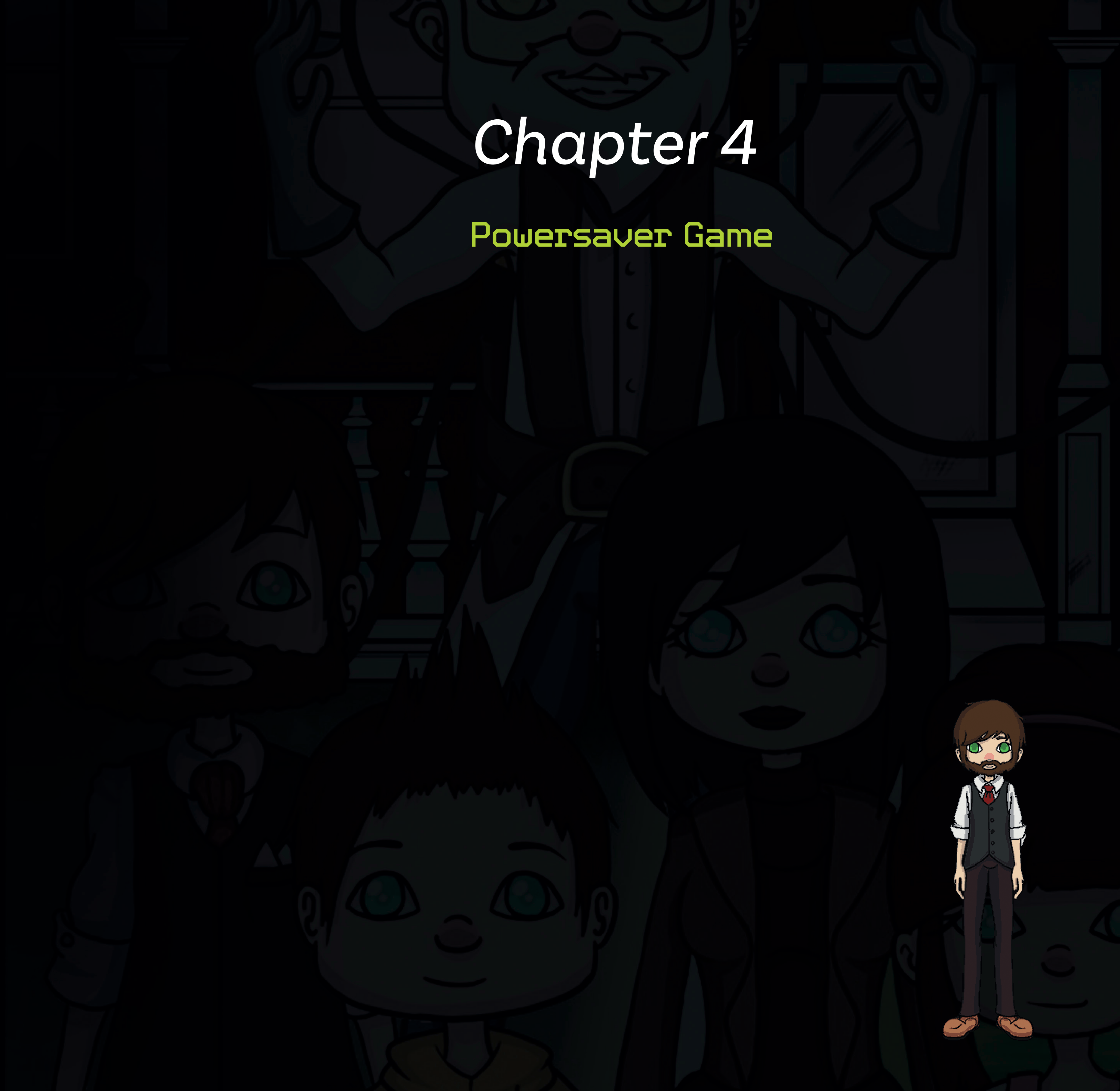
Competition

Competition is a rudimentary gaming element (Salen & Zimmerman, 2004) that stimulates goal orientation with respect to competitors (Cagiltay et al., 2015). Therefore clearly-defined goals, fair rules and social comparison opportunities enhance motivation (Dindar et al., 2020; Sanchez, 2017; Van Der Cruysse et al., 2013) and as a consequence stimulate learning (Cagiltay et al., 2015; Chen et al., 2020). Competition also positively influences excitement, perceived challenge, effort, efficacy, game frequency and enhances collaboration within teams (Cagiltay et al., 2015; Chen et al., 2020; Sanchez, 2017). Competition seems to be similarly beneficial for different types of users (Orji et al., 2018), however excessive competitive activities may cause negative influences on learning such as anxiety, damage of relationships, impeding performance on tasks, diminishing empowerment and irresponsibility for learning (Kohn, 1992). Although most authors report positive effects of competition, there is ambiguity on how competition influences the learning outcomes (Cagiltay et al., 2015; Chen et al., 2020; Sanchez, 2017). Chen et al. (2020) stated that competition is effective in well-structured domains like math, language learning, and science. But it is still unclear what its effectiveness is in less-structured domains such as social sciences. Chen et al. (2020) also found different effects of competition in different DGBL game types. Effects of competition in DGBL are significant for Role-playing games, Simulation, Puzzle and Strategy games, but not for Action games.

Van Der Cruysse et al. (2013) describe three approaches of competition in DGBL. The first is individual and team-based competition approach. In the individual competition approach, each individual is an autonomous player, and in the team-based competition approach, teams of players compete. Chen (2019) found that the team-based competition approach is more effective in learning outcomes and problem-solving, and there is less anxiety than in individual competition approaches. Furthermore, Van Der Cruysse et al. (2013) found that team-based competitive approaches are especially effective in making instructional materials more enjoyable and engaging. The second approach of competition is anonymity of opponent(s). Players do not know their opponents. Cagiltay et al. (2015) found that competition approaches that allowed players to see each other's scores, ranking and name (identity) enhanced learning and motivation. The third and last approach of competition involves reality-based versus computer-based opponents. While real opponents can be more motivating, computer-based competition mitigates several disadvantages of real competition (Chen & Chang, 2020). Kristan et al. (2020) recommend computer-based competition in which difficulty and chance of failure are adapted to the individual user. Adaptation provides the user with the right amount of challenge to maximize motivation and as a consequence stimulates learning. Chen and Chang (2020) report a significantly better learning performance and time effort with virtual competition. Van Der Cruysse et al. (2013) conclude that the effectiveness of the three approaches of competition depends on the context where the game is applied, since competition functions differently (e.g., in learning outcomes, behavior and motivation) in different situations (e.g., type of game and opponent (oneself, other(s) or computer)).

Chapter 4

Powersaver Game



4. Powersaver Game

Based on the comparative review that has been described in Chapter 3, the new game *Powersaver Game* focused on reducing energy consumption, which is the instrument of research, has been designed and its prototype is described in this chapter. In Section 4.1 the 'steps to design household energy game' is presented. Special attention is paid to the user-centered design process and iterations of the development. In Section 4.2 the construction of the first prototype of *Powersaver Game* is discussed. In Section 4.3 the design of *Powersaver Dashboard*, which involves the design of the control condition, is presented. All energy conservation activities that both applications (game and dashboard) provide (e.g., washing clothes on low temperatures) take place in the real-world and feedback is based on real-time energy consumption. This real-data into the game approach, so-called 'reality-enhanced game approach', aims to stimulate the transfer between the game world and the real-world (Fijnheer et al., 2019; Massoud, et al., 2018).

After designing the new prototype game *Powersaver Game*, Section 4.4 presents the next stage of iterative design, where potential players first evaluated the match between in-game scenes and household energy-saving activities. Since the aim is an effective transfer between the game world and real-world, gamification elements from the real-world are introduced, by energy-saving activities, in the game. In Section 4.5 the second evaluation is presented, where another group of potential players reviews design features of the prototype *Powersaver Game*. The outcomes of these evaluation studies contribute to effectively embedding real-world elements in the game and to improving aspects of the prototype in clarity and attractiveness. In Section 4.6 the final improvements in the prototype game are discussed. Ultimately, this thoughtful user-centered design process, by involving potential players, makes it possible to build a serious game, *Powersaver Game*, that is potentially effective in reducing household energy consumption.

4.1 Design steps

As presented in Figure 7, several design steps are taken to design *Powersaver Game*. Our approach has an iterative character because the prototype design is adjusted several times before a final design can be used for experiments. In the first part of step 1 the design of a game prototype is established by analyzing the designs of existing games that have a similar purpose and met the design goals or demands that are formulated. Also, the empirical effects of these games are reviewed. For this reason, we used the term *thoughtful* game design. Both review of design and review of empirical effects of energy games are already discussed in Section 3.1.

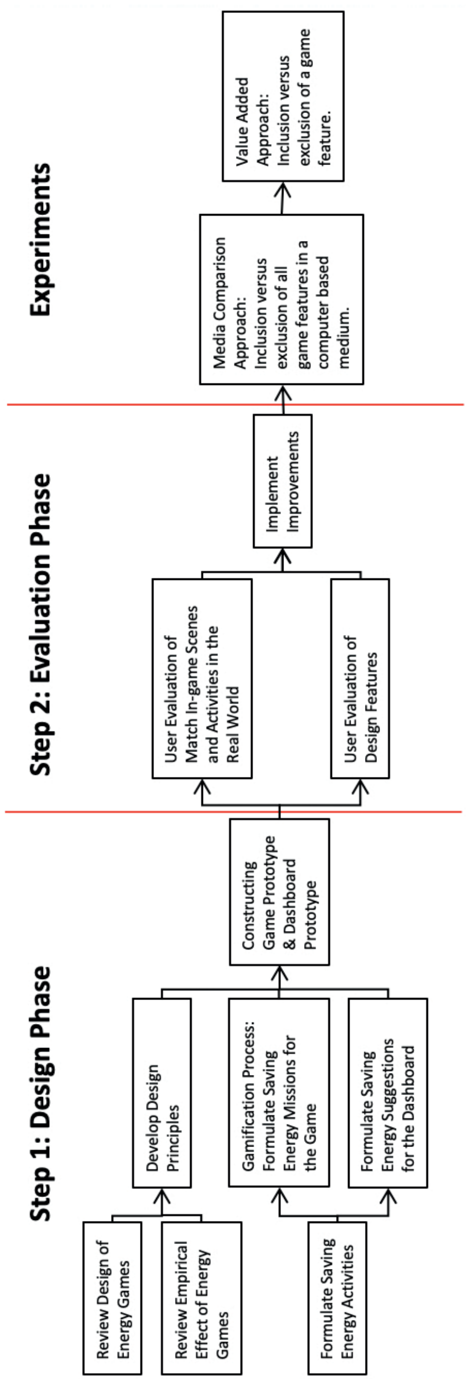


Figure 7. Steps to design a household energy game.

In the second part of step 1 energy saving activities are formulated and are incorporated in the game design by a novel gamification process where activities are transformed in missions. To complete step 1 a game prototype is constructed by combining design principles and energy saving missions.

In step 2 potential players evaluate the prototype. It is generally recommended that potential users of the game be involved in the development process (Benyon, 2010). In the first part of step 2 the match between in-game scenes and activities in the real-world is evaluated. Improvements will optimize the transfer between the game world and the real-world. In the second part of step 2 design features of the complete system are evaluated. Improvements will contribute to clarity and attractiveness of *Powersaver Game*. The assumption is that when the analysis (Step 1) is done properly and potential users are involved in the design process (Step 2), then this thoughtful user-centered game design will lead to a high-quality game that is effective in reducing household energy consumption.

4.2 Constructing game prototype

From Section 3.1, where the review of design and empirical effect of energy games are reported, the first part of step 1 in Figure 7 the following recommendations on design features to be implemented in the design of *Powersaver Game* are derived. Players should be all members of a household and play together. The game should have a compelling storyline and players have to accomplish real-life missions that are provided by the game. Knowledge should be provided by questions in in-game quizzes. Missions should become more difficult over time and have a connection with the development of the storyline. The duration of a mission should depend on its intensiveness and will vary between one to three days. Depending on the quantity of missions the game should take at least more than a month to play, because we want to look at the long-term effects. For that reason, it is assumed that the game should take a considerable length of time. In our perspective, long-term interventions have a duration about a week and longer, and long-term effects are measured in the weeks after the intervention. The game characters/avatars should have similarities with the players (by personalization). The world/setting of the game should have similarities with a household. Therefore, specific devices of households should be present in the game world. Feedback should be provided by means of earned points, badges/achievements and overviews of energy used and saved. Players should be stimulated to achieve high scores and should be in competition with other households. The game should provide readings from the electricity meter and/or if technically possible readings from household appliances.

In Section 3.1.5 (see Table 4) household energy games have been evaluated based on nineteen characteristics that are clustered into these five topics: (1) Identification, (2) Gameplay, (3) Game Design, (4) Technical Architecture and (5) Measurements. In order of these topics and characteristics the design of the prototype of *Powersaver Game* is described. The game has a storyline where avatars of the actual players face appliances in a bad situation in different rooms of a country house. By doing real-life energy saving activities in a household corresponding to the in-game appliances the players make progression. All members of a household are involved playing this game for almost eight weeks at home. Every two days energy saving activities will be provided by the game and have to be carried out in real-life. Results in energy savings that is provided by a datalogger connected to the smart energy meter are presented as feedback in the game.

Topic 1. Identification The game will be played in a household whereby in principle the whole family is involved (Characteristic 4. Player's profile).

Topic 2. Gameplay An impression of *Powersaver Game* can be seen at **https://youtube/0ukM9Q0MS98**. It is an Eco-feedback, Multiplayer, Roleplaying and Point & Click Adventure game (Characteristic 5. Game type). The game starts with an introduction of the story (Characteristic 6. Storyline). A family arrives at a dilapidated country house where something terrible has happened. The house used to be a peaceful place but that has changed dramatically caused by a failed experiment of a professor. The family enters the main hall of the house that contains several doors (see Figure 8). Behind each door a room is situated where a game character in the form of a confused electrical device is placed. In the game 8 different scenes occur, each triggering a mission that had to do with specific energy saving activities such as efficient use of lighting and chargers. An overview of scenes and mission goals is presented in Table 9. A ferret (former pet of the professor) called Kyoto guides the family in the game. Every week the family is asked to enter a preselected room. Before the door opens a quiz has to be played. A quiz contains questions that will transfer knowledge about saving energy as well as prepare players for the missions that are occurring in that specific room. When the family enters the room a character in the form of a device that is in a confused state is shown (see Figure 9 left). The family has to accomplish two missions to help the device character to get in a normal state (see Figure 9 right). During the game the missions are getting more difficult (Characteristic 7. Levels & Progress). The principle is that each new mission will take more effort to do than the previous one. Avatars of the family members are the central characters of the game (Characteristic 8. Game Characters) (see Figure 10).

Table 9. Scenes and mission goals.

Scenes	Mission goals
1. The ferret is captured in the wires of angry laps in the living room.	Efficient use of lighting and chargers
2. A stressed computer in the study room.	Efficient use of computer devices
3. An overheated central heater in the bathroom.	Efficient use of heating and hot water
4. A sick plant in the bedroom.	Efficient use of daylight and fresh air
5. An exhausted television in the television room.	Efficient use of the television
6. A sweating clothing dryer and washing machine with foam in the mouth in the washing room.	Efficient washing of clothing
7. A freezer with flu and a refrigerator with a cold in the scullery.	Efficient cooling
8. A wild blowing kitchen hood, overflowing dishwasher and fire-breathing oven in the kitchen.	Efficient cooking

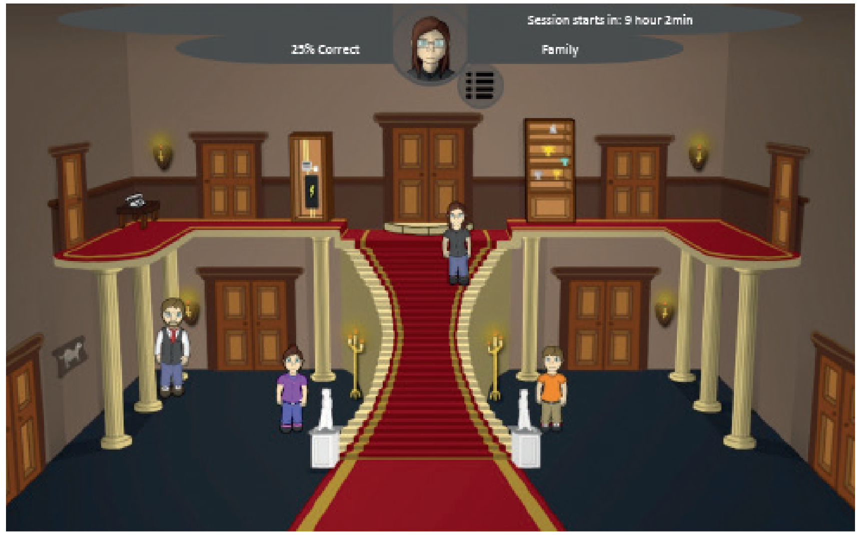


Figure 8. The main hall.

Figure 9. Scenes living room: bad state (on the left) and normal state (on the right).

Figure 10. Avatars.

Topic 3. Game Design As outlined earlier, in total there are eight scenes in eight rooms of the professor's house. There are fifty energy saving activities that are incorporated in thirteen missions distributed over the eight scenes (see Table 9). All missions (e.g., washing clothes on low temperatures) take place in the real-world (Characteristic 9. Mission world). It will take two to three days to complete a mission. The missions are developed by the analysis of general energy saving measures. As mentioned in Topic 2 to improve the situation of the electrical appliance(s) in the scenes, multiple energy saving activities have to be carried out. Another example is presented in Figure 11. The freezer and refrigerator are sick and can only be cured when the following energy saving activities concerning cooling are carried out:

- Turn the temperature of the refrigerator on 6 degrees/number 2 or 3.
- Do not keep products in the refrigerator that can be preserved outside it.
- Turn the temperature of the freezer on minus 18 degrees.
- Clean the rubber seal of the door of the refrigerator and freezer.
- Before you put warm food in the refrigerator let it cool down.
- Let frozen food melt in the refrigerator.
- Place the refrigerator minimal 10 centimeter of the wall.

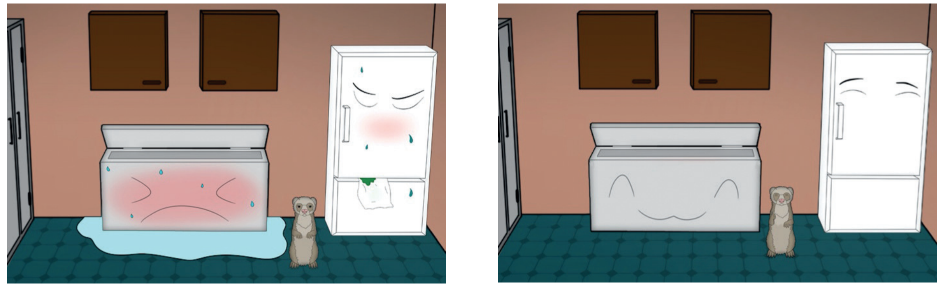


Figure 11. Scenes scullery: bad state (on the left) and normal state (on the right).

In each room there are one or more electrical appliances. In total there are eleven electrical appliances and one plant (see Figure 12). The objects on the left side are in a bad state and the same objects are in a normal state on the right side. To change each object from a bad state to a normal state the player has to carry out energy saving activities that are specific for each object. If there are more objects in one scene the player has to carry out several energy saving missions.

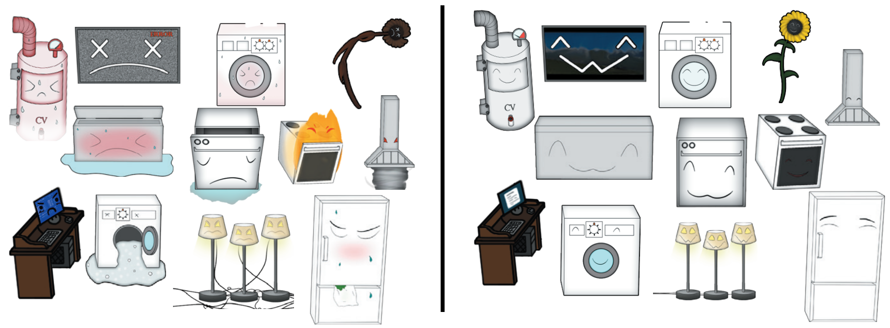


Figure 12. In-game objects: bad state (on the left) and normal state (on the right).

The game has also (eight) quizzes and an end-battle (Characteristic 10. Mission quantity). The family composition in the game is personalized to the household (Characteristic 11. Personalization). All general household devices are incorporated in the game prototype, and it is not possible to add specific devices from the household. The player is getting feedback during playing (Characteristic 12. Feedback and Rewards) (see Figure 13). A mission always ends after two days. In the game prototype the following results/feedback is presented:

- Energy savings
- Overall view of energy use
- Badge of the device character

The energy use and savings are displayed in kWh, m^3 gas and money. Also, the savings per year is provided. A graph is used to give the player an overview of the energy use and a meter is developed to stimulate the energy saving behavior. Players are stimulated to save specific percentages of energy corresponding to a mission. We assume that when missions are carried out the average energy consumption will drop accordingly. The achievement of a completed mission is displayed with a badge of the happy device character corresponding with that mission. The game also contains quizzes, consisting of multiple-choice questions, that prepare players for the missions taking place in each room (see Topic 2. Gameplay). The result of the quizzes, which are presented before a mission starts, is shown when a quiz has ended. The competition (Characteristic 13. Competition) feature is displayed as a simulated leaderboard where through displays of rank, comparisons with other virtual households are presented. A more detailed explanation of the competition feature is discussed in Section 6.4.3. The quality of the graphic design (Characteristic 14. Graphic design) appears to be adequate and the navigation by the player is done by point and click on the screen. The player's behavior in the real-world has a very strong effect on the game (Characteristic 15. Real-world effect), because real-life behavior influences progress by means of completing missions and feedback of real-life energy consumption that is monitored (Characteristic 16. Monitoring energy meter) and presented continuously. The total period of playing the game is seven and a half weeks (Characteristic 17. Duration) where each mission takes two days. In this period all saving activities can be carried out in a regular household.

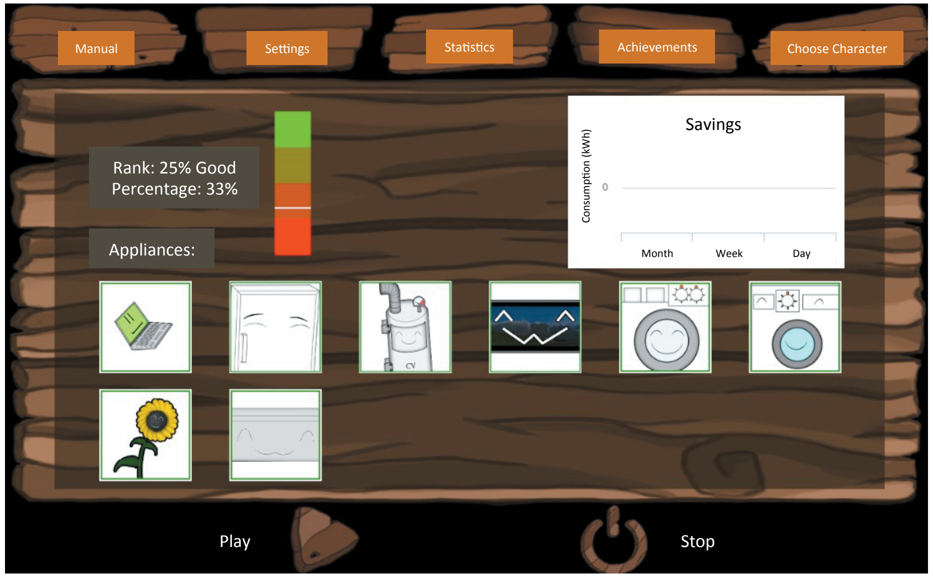


Figure 13. Feedback screen.

Topic 4. Technical Architecture Two overviews of the technical architecture are presented in Figure 14 (Characteristic 18. Technical Architecture). During the project the technical architecture has changed as explained below. *Powersaver Game* is basically an internet page. The browser of the player's device (tablet, pc and/or laptop) communicates with the webserver. The browser loads the game from the server, and, during gameplay, exchanges information with the server. That allows the server to store data such as missions that are completed and started, quiz questions that are answered, current scores, etcetera. Energy data is retrieved from an external server. On the server at the Utrecht University, several times a day is polled if new energy data are available and, if so, it is stored on the server. There are three sources that can change the status of the game. First of all, there are user actions: starting a mission, answering questions or completing a mission. Two, there is the delivery of energy data. This is not initiated by the user but is collected by an independent process. The third type of change happens through the passage of time. After the start of a mission, it takes 24 h before the user can complete the mission. In the meantime, the user is supposed to take action to save on energy.

Since the second intervention, the pilot experiment, as described in Section 6.3, there has been a change in the acquisition of energy data. This used to be done with the help of the smart home automatization company BeNext and currently is done via the service provider EDSN. This organization develops and operates the Dutch energy data hub on behalf of the Dutch transmission and distribution system operators.

There are technical differences between both organizations in the way the acquisition of energy data is done. The smart energy meter that records energy data in a household can be accessed via two interfaces: Port 1 (P1) and Port 4 (P4). The P1 interface of the smart energy meter is a physical connector, to which a device can be connected to record standings. This is the interface that was used in the old setup (Figure 14, old P1 interface above). The datalogger device was developed by BeNext and connected via the internet to the BeNext servers to store energy data. The P4 interface works more indirectly (Figure 14, new P4 interface below). The energy system operator can read out the hourly usage of gas and electricity via the mobile GPRS-network. All energy system operators in The Netherlands send those data to the service provider EDSN, which allows authorized parties like Utrecht University to access it. Of course, a household has to give explicit permission for this. So, both interfaces provide usage information. However, with the P4 interface, the data becomes available once a day. Depending on the energy system operator, the data of the previous day arrive between 7 pm and 2 am. With the P1 interface, it is possible to have a setup such that the data is available almost instantly. For the gameplay, the latter is clearly preferable. The results in *Powersaver Game* are based on energy savings during missions. However, with the P4 interface, it may take more than a day to get access to those data. The drawback of using the P1 port is that there needs to be extra hardware installed in the household. A datalogger device, a cable between the smart energy meter and this device, and some more hardware to connect it to the internet. This datalogger device has to be delivered and installed, and at the end of the game deinstalled and collected. On top of the hardware purchases, unexpected expenses had to be made to support households to install hardware and return it afterward. Furthermore, our aim was to involve more households than in previous studies. The drawbacks of using the P1 port were considered larger than the advantages. So, it has been decided to switch to the P4 port for the last study. This is the value-added study concerning the competition feature. To get swift gameplay, the energy data of a day old is used to compute the score. That means that changes in energy usage influence the score somewhat later than may be expected by the user.

There are several programming languages and libraries used in the system. In the web browser, the main programming language used is Typescript (Version 3.6, Microsoft). Some older parts of the application use JavaScript (ECMAScript 2018, Mozilla). The Phaser.io (Version 2.7, MIT License) game framework is used as a game engine. The server backend uses C# (Version 8.0, Microsoft) as language and ASP.Net (Version 4.6, Microsoft) as the library to communicate with the browser application. There is also a MySQL (Version 5.7, GPL) database on the server to store game data. The communication

with EDSN, the provider of energy data, is done with the help of the Java language and libraries via SOAP. This interface is dictated by EDSN. The communication is secured by means of a certificate. The certification is a formal process, which takes some time and effort. The certificate is signed by KPN, a Dutch telecom provider. KPN verifies the identity of the applicant and verifies that he is the owner of the domain name in the certificate. The certificate is used to encrypt and sign every message to EDSN.

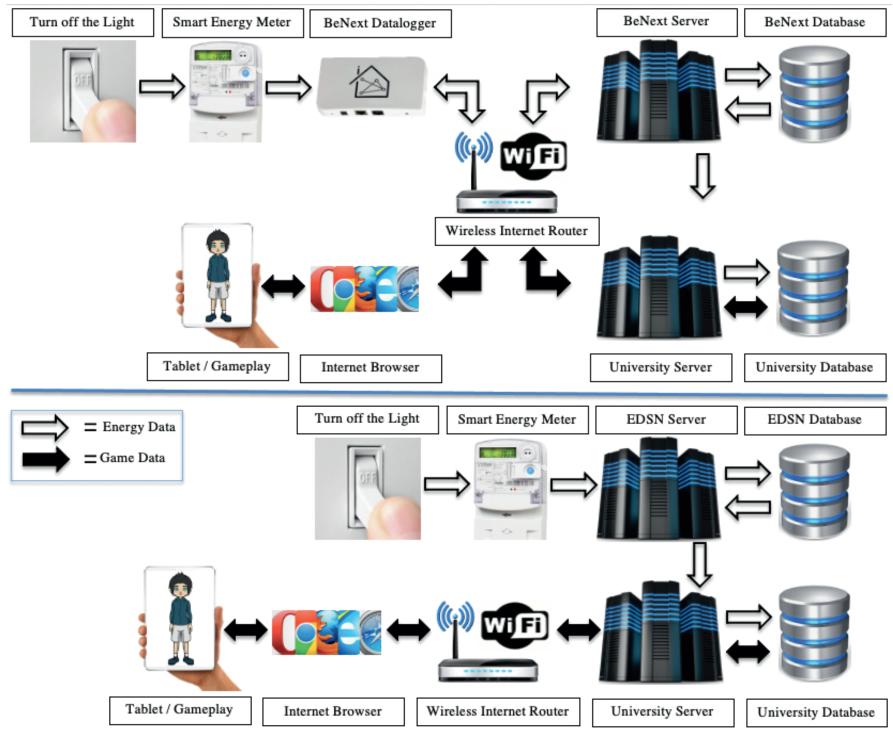


Figure 14. Technical architecture *Powersaver Game*: old P1 interface above, new P4 interface. below the line.

In total, it took almost one year to get authorization and rebuild the technical architecture.

Topic 5. Measurements Energy consumption is monitored three weeks before the game starts to set a good baseline of average energy consumption. All four effects of playing the game are measured (Characteristic 19. Measurements). Knowledge will be measured by using questionnaires before and after playing. Attitude will also be measured by using questionnaires before and after playing. Energy usage will constantly be monitored from the energy meter. Engagement will be measured by using questionnaires in the second week and the last week of the intervention.

4.3 Design of the control dashboard condition

In the first study, a media comparison approach (Mayer, 2014), households used *Powersaver Energy Dashboard* in the control condition. The energy dashboard has an identical design style as the menu page of the game. As presented in Figure 15, it contains a screen where energy conservation recommendations and a timer are presented, and in order to give feedback two screens with energy consumption charts and energy conservation results are presented. The form, timing and content of the information that the control condition receives, are highly similar as in the game condition, but with the exclusion of game features such as missions, quizzes, narrative, competition and rewards (Soekarjo & Van Oostendorp, 2015). Energy saving activities are presented as tips in *Powersaver Energy Dashboard* and as missions in *Powersaver Game*. Energy saving tips in the control condition are formulated in a slightly less active writing style compared to missions in the game condition, because there is no narrative where the tips refer to.

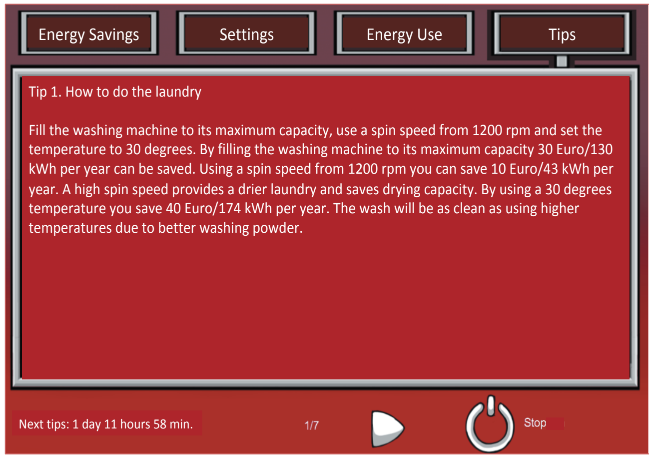


Figure 15. Control condition: Powersaver Energy Dashboard.

4.4 Evaluation of the match in-game scenes and activities in the real-world

In the first part of step 2 (see Figure 7) potential players evaluate the match between in-game scenes and activities in the real-world. Suggestions from this study will optimize the transfer between both worlds. As mentioned in Section 1.2 and Section 3.2.1, the gamification process that is used, a reality-enhance game approach, is expected to stimulate the transfer by implementing real-word processes in a game design.

In this paragraph a study is presented that evaluates the implementation of household energy saving activities in the game. Four potential players of *Powersaver Game* have evaluated the perceived match between in-game scenes and activities in the real-world. The aim of this user study is to assess the potential transfer between the game world and the real-world. The participants are instructed to read a text about the situation of an in-game scene and how well this situation can be solved by carry out energy saving activities in a household, for instance missions involving activities in lighting, media, washing, cooking, etc. In total there are fifty energy saving activities distributed over eight scenes with twelve cartoons of electrical appliances. To improve the situation of the electrical appliance(s) in a scene, multiple energy saving activities have to be carried out. An example mentioned before is presented in Figure 16. The freezer and refrigerator are sick and can be cured when energy saving activities concerning cooling are carried out, like cleaning the isolating rubbers on the door and resetting the temperature. The participants have rated the strength of the match between the situation of the electrical appliances (e.g., sick freezer and refrigerator) and the energy saving activities that have to be carried out (e.g., reset the temperature).

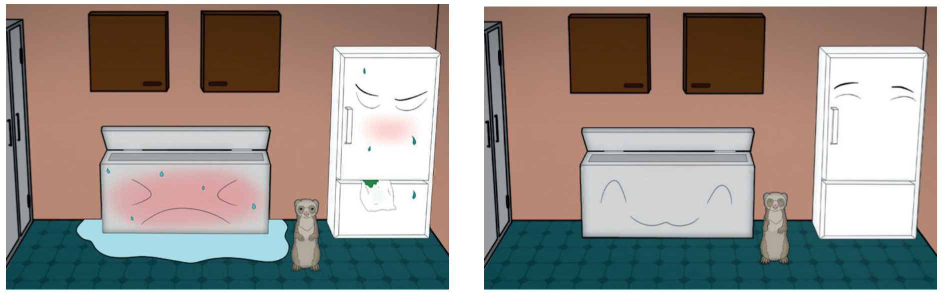


Figure 16. Scenes scullery: bad state (on the left) and normal state (on the right).

They are also invited to give comments in writing to make clear what possibly could be improved. The perceived match between the eight in-game scenes and the fifty activities in the real-world has an average score of 3.9 on a 5-point scale. A score of 5 means that the match between an in-game situation and an energy conservation activity is very strong. The standard deviation is 1.3, suggesting that it is still possible to make improvements. In order to get an impression of the reliability of the rating method, we calculated both the Cronbach's alpha and correlation between the ratings of the four participants. The Cronbach's alpha value of 0.777 suggests a sufficient internal consistency. The average correlation between the ratings of the four participants was not that high (.48, $p < 0.05$), however when one rater was deleted, the average correlation increased to an acceptable level (.61, $p < 0.05$).

In total there are eleven electrical appliances and one plant (see Figure 17) that are placed in one of the eight scenes. To change each object from a bad state to a normal state the player has to carry out energy saving activities (missions) that are specific for each object. If there are more objects in one scene the player has to carry out several energy saving missions.

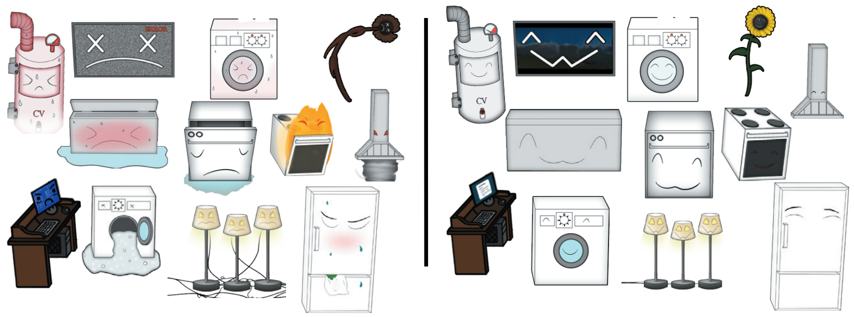


Figure 17. In-game objects: bad state (on the left) and normal state (on the right).

Because of this, both the match between energy saving activities (missions) and the twelve electrical appliances, and the match between energy saving activities (missions) and the eight scenes, which can contain more electrical appliances, can be evaluated. In Table 10 the match between the electrical appliances and missions and in Table 11 the match between scenes and missions are presented. The scores of appliances one to five in Table 10 are the same as the scores of scenes one to five in Table 11. This is caused by the fact that in scenes one to five only one appliance is present in each scene. The description of the appliance is then the same as the description of the scene.

Table 10. Match between in-game appliances and missions.

Match Appliances	Mean	Std. Deviation	Match Appliances	Mean	Std. Deviation
1. Lamps	3,0	1,3	7. Washing Machine	3,3	1,5
2. Computer	4,1	1,0	8. Freezer	4,8	0,5
3. Central Heating	4,3	1,0	9. Refrigerator	4,5	0,9
4. Plant	3,0	1,7	10. Kitchen Hood	4,7	0,5
5. Television	3,6	1,3	11. Dishwasher	4,4	0,7
6. Clothing Dryer	3,1	1,5	12. Oven	3,1	1,7

Table 11. Match between in-game scenes and missions.

Match Scenes	Mean	Std. Deviation
1. The ferret is captured in the wires of angry lamps in the living room.	3,0	1,3
2. A stressed computer in the study room.	4,1	1,0
3. An overheated central heater in the bathroom.	4,3	1,0
4. A sick plant in the bedroom.	3,0	1,7
5. An exhausted television in the television room.	3,6	1,3
6. A sweating clothing dryer and washing machine with foam in the mouth in the washing room.	3,6	1,5
7. A freezer with flu and a refrigerator with a cold in the scullery.	4,5	0,8
8. A wild blowing kitchen hood, overflowing dishwasher and fire-breathing oven in the kitchen.	4,0	1,3

The scores below four (near the midpoint of the scale, in the tables darkly coloured) indicate that improvements can be made. Based on comments of the participants, energy saving activities, scenes and objects have been changed for the new game version. In total 15 energy saving activities from the scenes 1, 4, 5, 6 and 8 are adjusted (as indicated in Table 10 and Table 11). The formulations of some activities were not explicit enough and are rewritten. Activities that are repetitions of earlier activities have been deleted, because players can reread all information at any moment in the game. During some activities players had to count items, like lamps and windows. Because these counts are not incorporated in the gameplay these activities are deleted. Activities for washing clothes are combined in one washing activity. The artwork of scene 4 (the plant) is improved and one scene is added. This new scene is placed after scene 6 and is called 'tea time'. The participants commented about the mismatch between scene 6 and some energy saving activities that had nothing to do with washing ('tea-time missions'). In the new scene the family is asked to make tea in a sustainable way and drink it in the teagarden. While drinking tea, they have to evaluate the gameplay till so far. With these improvements we are in a good position to enhance the match between in-game scenes and activities in the real-world. This should have a positive effect on the transfer between the game world and the real-world, which can make the game more effective (Kors et al., 2015).

4.5 Evaluation design features

In the second part of step 2 (see Figure 7) another group of potential players evaluated the design features of the complete system in order to possibly improve clarity and attractiveness of *Powersaver Game*.

After the match was optimised as a result of the first part of the user evaluation (see Figure 7), the features storyline, missions, quizzes, artwork, gameplay, feedback and reward systems, personal relevance and competition have been evaluated in a second user study. Twenty-one respondents, potential players of *Powersaver Game*, from seventeen households have filled in an extensive survey of 55 pages (Word-file), consisting more than 200 statements, options to give comments and pictures of game scenes (see Figure 18 for an example).

Statements and Question	1-Strongly Disagree 2-Disagree 3-Neutral 4-Agree 5-Strongly Agree
Figure 1a is a clear representation of a ferret.	
Figure 1b is a clear representation of a happy ferret lifting his thumb.	
Could the figures of the ferret be improved?	

Figure 18. Survey example.

Respondents specify their level of agreement on statements with a 5-point scale and it was possible to place comments. In order to get an impression of the reliability of the rating method, we calculated Cronbach's alpha. The value of 0.841 suggests a high internal consistency. In Table 12 the mean results are presented. The scores of individual questions are grouped together by the design features as indicated in Table 12. All mean scores, with the exception of artwork, are rated above 3. Although this is promising, the standard deviations of some features are high. This suggests that improvements can still be made. The storyline is attractive and match with the theme. A respondent suggested to add more "side-stories" in the scenes to make clear what is wrong with each appliance and how this happened.

Table 12. Evaluation design features.

Design Features		Mean	Standard Deviation	Design Features		Mean	Standard Deviation
Storyline	Attractive	3,2	1,0	**Gameplay**	Challenging	3,2	0,8
	Match with theme	3,7	1,1		Attractive	3,3	0,9
Missions	Clarity of formulation	4,2	0,6		Effective	3,7	0,8
	Level of challenge	3,7	0,9		Fun	3,3	1,0
Quizzes	Clarity of formulation	4,1	0,8		Educative	3,5	0,7
Artwork	Presentation	3,7	1,0		Clear goal	4,2	0,6
	Contrast bad/good state	3,4	1,1		Duration	3,2	1,0
	Art style	2,8	1,0		Balance progress and activities	3,7	0,9
Personal Relevance	Customisation options	3,9	0,7	**Feedback and Reward systems**	Relevance	3,6	0,7
Competition	Six households	3,8	0,9		Quantity of information	4,0	0,7
					Clarity of overviews	4,1	0,9

The clarity of formulation and level of challenge of missions and quizzes are good. One respondent suggested that more explanation is required. The style of the art is sufficient, but not attractive for all respondents. In general, respondents mentioned that it is important that contrasts in different emotions and states of in-game objects can be more expressive (see Figure 17). This is particularly the case for the state of the house of the professor, the emotions of the ferret, the art style of the computer in the study-room and the evil state of the professor need some improvements. The respondents are positive about gameplay, feedback, customization options and the size of competition. Based on this evaluation the most important improvements have to be made in the artwork of the *Powersaver Game*.

4.6 Final improvements

In this section, special attention is given to the elaboration of artwork improvements in the prototype game that are suggested in the two evaluations from step 2 (see Figure 7). As described in Section 4.4, in the first part of step 2 potential players evaluated the implementation of household energy saving missions in the game. As a result, the artwork of the plant in scene 4 is improved and presented in Appendix 6. Also, one new scene, called 'tea time', is added. As presented in Figure 19, in the new scene the family is asked to make tea in a sustainable way and drink it in the teagarden. While drinking tea they have to evaluate the gameplay till so far.

Figure 19. New scene 'Tea Time', in the teagarden.

As described in Section 4.5, from the next part of step 2 potential players evaluated the complete design, and several improvements in artwork are recommended for the prototype game. As a result of this review and presented in Appendix 6, artwork improvements have been made in (1) the state of the house of the professor, (2) the art style of the computer in the study-room and (4) the evil state of the professor. The improvements in artwork of (5) the emotions of the professor's pet are presented in Figure 20. We decided to replace the ferret with a cat, as some respondents noted their doubts about choosing for an unconventional pet. The different expressions of the cat are created by manipulation of the eyes, ears, tale and fur.

Figure 20. Original pet (ferret, on the left) and improved pet (cat, on the right).

Due to the art style change to make improvements, we decided for consistency reasons to also change the art style of the avatars (see Figure 21) and the lamps that are the in-game objects in the first scene (see Appendix 6).

Figure 21. Original avatars (on the left) and new avatars (on the right).

4.7 Conclusion and discussion

In this chapter the steps to design the household energy game *Powersaver Game* that is used in this research project are presented (see Figure 7). The thoughtful user-centered game design methodology includes two design steps to develop a persuasive game. In step 1 design principles have been formulated to design a game prototype of *Powersaver Game* and in step 2 potential users have been involved to evaluate this prototype. Following these steps has led to a high-quality reality-enhanced serious game that should be effective in changing behavior, knowledge and attitude and engage players during playing. It is equally important that the game developers have skills to design reality-enhanced serious games. This approach has an iterative character because the prototype design is adjusted several times before a final design can be used for experiments.

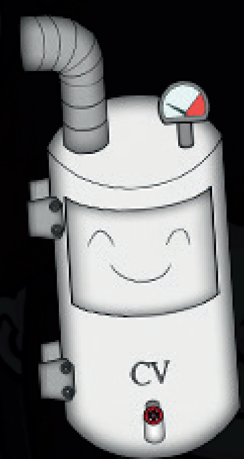
More specific, in the first step the design goals or demands are formulated. These goals concern effects of the games such as awareness, information transfer and behavior change and involve game characteristics such as integration in real-life, duration and storyline. In Chapter 3, the design features and empirical effects of related games that met these goals have been reviewed. Based on these results design features have been recommended for the game prototype. Also, household energy saving missions have been formulated in this step and have been incorporated in a prototype game design.

In the first part of step 2 potential players are involved to evaluate the implementation of household energy saving missions in the game, because we strive to develop a game that is based on user-centered design principles. As a result of this part of step 2 improvements in activities, scenes and objects in the prototype game design are made which will result in a better match for transfer of knowledge. In the next part of step 2 potential players are involved to evaluate the complete design by judging the storyline, missions, quizzes, artwork, gameplay, feedback and reward systems, personal relevance and competition. As a result of this review improvements in artwork are implemented.

We conclude that by taking the steps to design a household energy game (see Figure 7) and, thus, conducting a thoughtful, iterative user-centered design approach, it has been possible to develop a game design/instrument that is subsequently used in a media comparison study (see Chapter 5) and a value-added study (see Chapter 6) (Mayer, 2014).

Chapter 5

Comparing the Powersaver Game with a Dashboard Application



5. Comparing the Powersaver Game with a Dashboard Application

5.1 Introduction

In Chapter 4 the thoughtful, iterative user-centered design approach to develop the application *Powersaver Game* is described and the game is presented. This chapter presents a media comparison study (Mayer, 2014) where *Powersaver Game* is used as a tool to examine the influence of playing in the real-world on attitudes towards energy conservation and on energy conservation behavior in the long term, and compared with a *Dashboard Application*. The focus is specifically on energy consumption in households by means of electricity and gas usage.

5.2 Method

Media comparison research examines differences in learning the same content of a game - or as similar as possible - with conventional media (Mayer, 2014), answering the research question: '*Do people learn better from games or from conventional media?*' Inspired by this approach, the focus of this study is comparing a persuasive reality-enhanced game (*Powersaver Game*) and control condition (*Powersaver Energy Dashboard*) both within a computer-based medium. This possibly will contribute to get more inside in the persuasiveness between both applications (Van 't Riet et al., 2018), and prevents problems with possible media differences. As an example, interaction with a computer compared to instructions from paper. Similar studies have general shortcomings (see Chapter 3) such as: the lack of a control condition, the intervention time was short, no real consumption measurements are used, implementation of gamification could be better, limited number of variables is measured and/or the lack of pre-measurements and post-measurements. This study attempts to overcome these limitations. *Powersaver Game* is a reality-enhanced serious game where several game features are incorporated, and can be expected to stimulate energy conservation. *Powersaver Energy Dashboard* is a learning application that provides instruction and feedback on energy conservation. Dashboards are control panels that display learning features such as assessments, recommendations, comparisons, social interactions, feedback and/or gamification elements (e.g., leaderboards and badges). In general, visualization techniques such as line chart, bar chart, progress bar, textual feedback, timeline and pie chart are used in dashboard designs (Sahin & Ifenthaler, 2021). In both conditions (game and dashboard) every 2 days families receive the same general information about a specific theme in energy conservation, e.g., washing clothes, and receive feedback. Besides knowledge transfer, i.e., learning results, also attitude, engagement and behavior, i.e., energy consumption, is measured.

In research on the use of smart meter-related feedback applications to stimulate energy conservation, that have similarities with the control condition, the *Powersaver Energy Dashboard*, inconsistent outcomes are reported. In a study of Geelen et al. (2019) a sample of Dutch households (*n* = 519) is divided into an intervention group that had an energy dashboard and control group that did not have that. Results show no significant difference in reduction in electricity and gas consumption between both groups over a long period. Similar results are reported in an earlier study of Hargreaves et al. (2010, 2013), where 275 UK households participated in. They conclude that over time, energy dashboards increase participants knowledge about energy consumption, but the use of the dashboards become 'backgrounded' within normal household routines and practices, and as a consequence do not motivate to reduce their energy consumption. A recent publication by PBL Netherlands Environmental Assessment Agency, the national institute for strategic policy analysis in this field, also confirms the limited effects of energy dashboards (Vringer et al., 2021). These results are in line with the main conclusions of a meta-analysis of Clark et al. (2016). Their first conclusion is that games enhance learning relative to nongame conditions such as energy dashboards. It should be noted that no computer-based medium was used in the control conditions. Their second conclusion is that games that incorporate reality enhance learning more than standalone games. However, opposite outcomes about the effectiveness of energy dashboards are reported in a meta-analysis of Karlin et al. (2015). This study concludes that applications, such as energy dashboards, that provide feedback are most effective for promoting energy conservation when they are combined with goal-setting or external incentive interventions. Also, an earlier meta study of Darby (2006) reports positive results. She concludes that feedback provided by energy dashboards reduces household energy consumption by 5% to 15%. Despite the inconsistent outcomes of these studies, *Powersaver Energy Dashboard* can be seen as an ideal instrument as control condition, because of the absence of gamification features. This makes it possible to relate differences in outcomes, in energy conservation between game and dashboard users, to these gamification features.

5.2.1 Research Question

The research question is whether there are changes in knowledge transfer, attitude towards energy conservation, engagement and energy conservation between the game and control condition. This involves, basically, examination of the effectiveness of a game focused on energy conservation. The hypothesis is that knowledge, attitude, engagement and energy conservation of participants playing the game will increase more than that of participants in the dashboard control condition. The aim of current study is to contribute to the stimulation of individual sustainable behavior by studying how gamification can be a positive means for people to change their behavior regarding energy use at home. It also aims, as in the study of Soekarjo and Van Oostendorp (2015), to examine whether transfer from gameplay to real-life behavior has a long-term character, in the weeks immediately following the intervention. It is conducted over a longer period of time (several weeks), measures changes in knowledge, attitude, engagement and behavior also after delay, and includes an adequate control condition. To attain these aims families played the *Powersaver Game* or used in the control condition the *Powersaver Energy Dashboard* version that contains no game features.

5.3 Participants

In this study 21 households including 49 participants older than 12 years participated on a voluntary basis. Six households with a total of 17 participants dropped out during the intervention. From the remaining 32 participants who finished the game only 15 participants from 7 households in the game condition filled in all questionnaires.

5.4 Measurements

An overview of measurements is presented in Table 13, and the questionnaires are presented in Appendix 1 to 5. Participants completed an online pretest as well as an online posttest questionnaire to assess their attitude towards sustainable energy consumption related topics and knowledge level towards household energy conservation. Also, participants completed an online questionnaire in the second week and the last week of the intervention to assess their engagement.

For attitude measures both questionnaires included 30 statements rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree. Different statements on the same topics are used in pretest and posttest. Fifteen statements are regarding micro-level attitude topics (about sustainable energy consumption in a household) (see Appendix 5) as well as 15 statements regarding macro-level attitude topics (10 statements about sustainable energy and 5 statements about sustainability) (see Appendix 4). Macro-measures are composed partly based on previous research on attitudes toward sustainability, such as the study of Soekarjo and Van Oostendorp (2015). With this approach specific hierarchical attitude attributes (Watt et al, 2008) of the object of sustainable energy attitude can be measured. Krosnick and Petty (1995) describe that strength-related attributes of attitudes are categorized in affective, cognitive and behavior intention components. In the questionnaire of this study only statements from affective and cognitive categories are used, because the behavior intention to save energy in the household was already high by voluntary registration to participate in this experiment.

For the knowledge measures 12 multiple-choice questions including 4 answer options per question are used (see Appendix 3). The questions are related to the content about energy conservation from both applications. The same questions are used in the pretest and posttest.

To monitor engagement participants completed an online questionnaire in the second week and the last week of the intervention (see Appendix 1). Both questionnaires include the same 7 statements to be rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree. Engagement measures are composed based on previous research on engagement in serious games (Van Der Spek, 2011).

Behavior, in the form of energy consumption, is monitored during 21 days right before the intervention to set a good baseline of average energy consumption. Energy consumption is monitored during the intervention. In both applications the user is getting feedback (on energy use and savings) during the intervention. Right after the intervention the energy consumption is monitored for 21 days to examine the impact of the intervention.

To evaluate the application itself in the online posttest questionnaire 11 statements, rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree, and 1 open question, are used (see Appendix 2). The 11 statements are about learning to save energy with the application, and in the last question is asked to give suggestions for improvements.

Table 13. Overview of measurements.

	Pre-intervention	Intervention	Post-intervention
kWh electricity & m^3 gas consumption data from the smart energy meter	21 days monitoring	Continuous monitoring	21 days monitoring
Macro and Micro-attitude assessment	30 Statements *: 15 Micro-level attitude and 15 Macro-level attitude		30 Statements *: 15 Micro-level attitude and 15 Macro-level attitude
Knowledge level	12 Multiple-choice questions including 4-answer options		12 Multiple-choice questions including 4-answer options
Engagement		7 Statements *: In the second week and last week of the intervention.	
Evaluation of application			11 Statements * about learning to save energy with the application and 1 open question about suggestions for improvements.

* 7-Point Likert-scale ranging from strongly disagree to strongly agree

5

5.5 Procedure

Participants have been recruited using various methods and communication channels like social media, direct mail, digital newsletters and public lectures. Participants registered at the beginning of 2017 using an online form. They could participate when the technical situation of their energy supply (e.g., presence of smart energy meter) was adequate. In spring 2017, 49 participants from 21 households filled in the online pretest. To monitor real energy consumption in this period also hardware was installed in the households. It took at least 21 days of monitoring to set a firm baseline. All participants above 12 years replied to the pretest questionnaire about attitude and knowledge and the first engagement questionnaire in the second week of the intervention. Participants are randomly assigned to conditions, however we ensured that there was a global matching between conditions on the composition of the household (adults and children), attitude towards energy conservation (higher or lower than average compared to other participants) and energy consumption (higher or lower than average of the same type of households in The Netherlands). Knowledge scores are not used in this assignment process because all participants scored very low. All household types are equally represented in each condition: 11 households are assigned to the game condition and 10 households are assigned to the control condition. The intervention started in June and ended in July 2017, and over this period energy consumption is measured. Some households ended later, due to delay in starting new sessions. From the 11 households that started in the game condition 6 households finished on schedule (on average 5.5 weeks) and 4 households finished later (on average 18 weeks). One household did not finish the game, due to personal circumstances. From the 10 households that started in the control condition 5 finished in on average 13 weeks and the other 5 households stopped halfway after 4 weeks. From these 5 households in the control condition that stopped 4 households have children in the adolescence age group. The 5 households that finished in the control condition do not have children in the adolescence age group. When a household finished all the sessions, they were asked to fill in the online posttest. Only 15 participants, a third of the total, responded to the second questionnaire about engagement before the last week of the intervention and the posttest questionnaire about attitude and knowledge after the intervention. These 15 participants who responded to all questionnaires are from 7 households in only the game condition. The hardware was disconnected after at least 21 days from the end of the intervention, and was collected by the researcher.

5.6 Results

The effects on energy conservation and knowledge, engagement, and attitude measures are presented below. The difference in energy conservation between the game and control condition is based on 6 households from the game condition that have finished on schedule (on average 5.5 weeks) and 5 households from the control condition that have finished (on average 13 weeks). 4 Households that finished the game later (on average 18 weeks) did not provide data on energy consumption within the time constraints for our study. Unfortunately, the post-measurements fell in the heating season. In this season Dutch households warm their houses using gas boilers, because the average outside temperature is below 18.5 degrees. This causes a large difference in gas consumption between the heating - and non-heating season, so that post- and premeasurements in both seasons cannot be compared. Only knowledge, engagement, and attitude measures from the game condition - and not from the control condition - are discussed, due to lack of sufficient observations in the control condition on the questionnaires.

5.6.1 Energy Conservation measures

The results in energy conservation of households, (1) during the total intervention period compared to the pre-intervention period, and (2) during the 21 days post-intervention period (right after the intervention) compared to the pre-intervention period, for the game and control condition are presented in Table 14. The average energy consumption per day from 21 days right after the intervention is compared to the consumption over 21 days right before the intervention. The difference in percentage change of total energy consumption (%Δ kWh electricity + %Δ m^3 gas / 2) is presented as well as the percentage change in consumption in kWh electricity and m^3 gas. Percentage change is defined as the change from the original value at the pre-intervention. Because household conservation of both kWh electricity and m^3 gas are related first a multivariate analysis of variance (MANOVA) is conducted. We have used a Wilk's L test to find if there are differences between group means of the game and control condition, for the combination of the dependent variables conservation of kWh electricity and m^3 gas. There is a significant difference between game and control condition when considered jointly on the variables conservation of kWh electricity and m^3 gas: at the intervention, Wilk's L = 0.17, $F(2, 8) = 19.66$, $p = 0.001$, partial $h^2 = 0.83$, and at the post-intervention, Wilk's L = 0.34, $F(2, 8) = 7.82$, $p = 0.01$, partial $h^2 = 0.66$. The outcome of Wilk's L is a measure of the percent variance in the combination of the dependent variables conservation of kWh electricity and m^3 gas, that is not explained by differences in levels of the independent variable game and control condition. A smaller value of Wilk's L indicates greater differences between the game and control condition. Both scores at the intervention and at the post-intervention are small. A high partial h^2 represents the proportion of variance in the combination of the dependent variables conservation of kWh electricity and m^3 gas that can be explained by the variance in the game and control condition. Both scores at the intervention and at the post-intervention are high. To examine whether the game and control condition had an effect both on kWh electricity and m^3 gas, independent-samples *t*-tests on the gain scores are performed to test if differences in percentages of change between the game and control condition on each of the energy conservation measures are significant.

Table 14. Energy conservation: mean changes, standard deviations, t-statistic and significance level of difference.

Energy Conservation	Game M	Game SD	Control M	Control SD	Diff M	*t*	*p*
At intervention							
Total	20.9%	9.4	3.7%	15.5	17.2%	-2.28	< 0.05
kWh Electricity	16.7%	5.6	-1.9%	3.4	18.6%	-6.45	< 0.05
M³ Gas	25%	20	9.3%	29.9	15.7%	-1.05	ns
Post-intervention							
Total	21.4%	7.7	-12.2%	18.5	33.6%	-4.08	< 0.05
kWh Electricity	12.9%	7.9	-1.7%	16.6	14.5%	-1.92	< 0.05*
M³ Gas	30%	12.1	-22.7%	38.3	52.7%	-3.21	< 0.05

* One-tailed ns - not significant at 0.05 level

In the intervention period there is a significant difference of 17.2% in total change in energy conservation between both conditions: $t\,(9) = -2.28$, $p < 0.05$: while the game condition consumes 20.9% less energy than in the total pre-intervention period of 21 days, the control condition only consumes 3.7% less energy. When looking specifically at conservation of kWh electricity there is a significant difference of 18.6% between groups: $t\,(9) = -6.45$, $p < 0.05$. The game condition consumes 16.7% less kWh electricity than before, while the control condition consumption consume 1.9% more kWh electricity. The difference between the groups of 15.7% m^3 gas consumption is not significant: $t\,(9) = -1.05$, $p > 0.05$.

The change in energy conservation during the intervention continues after the intervention. In the total 21 days post-intervention period there is a significant major difference of 33.6% in total change in energy conservation between both conditions: $t\,(9) = -4.08$, $p < 0.05$: while the game condition consumes 21.4% less energy than in the total 21 days pre-intervention period, the control condition consumes 12.2% more energy. When looking specifically at conservation of kWh electricity there is a significant difference of 14.5% between groups: $t\,(9) = -1.92$, $p < 0.05$ (one-tailed t-test). The game condition consumes almost 13% less kWh electricity than before, while the control condition consumption is almost the same as before the intervention. The largest significant difference between the groups is 52.7% m^3 gas consumption: $t\,(9) = -3.21$, $p < 0.05$. Notable is that in general the standard deviation of the control condition is high.

5.6.2 Knowledge, Engagement and Attitude measures

The results in knowledge, engagement and attitude measures of participants are presented in Table 15. These 15 participants who filled out all questionnaires (30% of all participants), as explained in Section 5.3, are only from the game condition. Paired-samples t-tests are executed to conclude whether differences between the pretest and posttest are significant.

Table 15. Knowledge, engagement and attitude in the game condition: means, standard deviations, t-statistic and significance level of difference.

	Pretest M	Pretest SD	Posttest M	Posttest SD	Post - Pre M	Post - Pre SD	*t*	*p*
Knowledge*	4.27	1.62	5.8	1.93	1.53	1.81	-3.29	< 0.05
Engagement	5.35	0.94	5.29	0.75	-0.06	0.45	0.54	ns
Attitude								
Total	5.38	0.85	5.34	0.74	-0.04	0.4	0.39	ns
Micro-level	5.35	0.88	5.43	0.75	0.09	0.51	-0.66	ns
Macro-level	5.41	0.92	5.25	0.81	-0.17	0.4	1.61	ns

* Maximum score = 12 ns - not significant at 0.05 level

The average score on knowledge increased from 4.27 to 5.8 points. Although the average score in the posttest is not high (the maximum score possible is 12 points), knowledge about energy conservation increased significantly: $t\,(14) = -3.29$, $p < 0.05$.

The engagement is high and constant during the intervention. There is no significant difference in engagement between the beginning and end of the intervention: $t\,(13) = 0.54$, $p > 0.05$.

All attitude scores are already high from the beginning and the intervention did not lead to a significant attitude change: Attitude total: $t\,(14) = 0.39$, $p > 0.05$; Attitude at micro-level: $t\,(14) = -0.66$, $p > 0.05$; Attitude at macro-level: $t\,(14) = 1.61$, $p > 0.05$.

5.6.3 Correlations between measures within the game group

To explore if the assumed chain of events as expressed in Figure 2 (see Section 2.1.2) occurs, that is, more accessible knowledge leads to more attitude change which leads to greater behavior change, we analyze the relationships between variables. We first examine the correlations of the variables Δ-knowledge, Δ-attitude and Δ-behavior, where the delta sign Δ denotes the difference between posttest - and pretest measurements. Remarkably, there are no significant correlations detected between these variables.

Next, we conduct a linear multiple regression analysis to explore which variables are significant predictors of the most important criterion variable Δ-behavior in the total 21 days post-intervention period. This technique examines the relative influence of variables (the predictors) on the criterion variable. We use the 'Enter method' (IBM SPSS Statistics for Macintosh, Version 25), in which all variables in a block are entered in a single step, because all the predictor variables of Δ-behavior in the total 21 days post-intervention period will be given equal importance. We have no presumption that some predictor variables are more important than others. A significant model emerged (F (3, 11) = 25.695, $p < 0.05$). The adjusted R *square* = .841 and the predictor variables with their Beta values are shown in Table 16. These outcomes indicate that 84% of the differences in behavior changes are explained by the predictor variables. The Beta coefficients indicate how much a predictor - if significant - contributes to the performance on the criterion variable. Δ-Behavior during intervention is the most important predictor (explaining 81% of the differences on Δ-behavior post-intervention), and attitude the second important one (explaining 7%). Other variables are not significant ($p > 0.05$).

Table 16. Predictor variables (criterion variable = Δ-behavior at post-intervention).

Predictor variable	Beta	*p*
Δ-Energy conservation during intervention period	0.9	< 0.05
Attitude pre-intervention	0.265	< 0.05
Δ-Knowledge during intervention period	0.177	ns

ns - not significant at 0.05 level

5.6.4 User evaluation of Powersaver Game

The fifteen participants who filled out all questionnaires from the game condition evaluated *Powersaver Game* by means of 11 statements and one open question where was asked to give suggestions for improvement. The score is on average 5 on a 7-point Likert-scale, and the standard deviation is 1.3. The following suggestions for improvement are given: Automatic (push-)notifications when a session has ended, energy consumption overviews of specific appliances, pre-selection of specific appliances that are relevant to particular households, more specific feedback about energy consumption, shorter mission texts and general game art improvements.

5.7 Conclusion and discussion

Based on the results of this media comparison study (Mayer, 2014), it can be concluded that there are differences in learning the same content of a persuasive energy conservation game, developed by using a thoughtful, iterative user-centered

game design methodology, compared to a dashboard control condition. Furthermore, and most importantly, it can be concluded that energy consumption changed significantly during the intervention and in the long term. Our persuasive game that includes reality by using reality-enhanced gamification principles is, thus, effective in learning people to save energy in the household and to actually do that for the long term, while the energy dashboard does not change that behavior at all. Similar studies, as discussed in Section 3.1, also presented positive results but had some shortcomings: the lack of a control condition, the intervention time was short, no real consumption measurements are used, implementation of gamification could be better, limited number of variables is measured and/or the lack of pre-measurements and post-measurements. Which altogether could explain that the positive effect on energy conservation in our study is higher than in previous studies.

From the beginning of the intervention, participants in the dashboard control condition had a delay in starting missions (on average 13 weeks to finish while 5 weeks is possible), did not carry out missions (little or no energy conservation) or quit (50% in 4 weeks). The 5 households in the dashboard control condition that finished the application conserved a little amount of energy during the total intervention period. This was only caused by m^3 gas conservation, while there was no kWh electricity conservation. Remarkably, the m^3 gas consumption rose enormously in the post-intervention period. Unfortunately, these participants in the control condition were not motivated to respond to questionnaires, so the resulting number of questionnaires is too small for meaningfully analyzing the data. It is possible that some participants are disappointed in that they are not assigned to the game condition and therefore less motivated. However, there are also participants from the control condition who stated after the intervention that they did not prefer to be assigned to the game condition.

In the game condition energy consumption (behavior) changed and knowledge about saving energy at home increased. Also in this condition, despite of the long intervention time, engagement remained high during the whole intervention. This suggests that the game is effective in stimulating participants long-term involvement in household energy conservation activities. The earlier mentioned chain of events (see Figure 2, Section 2.1.2) does not completely align with these results. Higher awareness (more accessible knowledge) for a longer period leads to increased knowledge, which leads to behavior change in the long term, but attitude change did not take place. Also, there are no significant correlations between these variables found. However, if a linear multiple regression analysis is conducted 'Δ-energy conservation during the intervention' and 'pre-intervention attitude scores' are significant predictor variables for behavior change in the long term. It is somehow unexpected that

'Δ-knowledge' is not a significant predictor variable. Although there is not enough data to interpret this effect, it can be assumed that knowledge transfer from the game to participants endures in (routine) behavior, and not in increased reproducibility of that knowledge at the test. It is expected that the degree of energy conservation during a long intervention time, which is high in the game condition, endures after the intervention and therefore is a strong predictor variable. The attitude scores on micro-level and macro-level are extremely high, both nearly the same and the intervention did not change it. Because of this, a ceiling effect regarding attitude could be the case, resulting in no-gain in attitude, but still being a significant predictor for energy conservation in the long term as the multiple regression analysis showed. Krosnick and Petty (1995) mention that the more extreme an attitude is, the more an individual likes the object of the attitude, and the more likely it guides behavior. All participants have a high attitude score, and thus an extreme attitude towards energy conservation, also those in the control condition. It is unexpected that during the intervention period a substantial number of mainly adolescent participants in the control condition dropped out.

The results of this study can have considerable implications for policymakers and companies in the field of smart energy meters. Currently in practice only dashboard designs (Sahin & Ifenthaler, 2021) are used to give feedback on energy consumption (e.g., Nest) and data from this study seem to indicate that these designs are probably not effective in the long term (Geelen et al., 2019; Hargreaves et al., 2010).

Limitations of this study are that only from participants in the game condition all dependent variables (knowledge, attitude, engagement and behavior) could be analyzed and that there is not sufficient data to look closely at the control condition. Independent of the preceding, the results also showed that in the control condition no positive change in energy consumption was attained in the long run. Another limitation is the limited number of households participating in this study. This limitation also occurs in related studies (see Section 3.1) and points to the difficulties of this kind of research. It is worthwhile to note that, although the number of households was limited, still significant differences are found. There is a possibility to scale up the number of participants if the smart energy meter can be monitored without additional hardware and a large(r) campaign to recruit households is launched. The results of the evaluation of *Powersaver Game* are sufficiently positive and modifications to it are not necessary, however, the texts of the missions will be shortened, and there will be more attention to the feedback-screens in the user manual.

Chapter 6

Effectiveness of Personal Relevance and Social Interaction

6. Effectiveness of Personal Relevance and Social Interaction

6.1 Introduction

Research in persuasive game's should focus on the game characteristics that contribute to the game's persuasiveness (Van 't Riet et al., 2018). To bring the research field on energy reduction games theoretically, but also practically a step further, the third research question, '*What is the long-term effectiveness of specific game features of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players?*' (see Section 2.2), is examined using a value-added approach (Mayer, 2014). In this chapter the effects of the persuasive features *personal relevance* (by means of personalized avatars) and *social interaction* (by means of competition) on participants' engagement, knowledge, attitude and behavior with respect to sustainable energy consumption with *Powersaver Game* are examined. Both features can enhance engagement in DGBL, although there is limited empirical evidence of effects when intervention periods are long and when the features are applied in less-structured domains (Cagiltay et al., 2015; Chen et al., 2020; Clark et al., 2019; Kang & Kim, 2020; Li et al., 2013; Sanchez, 2017). This chapter intends to provide more insight into this.

In Chapter 5 we conclude from the media comparison study (Mayer, 2014) that there are differences in learning the same content of a persuasive energy conservation game compared to an energy dashboard control condition. Furthermore, we conclude that energy consumption changed significantly in the long term. Our persuasive game that includes reality by using reality-enhanced gamification principles is, thus, effective in learning people to save energy in the household and to actually do that for the long term, while the energy dashboard does not change that behavior at all (Fijnheer et al., 2019; Geelen et al., 2019; Hargreaves et al., 2010). In this chapter the research in reality-enhanced serious games focuses on *specific* game features that may contribute to the game's persuasiveness to promote lasting changes in engagement, knowledge, attitude and behavior regarding sustainable energy use of households (Van 't Riet et al., 2018). This chapter presents a value-added approach (Mayer, 2014), and examines the effects of the features, personal relevance using personalized avatars and social interaction through competition, on engagement, knowledge, attitudes and behavior concerning energy consumption.

6.2 Experiments on personalization of avatars and competition

Research on how different game elements can enhance learning outcomes needs more empirical proof (Chen et al., 2020; Chen & Law, 2016; Cruz et al., 2017; Erhel & Jamet, 2013; Hamari, et al., 2016). For that purpose, in the next phase of research a 'value-added' approach is applied. Studies using this approach focus on the question of which features of a game promote learning. Conditions including preselected features are compared to a condition with a base version of the game (Mayer, 2014). In this chapter the effects of the persuasive features personal relevance using personalized avatars and social interaction by means of competition on participants' engagement, knowledge, attitude and behavior with respect to sustainable energy consumption with *Powersaver Game* are examined.

It is to be expected that personalization of game features in general should lead the game to be more relevant for the player, and as a consequence stimulate the transfer of information from the game world to the real-world (Van Der Spek, 2011; Wouters & Van Oostendorp, 2017). To give an example: A feedback feature is more personalized when simulations of future scenarios are customized for a household and presented to players, such as how much energy and money will be saved when conservation measures are continued. The use of adaptive algorithms that incorporate player data (in the case of household energy conservation, e.g., household characteristics, appliances and historical energy consumption) are effective in forecasting, and can create realistic simulations of future scenarios, making the game more relevant for players. Personalized feedback will then provide more insight of future effects of behavior changes to players (Dennis et al., 2016; Pham et al., 2020). It is then also possible to personalize instructions that are provided by the game (Johnson et al., 2017; Johnson & Priest, 2014). Energy conservation missions will then be adjusted to household characteristics and its performances. Unfortunately, *Powersaver Game's* technical architecture is not sufficient to examine personalization of feedback and instructions features.

In this thesis, an approach has been chosen to stimulate personal relevance by using personalized avatars. The avatars represent the residents of the household in the game. This feature can enhance considerably the engagement of users (Clark et al., 2019; Kang & Kim, 2020; Li et al., 2013). The second game feature in this value-added study is competition. In general, competition is a fundamental game feature (Salen & Zimmerman, 2004) that should enhance motivation and stimulate cooperation and learning. However, research provides no empirical evidence yet of effects when intervention periods are long and competition is applied in less-structured domains (Cagiltay et al., 2015; Chen et al., 2020; Sanchez, 2017). As described in Section 3.3, there are many game features that are recommended to be examined (Mayer, 2016; Wouters & Van Oostendorp, 2017). The main argument for choosing the features personalization and competition for this study is that both are relatively easy to implement in the game design and technical architecture of *Powersaver Game*.

In experiments, the focus is on comparing a group of households in the intervention condition that play *Powersaver Game with* the feature (personalized avatars or competition feature) and a similar group of households in the control condition that also play *Powersaver Game* but *without* the feature (personalized avatars or competition feature). The hypothesis is that engagement, knowledge, attitude and energy conservation of participants playing the game with personalized avatars or the competition feature will increase more than that of participants in the control condition, because personalized avatars can enhance engagement (Clark et al., 2019; Kang & Kim, 2020; Li et al., 2013), and it is expected that social comparison between households by means of competition will stimulate goal orientation with respect to competitors/other households, and therefore enhance collaboration within households (Cagiltay et al., 2015; Chen et al., 2020; Sanchez, 2017). Therefore, they will make more effort to accomplish missions that take place in the real-world (e.g., washing clothes at low temperatures and taking shorter showers) than households in the non-competition condition, and therefore probably attain better results.

We decided to first conduct a pilot experiment to examine the effects of personalized avatars, because, as described below, it takes researchers a lot of effort to customize/adapt the appearance of the avatar's head to a player. Also, we decided to shorten the mission time to 48 hours, and let households install the datalogger themselves. In this pilot experiment, the competition feature in *Powersaver Game* is absent and thus does not affect outcomes. The aim is to focus the experiment only on the effects of the personalized avatars without the influence of competition.

6.3 Method pilot experiment personalization of avatars and no competition

6.3.1 Research question

A value-added approach examines the instructional effectiveness of game features within DGBL applications, answering the research question: '*Which game features of a DGBL application exactly promote lasting changes in engagement, knowledge, attitude and behavior?*' In a value-added experiment, the primary independent variable is the presence or absence of an instructional feature, in this case, the personalization of avatars in *Powersaver Game*, a reality-enhanced serious household energy conservation game (Mayer, 2014). Before the intervention starts, the avatars (customized to the household or standard) in *Powersaver Game* are selected by the researchers to create an intervention condition (including personalized avatars) and control condition (including standard avatars) of families. In both conditions, everyday families receive the same information about energy conservation measures and receive feedback. Engagement, knowledge transfer, i.e., learning results of participants, but also their attitude and behavior, i.e., energy consumption, are measured.

6.3.2 Participants pilot experiment

In this pilot experiment 9 households including 16 participants older than 12 years participated on a voluntary basis. The households consist of 3 families with children, 4 families without children and 2 single-person households. We decided to do this pilot with a small number of participants because, it takes a lot of effort to customize/adapt the appearance of the avatar's head to a player. Also, we want to examine the effects of shortening the mission time to 48 hours and of households installing the datalogger themselves.

No less than 7 households with a total of 13 participants dropped out during the intervention. The remaining 3 participants who finished the game and 4 participants that dropped out filled in all questionnaires.

6.3.3 Design feature personalized avatars

Personalized avatars are created prior to the intervention and provided to households in the experimental group. This requires a lot of effort from both the participants and the researchers involved. Participants assigned to the intervention condition are asked to send pictures of their faces, from multiple angles and a neutral background, to the researchers. These photos are turned into personalized avatars using the mobile application Myidol (version 1.0, TinyCell). Using the Photoshop application (version 2018, Adobe), the faces of the personalized avatars are then superimposed on the original avatars in *Powersaver Game*. Households assigned to the control group use the original avatars. An example of both the personalized and the standard avatars are presented in Figure 22.

The personalized avatars represent the residents of the household and are expected to considerably increase user engagement (Clark et al., 2019; Kang & Kim, 2020; Li et al., 2013). However, it should be noted that both personalized and standard avatars in *Powersaver Game* are 'static', meaning that their physical appearance and clothing are standard, i.e., not personalized to the player, and their state/emotions are not dependent on the game results and/or game narrative. This is due to technical limitations, which could be a possible weakness of the implementation of this feature.

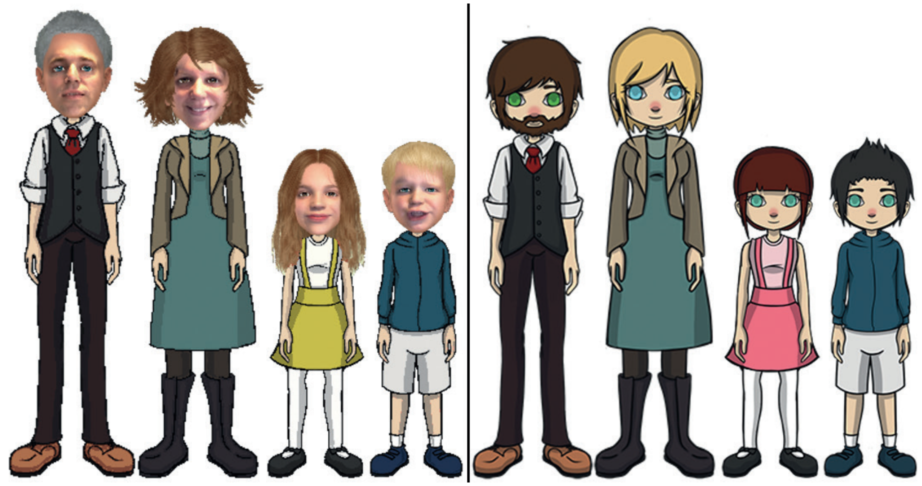


Figure 22. Personalized avatar (on the left) and standard avatar (on the right).

6.3.4 Measurements pilot experiment

The measurements in this pilot experiment are done in exactly the same way as in the previous media comparison study (see Section 5.4). Participants completed an online pretest as well as an online posttest questionnaire to assess their attitude towards sustainable energy consumption related topics and knowledge level towards household energy conservation. For attitude measures both questionnaires included 30 statements rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree. Different statements on the same topics are used in pretest and posttest. Fifteen statements are regarding micro-level attitude topics (about sustainable energy consumption in a household) (see Appendix 5) as well as 15 statements regarding macro-level attitude topics (10 statements about sustainable energy and 5 statements about sustainability) (see Appendix 4). For the knowledge measures 12 multiple-choice questions including 4 answer options per question are used (see Appendix 3). The questions are related to the content about energy conservation from both applications. The same questions are used in the pretest and posttest. To monitor engagement participants completed an online questionnaire in the second week and the last week of the intervention (see Appendix 1). Both questionnaires included the same 7 statements to be rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree. Behavior, in the form of energy consumption, is monitored during 21 days right before the intervention to set a good baseline of average energy consumption. Energy consumption is monitored during the intervention. In both applications the user is getting feedback (on energy use and savings) during the intervention. Right after the intervention the energy consumption is monitored for 21 days to examine the impact of the intervention. To evaluate *Powersaver Game* itself in the online posttest questionnaire 15 statements, rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree, and 1 open question, are used. Of those, 11 statements are about learning to save energy with the game (see Appendix 2), and the 4 remaining statements are about the avatars and the absence of the competition feature.

6.3.5 Procedure pilot experiment

Participants have been recruited using various methods and communication channels like social media, direct mail, digital newsletters and public lectures. Participants registered at the beginning of 2018 using an online form. They could participate when the technical situation of their energy supply (e.g., presence of smart energy meter) was adequate. In spring 2018, 16 participants from 9 households filled in the online pretest. To monitor real energy consumption in this period also hardware was sent to the households, and had to be installed by the participants themselves. This was a difficult task for some households, and support had to be provided. It took at least 21 days of monitoring to set a firm baseline. All participants above 12 years replied to the pretest questionnaire about attitude and knowledge and the first engagement questionnaire in the second week of the intervention. Participants are randomly assigned to conditions, however we ensured that there was a global matching between conditions on the composition of the household (adults and children), attitude towards energy conservation (higher or lower than average compared to other participants) and energy consumption (higher or lower than average of the same type of households in The Netherlands). Knowledge scores are not used in this assignment process because all participants scored very low. Five households are assigned to the game condition and 4 households are assigned to the control condition. The intervention started in April and ended in July 2018, and over this period energy consumption is measured. From the 5 households that started in the intervention condition 1 household finished after 9 weeks. From the 4 households that started in the control condition 1 finished after 10 weeks. 7 Households that didn't finish, didn't get far in the gameplay and didn't do many missions in real-life. They eventually stopped permanently between 2 and 9 weeks.

When a household finished all the sessions or permanently quit the game, they were asked to fill in the online posttest. Twelve participants responded to the posttest questionnaire after the intervention. The hardware was disconnected after at least 21 days from the end of the intervention, and had to be returned in a post package. Some households refused to do this.

6.3.6 Results pilot experiment

As expected, there are no significant differences detected, due to the fact that even after a much longer period than intended, only 2 households finished the game/intervention and 7 households stopped the intervention early at different moments in time. Thus, it is not possible to measure effects on engagement, energy conservation, knowledge, and attitude within nor between conditions.

Based on the results of the media comparison study (see Chapter 5) it was unexpected that *Powersaver Game* was not effective at all in this pilot experiment. To interpret this outcome, household and participant characteristics of both experiments are examined (see Appendix 7). The characteristics of households, e.g., compositions and type of houses, in this pilot experiment do not differ much from those in the previous media comparison study. Also, knowledge and attitude pre-intervention scores in both studies are similar. A major difference between the studies is detected in the engagement scores, measured in the third week of the intervention. There is a significant difference of 1.9 points between groups. The average score in the pilot experiment is 3.5 (SD = 1.3, N = 13) and 5.4 (SD = 0.9, N = 15) in the previous media comparison study. An independent-samples *t*-test is performed to test if this difference between the two studies on engagement measures is significant. As expected, the difference is significant: $t(28) = 5.18$, $p < 0.05$.

Participants suggested to reduce the mission time and/or provide automatic (push-) notifications when a session has ended, because they regularly forgot that they could proceed in the game. They also suggested that they would be more motivated if they competed with other households: mean 4.4 (SD = 1.2, N = 12).

6.3.7 Conclusion and discussion pilot experiment

Based on the results of this pilot experiment, it can be concluded that after two weeks from the start engagement of participants in both the intervention condition and control condition is low. As a result, only 2 households finished the game after a much longer period than intended, and 7 households dropped out completely. Because of this, it was not possible to analyze the most relevant effects of the game such as knowledge transfer, energy conservation behavior and attitude change, and as a result, we cannot draw any conclusions about the effect of personalization of avatars.

The characteristics of households and pre-intervention scores on knowledge and attitude are similar as in the previous study, where engagement of participants was higher in the previous study and they did not drop out. The main difference between these studies, which could have had an influence on engagement is the absence of competition in the pilot experiment, because participants in the pilot experiment suggested that competition with other households would have motivated them. This will be further explored in the next value-added study examining the effects of the feature social interaction by means of competition.

Although it is a pilot, a clear limitation of this study is the limited number of households participating in this experiment. This limitation also occurs in previous studies (see Chapter 3) and, as mentioned before, points to the difficulties of this kind of research. A more effective strategy for recruiting participants should be considered for the next experiment. Another possible limitation could be the implementation of the personalization feature. The physical appearance and clothing of avatars are standard and their state/emotions are not dependent on game results and/or game narrative. An interesting hypothesis that can be derived from this is that if avatars were adaptive and not static, they could have a stronger influence on engagement in the long term. This should be addressed in future research in reality-enhanced games that focus on the game characteristics that contribute to the game's persuasiveness.

In the next study, the heads of the avatars will not be personalized to participants, because it takes a lot of effort from both the participants and researchers, and the effect on engagement in the long term is questionable. Possible modifications for improvements for the next study are: First, to reduce the mission time from 48 hours to 24 hours, so participants can integrate the use of the game within normal daily household routines and practices. Although the mission time had been shortened to 48 hours, it is possible that this was still not enough for households to integrate the use of the game into normal daily household routines and practices. Second, to provide notifications when they forget to proceed in the game. Third, to monitor the household smart energy meter without having hardware had to be installed in the households. The results provide direction for further research, based on a value-added approach (Mayer, 2014). This is why in the next phase of the value-added study, the effects of the competition feature have been examined.

6.4 Value-added study on competition feature

6.4.1 Method

In the second value-added experiment, the primary independent variable is the presence or absence of the instructional feature competition. The effects of the feature social interaction, by means of competition, on participants' engagement, knowledge, attitude and behavior with respect to sustainable energy consumption with *Powersaver Game* compared to a base version of *Powersaver Game* are examined. Before the intervention starts the competition feature can easily be turned on or off to create an intervention condition and control condition of families. In both conditions, everyday families receive the same information about energy conservation measures and receive the same feedback.

6.4.2 Participants

In this study, 18 households including 31 participants older than 12 years participated on a voluntary basis in this experiment. The households consist of 11 families with children, 4 families without children and 3 single-person households. No households dropped out during the intervention.

6.4.3 Design competition feature

Powersaver Game has a team-based approach of competition, because all persons in the household are involved and form a team. It is expected that this approach stimulates collaboration, and as a consequence makes energy conservation measures to be more enjoyable and engaging. Furthermore, through this team-based approach, the players are aware that for success, collaboration is necessary (Villalta, et al., 2011).

Competition features should be designed in such a way that the experience of uncertainty in winning always remains to the ending (Sanchez, 2017). Therefore, each household in the intervention condition is in competition with 9 virtual (computer-based) households but assumes to play against 9 real households. Competition is simulated to stimulate households to achieve high scores. This way positive influences of social comparison opportunities are stimulated and negative influences prevented like frustration, discouragement and potentially dropping out of less-able players who always lose while more-able players always win (Dindar et al., 2020). Negative feedback was not part of the manipulation. The assumption to compete with real households, which are actually virtual households, should enhance learning and motivation. Players have the impression to be assigned to equal opponents with similar abilities (Cheng et al., 2009). Beside these advantages, it was technically not feasible to implement a real and fair competition.

The competition feature is displayed as a simulated leaderboard where, through displays of rank, comparisons with other virtual households are presented (see Figure 23). Nebel et al. (2020) describe this design as 'artificial social competition' where opponents offer humanlike features, by means of real-looking scores and family names, without actually being human but simulated by a computer algorithm. The energy conservation data of virtual households follow a logical pattern based on the real-time energy conservation results of the real household (see Figure 24). The black line represents the real household of the participant competing against nine other households. The scores of the top 4 ranking households, including the real household, are close to each other, and therefore should stimulate desired behavior.

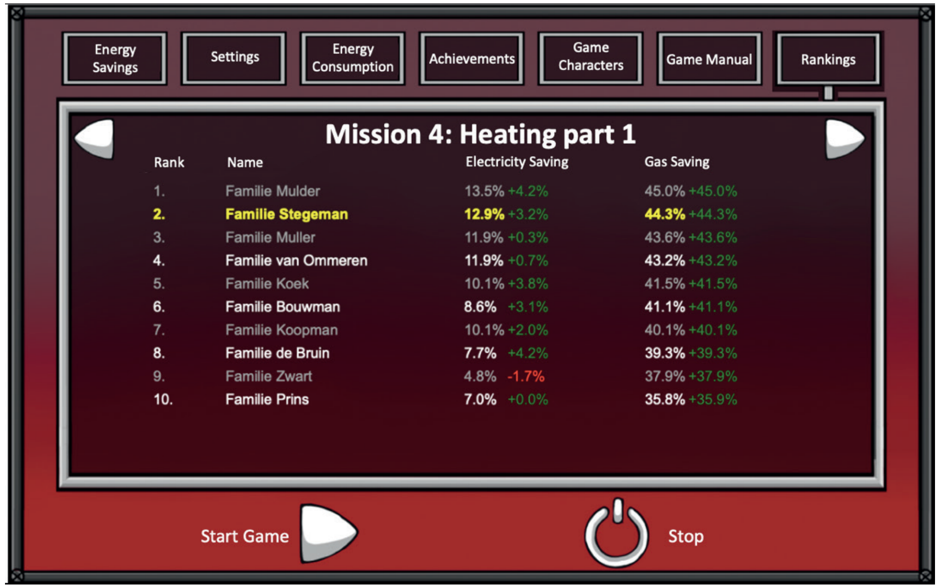


Figure 23. Competition feature *Powersaver Game.*

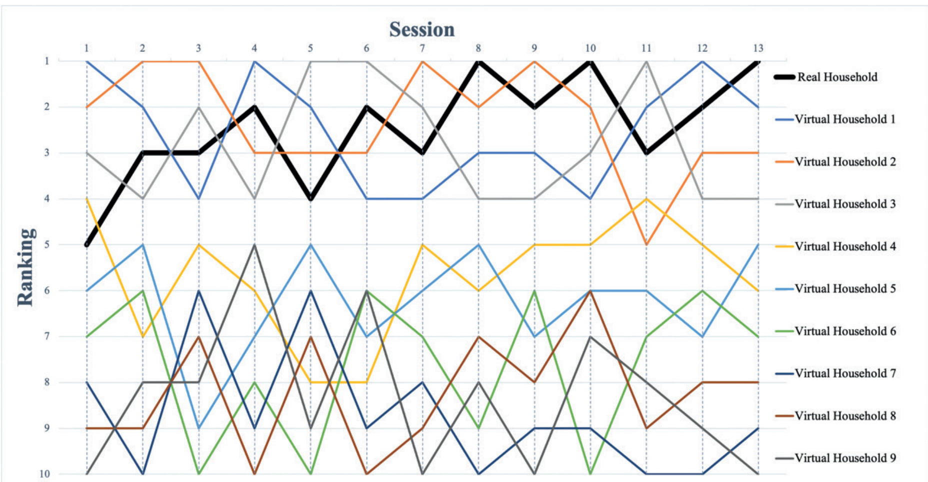


Figure 24. Pattern ranking simulated competition.

Control Condition

For our approach in this study, families used *Powersaver Game* without the competition feature in the control condition. The form, timing and content of the information that the control condition receives, are similar as in the intervention condition, but with the exclusion of the game feature competition. The design of both versions of *Powersaver Game* is identical except the option 'Rankings' —right above in Figure 23, which represents the competition feature— is absent in the control condition.

6.4.4 Measurements

An overview of measurements is presented in Table 17, and the questionnaires are presented in Appendix 1 to 5. Similar to the previous two experiments, participants completed an online pretest as well as an online posttest questionnaire to assess their attitude towards sustainable energy consumption-related topics (see Appendixes 4 and 5) and knowledge level towards household energy conservation (see Appendix 3). Behavior, in the form of energy consumption, is monitored for 21 days right before the intervention. Both kWh electricity and m3 gas consumption are monitored from the smart energy meter. No hardware had to be installed in the households, because the new technical infrastructure is used. Energy consumption data is obtained through the GPRS-network (see Section 4.2: Topic 4. Technical Architecture). Energy consumption is monitored during the intervention. Right after the intervention, the energy consumption is again monitored for 21 days.

To evaluate *Powersaver Game* itself in the online posttest questionnaire 14 statements, rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree, and 1 open question, are used. Of those, 11 statements are about learning to save energy with the game (see Appendix 2), and the 3 remaining statements are about the competition feature. Two questions are for the participants in the control condition and are about pre-expectations of a competition feature and the estimated effect of missing it. One question about the competition feature is for the participants in the intervention condition and is about the assumed effect of it. The last question of the posttest is an open question where was asked to give suggestions for improvements.

Contrary to previous studies, we decided not to use questionnaires to measure engagement, because the intervention has been shortened to three weeks. This is due to the reduction of mission time to 24 hours. In the previous studies, the first engagement questionnaire is completed in the third week of the intervention.

Table 17. Overview of measurements.

	Pre-intervention	Intervention	Post-intervention
kWh electricity & m^3 gas consumption data from the smart energy meter	21 days monitoring	39 days (SD 10 days) monitoring	21 days monitoring
Macro and Micro-attitude assessment	30 Statements *: 15 Micro-level attitude and 15 Macro-level attitude		30 Statements *: 15 Micro-level attitude and 15 Macro-level attitude
Knowledge level	12 Multiple-choice questions including 4-answer options		12 Multiple-choice questions including 4-answer options
Evaluation of application			14 Statements *: 11 about learning to save energy with the game and 3 about the competition feature. One open question about suggestions for improvements.

* 7-Point Likert-scale ranging from strongly disagree to strongly agree

6.4.5 Procedure

The participants in this study are recruited using various methods and communication channels such as social media, digital newsletters and public lectures. Based on the results of the previous two studies, a new strategy was also chosen to recruit participants. Most effort is put into sending direct mail, by sending 3000 randomly selected households in a representative Dutch municipality a letter with the request to register for participation. Participants registered at the end of 2019 and the beginning of 2020 using an online form. They could participate when the technical situation of their energy supply (e.g., presence of smart energy meter) was adequate.

In March 2020, 31 participants from 18 households filled in the online pretest. To monitor real energy consumption in this period also the connection of the smart energy meter and game database was made (see Section 4.2: Topic 4. Technical Architecture)). It took at least 21 days of monitoring to set a firm baseline. All participants above 12 years replied to the pretest questionnaire about attitude and knowledge. Participants are randomly assigned to conditions. However, it is taken care of that there is a global matching between conditions on the composition of the household (adults and children) and energy consumption beforehand (higher or lower than average of the same type of households in The Netherlands). Knowledge scores and attitude towards energy conservation are not used in this assignment process, because all participants scored very low on knowledge and very high on attitude. All household types are equally represented in each condition, finally, 10 households are randomly assigned to the intervention 'competition' condition and 8 households are randomly assigned to the control 'noncompetition' condition.

The intervention started in March 2020 and ended in May 2020. Some households ended at the beginning of June, due to delays in starting new sessions. During this period, the energy consumption is measured by monitoring the energy consumption data from the smart energy meter. The energy measurement stopped after at least 21 days from the end of the intervention. All 18 households that started, finished on schedule. When a household finished all the sessions, they were asked to fill in the online posttest. On average the intervention took 39 days (SD 10 days), and no significant difference between conditions is detected.

6.4.6 Results

The effects on energy conservation, knowledge measures, and attitude measures are presented below. Energy conservation between the competition condition and control 'non-competition' condition is based on 10 households from the competition condition and 8 households from the control condition. Unfortunately, part of the post-measurements fell outside the heating season. In this season, Dutch households warm their houses using gas boilers because the maximum outside temperature is below 18.5 degrees. This causes a large difference in m^3 gas consumption between the heating and non-heating seasons. Although the heating season has ended somewhere in the post-measurements period, still, conditions can be compared because the seasonal effect is for both the same.

6.4.6.1 Energy Conservation measures

The results in energy conservation of households, during the 21 days post-intervention period (right after the intervention) compared to the pre-intervention period, for the 10 households in the competition condition and 8 households in the control condition are presented in Table 18. The average energy consumption per day from 21 days right after the intervention is for all households compared to the consumption over 21 days right before the intervention. The difference in percentage change of total energy consumption (%Δ kWh electricity + %Δ m^3 gas/2) is presented as well as, separately, the percentage change in consumption in kWh electricity and m^3 gas, respectively. Percentage change is defined as the change from the original value at the pre-intervention. As household conservation of both kWh electricity and m^3 gas are related, we conduct first a multivariate analysis of variance (MANOVA). There is no significant difference between the competition and control condition when considered jointly on the variables conservation of total energy, kWh electricity and m^3 gas: Wilk's $\Lambda = 0.77$, $F(2, 15) = 2.19$, $p = 0.146$, partial $\eta^2 = 0.226$. The outcome of Wilk's L is a measure of the percent variance in the combination of the dependent variables conservation of kWh electricity and m^3 gas, that is not explained by differences in levels of the independent variable competition and control condition. A higher value of Wilk's L indicates smaller differences between the competition and control condition. The value of 0.77 is high. A high partial h^2 represents the proportion of variance in the combination of the dependent variables conservation of kWh electricity and m^3 gas that can be explained by the variance in the competition and control condition. The value of 0.226 is small. Next, we conduct a correlation analysis. There is no significant correlation detected between electricity and gas consumption, $r(18) = -0.1$, $p = 0.69$. Surprisingly, the intervention had somehow a different positive effect on kWh electricity compared to m^3 gas conservation. Probably this is caused by the seasonal effect on m^3 gas conservation. In view of these results, also a univariate analysis is conducted. Independent-samples *t*-tests on the gain scores are performed to test if differences in percentages of change between the competition and control condition on each of the energy conservation measures are significant.

At the post-intervention period there is a significant difference of 7.9% in total change in energy conservation between both conditions: $t(16) = -1.83$, $p < 0.05$ (one-tailed t-test): while the competition condition consumes 51.5% less energy than in the total 21 days pre-intervention period, the control condition consumes 43.6% less energy. The difference between the groups of 4.3% kWh electricity consumption is not significant: $t(17) = -1.1$, $p > 0.05$. When we look specifically at the conservation of m^3 gas there is a significant difference of 9.6% between groups: $t(16) = -1.81$, $p < 0.05$ (one-tailed t-test). The competition condition consumes almost 71.5% less m^3 gas than before, while the control condition consumes 61.9% less m^3 gas than before.

Table 18. Energy conservation: mean changes, standard deviations, t-statistic and significance level of difference.

Energy Conservation	Competition		Control		Difference		
	M	SD	M	SD	M	t	p
Total	51.5%	10.3	43.6%	7.5	7.9%	-1.83	<0.05 *
kWh electricity	15.8%	8.8	11.5%	8.3	4.3%	-1.1	ns
m^3 gas	71.5%	11.2	61.9%	11.2	9.6%	-1.81	<0.05 *

* One-tailed   ns—not significant at 0.05 level

6.4.6.2 Knowledge measures

In total, 31 participants filled in all questionnaires for knowledge and attitude measures: 16 from the competition condition and 15 from the control (non-competition) condition. Paired-samples *t*-tests and independent-sample *t*-tests are executed to conclude whether differences between the pretest and posttest are significant within and between conditions. The results in knowledge measures of all participants are presented in Table 19.

Table 19. Knowledge in the competition and control condition: means, standard deviations, t-statistic and significance level of difference.

Knowledge *	Competition		Control		Difference		
	M	SD	M	SD	M	t	p
Difference (Post-Pre)	2.19	2.56	1.2	2.18	0.99	1.15	ns
Pretest	4.06	1.57	4.60	1.5	-0.54	-0.97	ns
Posttest	6.25	1.88	5.80	2.18	0.45	0.62	ns
t	3.42		2.13				
p	<0.05		<0.05				

* Maximum score = 12   ns—not significant at 0.05 level

The average score on the knowledge of participants in both conditions increased. Although the average score in the posttest is not high (the maximum score possible is 12 points), knowledge about energy conservation increased significantly. In the competition condition the average score on knowledge increased 2.19 points: $t\,(15) = 3.42$, $p < 0.05$. In the control condition, the average score on knowledge only increased 1.2 points: $t\,(14) = 2.13$, $p < 0.05$. However, there is no significant difference between the competition and control conditions in gain scores $t\,(29) = 1.15$, $p > 0.05$.

6.4.6.3 Attitude measures

As the attitude of both micro-level and macro-level are related, we conduct first a multivariate analysis of variance (MANOVA). There was no significant difference between the competition and control condition when considered jointly on the variables (difference scores) attitude total, micro-level attitude and macro-level attitude: Wilk's $\Lambda = 0.95$, $F\,(3, 27) = 0.44$, $p = 0.73$, partial $\eta^2 = 0.46$. The outcome of Wilk's L is a measure of the percent variance in the combination of the dependent variables attitude total, micro-level attitude and macro-level attitude, that is not explained by differences in levels of the independent variable competition and control condition. A higher value of Wilk's L indicates smaller differences between the competition and control condition. The value of 0.95 is high. A high partial h^2 represents the proportion of variance in the combination of the dependent variables attitude total, micro-level attitude and macro-level attitude, that can be explained by the variance in the competition and control condition. The value of 0.46 is small. Despite these results, we decided to analyze the univariate effects of variables to examine whether the manipulation of the competition influenced change in attitude. For attitude measures, paired-samples *t*-tests and independent-sample *t*-tests are executed to investigate whether differences between the pretest and posttest are significant within and between conditions. The results are presented in Table 20.

Attitude scores from all participants are already high from the beginning. There is a small but significant difference of 0.38 points between conditions before the intervention: attitude total: $t\,(29) = 1.99$, $p < 0.05$. On a deeper level this difference is located in micro-level attitude: $t\,(29) = 1.89$, $p < 0.05$ (one-tailed t-test). In the posttest this difference disappeared: attitude total: $t\,(29) = -0.61$, $p > 0.05$. Attitude scores in the control condition changed significantly: attitude total control condition: $t\,(14) = 1.81$, $p < 0.05$ (one-tailed t-test). On a deeper level this difference is detected in micro-level attitude control condition: $t\,(14) = 2.08$, $p < 0.05$. Surprisingly, no significant attitude change was detected in the intervention condition. This indicates that probably a ceiling effect occurred in this condition. Regarding macro-level attitude and micro-level attitude, no significant effects of competition in the change of attitude are found.

Table 20. Attitude in the competition and control condition: means, standard deviations, t-statistic and significance level of difference.

Attitude Total * (Micro-level and Macro-level)	**Competition**		**Control**		**Difference**		
	M	**SD**	**M**	**SD**	**M**	**t**	***p***
Difference (Post-Pre)	0.08	0.41	0.16	0.34	−0.08	−0.61	ns
Pretest	5.71	0.49	5.33	0.57	0.38	1.99	<0.05 ***
Posttest	5.79	0.42	5.49	0.60	0.30	1.60	ns
t	0.74		1.81				
p	ns		<0.05 **				
Micro-level attitude *	**Competition**		**Control**		**Difference**		
	M	**SD**	**M**	**SD**	**M**	**t**	***p***
Difference (Post-Pre)	0.15	0.64	0.29	0.55	−0.14	−0.69	ns
Pretest	5.51	0.57	5.08	0.68	0.43	1.89	<0.05 **
Posttest	5.66	0.47	5.38	0.56	0.28	1.50	ns
t	0.92		2.08				
p	ns		<0.05 ***				
Macro-level attitude *	**Competition**		**Control**		**Difference**		
	M	**SD**	**M**	**SD**	**M**	**t**	***p***
Difference (Post-Pre)	0.006	0.44	0.03	0.32	−0.02	−0.15	ns
Pretest	5.91	0.53	5.58	0.80	0.33	1.36	ns
Posttest	5.91	0.54	5.60	0.77	0.31	1.30	ns
t	0.06		0.33				
p	ns		ns				

* Maximum score = 7, ** one-tailed, *** two-tailed

ns—not significant at 0.05 level

6

6.4.6.4 Chain of events: dependencies between measures

To explore if the assumed chain of events, which is based on theoretical reasoning, as expressed in Figure 2 (see Section 2.1.2) occurs, that is, more accessible knowledge (higher awareness) leads to more attitude change which subsequently leads to greater behavior change (energy conservation change), a path analysis technique is used (Nayebi, 2020). A path analysis is an extension of regression analysis and used to test the fit of a correlation matrix against, in this case, the assumed chain of events (Garson, 2018). To perform a path analysis, first, variables that are related to the events in Figure 2 (see Section 2.1.2) are selected. Next, the path analysis technique is used to explore, by taking successive steps, the directed dependencies of these variables. The emerged path diagram is then compared to the assumed chain of events in behavior change.

The major variables and associated descriptions used in the path model are presented in Table 21. First, accessible knowledge is related to the knowledge score at the post-intervention. Second, attitude change regarding micro-attitude is related to post-intervention micro-level attitude score. Attitude change regarding macro-attitude is related to post-intervention macro-level attitude score. Third, behavior change is related to energy conservation in the 21-day period after the intervention (post-intervention period).

Table 21. Variables path model.

Variables	
Knowledge:	Knowledge score, at post-intervention
Attitude:	Micro-level attitude score, at post-intervention
	Macro-level attitude score, at post-intervention
Behavior change:	Energy conservation, difference between 21-day post-intervention period and 21-day pre-intervention period of kWh electricity and m^3 gas together

Next, a path analysis technique is used to explore the directed dependencies among the selected variables. A path analysis method estimates both the magnitude and significance of relationships between a set of independent variables and the dependent variables, and between the independent variables (Crossman, 2020; Nayebi, 2020). In this way, it makes all causal assumptions in the model explicit (Garson, 2018). Thus, an emerged path diagram consists of independent and dependent variables that have direct and indirect effects on each other, and as a result, can express a chain of events. The terms 'independent variable' and 'dependent variable' can be confusing because, in the procedure, which consists of a series of multiple linear regressions, variables fulfill both roles, except our criterion variable 'Energy conservation'. The calculated path coefficients are standardized regression coefficients (Beta's) showing the direct effect of an independent variable on a dependent variable in the path diagram (Garson, 2018; Nayebi, 2020). Beta coefficients indicate how much a predictor—if significant—contributes to the performance on the criterion variable. It is noticeable that all independent variables in our path diagram are affected by each other and therefore have an indirect, mediating effect (Nayebi, 2020) on the dependent variable Energy conservation. In this study, IBM SPSS AMOS 27.0 was used. A chi-square test, also called the likelihood ratio test, was performed to assess the overall fit of the model. A finding of non-significance corresponds to an adequate model. This is when the model-*implied* covariance matrix does not differ significantly from the *observed* covariance matrix (Garson, 2018).

Based on the assumed chain of events in behavior change Figure 2 (see Section 2.1.2) we take four successive steps to explore: (1) the magnitude and significance of relationships between the independent variables macro-level attitude score, micro-level attitude score and knowledge score, (2) and at the same time the magnitude and significance of relationships of these three independent variables on the dependent variable energy consumption.

The *first* path diagram, presented in Figure 25, is a direct path from the variables macro-level attitude, micro-level attitude and knowledge to energy conservation. The outcome of χ^2 (3, N = 30) = 18.594, $p < 0.05$ indicates that this model is not adequate. There is only a significant path from macro-level attitude to energy conservation (β = 0.339).

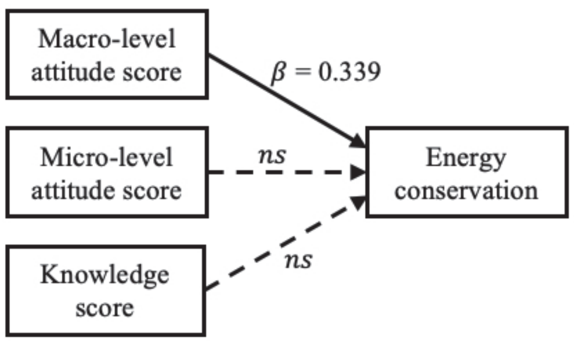


Figure 25. First path diagram: all independent variables separate to energy conservation.

In the *second* path diagram, presented in Figure 26, the significant path between macro-level attitude and energy conservation, as in Figure 25, remains. The hypothesized path runs from the variables micro-level attitude and knowledge via macro-level attitude to energy conservation. The outcome of χ^2 (3, N = 30) = 8.381, p < 0.05 indicates that this model is also not adequate. In this path diagram, only the path from knowledge to macro-level attitude score is not significant.

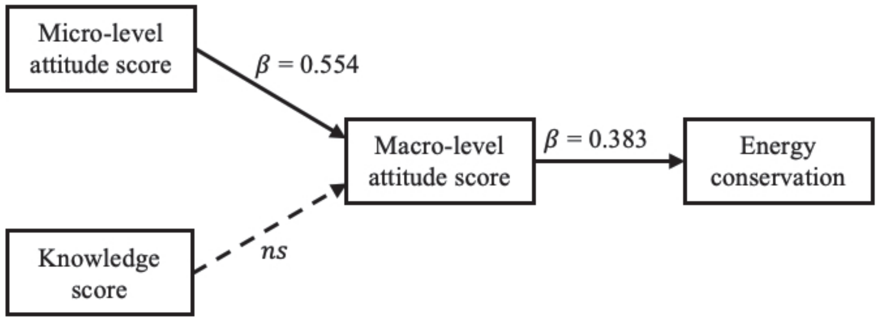


Figure 26. Second path diagram: micro-level attitude score and knowledge score via macro-level attitude score to energy conservation.

In the *third* path diagram, presented in Figure 27, the hypothesized path runs from the variables macro-level attitude and knowledge via micro-level attitude to energy conservation. Compared to the second model, micro-level attitude and macro-level attitude have therefore switched places. Although this model is adequate, χ^2 (3, N = 30) = 5.245, p = 0.16, the most important path from micro-level attitude to the criterion variable energy conservation is not significant.

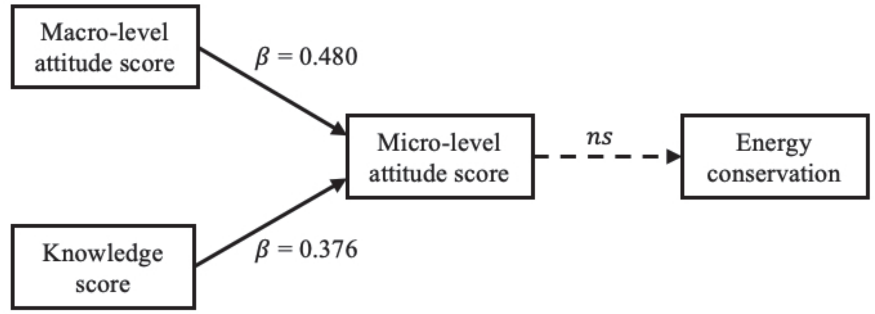


Figure 27. Third path diagram: macro-level attitude score and knowledge score via micro-level attitude score to energy conservation.

In the *fourth* and overall path diagram, presented in Figure 28 (below the line), the path runs first from the independent variable knowledge to micro-level attitude, second from micro-level attitude to macro-level attitude and third from macro-level attitude to the criterion variable energy conservation. The outcome of χ^2 (3, N = 30) = 0.577, p = 0.90 indicates that this model is adequate, and all paths are significant.

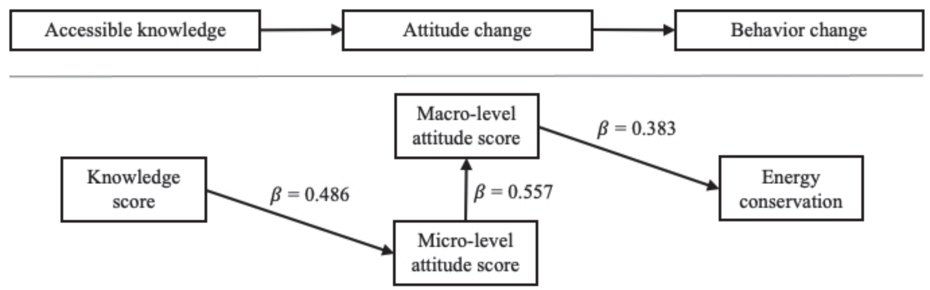


Figure 28. Assumed chain of events in behavior change (above) and overall path diagram (below): First, knowledge score to micro-level attitude score, second micro-level attitude score to macro-level attitude score, and third macro-level attitude to energy conservation.

The outcomes in Figure 28 (below the line) generally support the assumed chain of events as expressed in Figure 28 (above the line). The same relationships between variables emerge empirically and indicate the same direction of causality: First, more accessible knowledge (higher awareness) provided by *Powersaver Game*, is a significant predictor variable of micro-level attitude. Second, micro-level attitude is a predictor of macro-level attitude. Third, macro-level attitude is a predictor of behavior change as expressed in energy conservation.

6.4.6.5 User Evaluation Powersaver Game

The 31 participants evaluated *Powersaver Game* by means of 11 statements about learning to save energy with the game and one open question where participants are asked to give suggestions for improvement. The score on learning to save energy with *Powersaver Game* is on average 4.7 on a 7-point Likert-scale, and the standard deviation is 1.3. There is no significant difference, at the 0.05 level, between groups. The following valuable suggestions for improvement are given: (1) automatic (push-) notifications when a session has ended, (2) shorter mission time (e.g., 20 h), (3) shorter mission texts and (4) general game art improvements (game buttons, animations and saving overviews). Implementation of adaptation features are also recommended by the participants, specifically pre-selection of appliances and energy-saving activities that are relevant to particular households, and composition and appearance of game avatars. It is noticeable that more or less the same suggestions are made as in the previous two studies, while earlier suggestions have been followed.

Competition Evaluation

The competition feature is evaluated by using 3 statements, rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree. One statement is for participants in the intervention competition condition and 2 statements are for participants in the control ‘non-competition’ condition. The participants in the intervention ‘competition’ condition responded positively, mean 4.4 (SD = 1.7), on the statement that the competition feature stimulates to be more involved in *Powersaver Game*. The participants in the control ‘non-competition’ condition scored relatively low, mean 2.8 (SD = 1.4), on the statement if they assumed in advance to compete with other households. Despite this low expectation, they indicate that they would be more motivated, mean 4.1 (SD = 1.8), to accomplish energy conservation missions, if they had to compete with other households in *Powersaver Game*.

6.4.6.6 Validity and COVID-19 measures

To ensure validity, we used extensive questionnaires in the pre- and post-intervention period for knowledge and attitude measures that are based on previous research, and we monitored actual energy consumption over a long period. Nevertheless, during the pre-intervention period, the Dutch government decided to take COVID-19 measures which influenced the regular energy consumption of households. People had to work at home, if possible, and schools were closed. These COVID-19 measures continued during the intervention and post-intervention period. To ensure the validity of the measures, we decided to analyze data from the pre-intervention before the COVID-19 measures were taken. When energy consumption was lower than in the COVID-19 measures period, these are the days that people are partly not at home, it has been replaced for days further back in time when people are the whole day at home. It was possible to obtain this historical data because it was stored in the smart energy meter itself. As a result, the total energy consumption in the pre-intervention period is in line with the situation where people are at home instead of at school or work.

Another validity issue is the composition of the households. Eleven of eighteen households consist of families with children. Although we would like to have more of each type of household represented in this study, all household types are equally represented in each condition. A more general limitation is the limited number of households participating in this study, although still significant differences are found.

Finally, the biased selection of participants is potentially a threat to the validity of the current study. All participants had a high positive attitude towards reduction of energy consumption which on the one hand made it difficult to find changes in attitude, and on the other hand, it restricts the range of participants to which we can generalize.

6.4.7 Conclusion and discussion

In the present study, the long-term effects (in the weeks immediately following the intervention) of the persuasive feature social interaction by means of competition on participants’ knowledge, attitude and behavior with respect to sustainable energy consumption with *Powersaver Game* are examined. Using a value-added approach, *Powersaver Game* including a competition feature versus the same game excluding a competition feature have been compared.

First, we conclude that based on the results of this study, energy consumption changed significantly in the long term. A reality enhanced game, with or without a competition feature, is thus effective in learning people to save energy in the household and to actually do that for the long term. Second and most importantly, a positive effect of competition on behavior change is found: the 10 households in the intervention ‘competition’ condition conserved 8% more energy during the 21 days post-intervention period, compared to the 8 households in the ‘non-competition’ control condition, and this gain effect was significant. This was mainly caused by m^3 gas conservation, while there was no significant difference between both conditions in kWh electricity conservation. Probably this latter difference is not significant because of the high standard deviation in kWh electricity conservation. Despite the fact that there is only a modest (but significant) difference between conditions in energy conservation, participants confirm in post-intervention measures that competition stimulates engagement. Besides energy conservation, no further differences are detected between conditions.

In both conditions knowledge about saving energy at home increased, however, there is no effect found of introducing competition on knowledge. It is somehow unexpected that knowledge measures are low in both pre- and post-measurements. It might be assumed that knowledge transfer from the game to participants progresses in (routine) behavior, but not in increased explicit reproducibility of that knowledge at the test.

The attitude scores on micro-level and macro-level are extremely high and both nearly on the same level. The intervention led only to minor changes and no effect of competition on attitude scores was found. Due to this, a ceiling effect regarding attitude could be the case, resulting in a minor gain in attitude. However, attitude scores are still a significant predictor for energy conservation in the long term as the path analyses show. Krosnick and Petty (1995) argue that the more extreme an attitude is, the more a person likes the object of the attitude and the more likely it is to direct behavior. All participants have a high attitude score, and therefore an extreme attitude towards energy conservation.

The earlier mentioned chain of events of behavior change aligns with the results of the path analysis we performed (see Figure 28). Higher awareness (more accessible knowledge) for a longer period leads to attitude change, which in turn results in behavior change in the long term; particularly the macro-attitude plays here a significant role. Also, important to notice is that both knowledge and micro-attitude are playing an indirect role: the influence on energy conservation runs via macro-attitude. So, there is no direct link between micro-attitude and energy conservation, and no direct link between knowledge and energy conservation. We conclude that knowledge about energy conservation that transfers from the game to the participants is a trigger for attitude about sustainable energy consumption in a household (micro-attitude). Subsequently, attitude about sustainable energy consumption in a household (micro-attitude) acts as a trigger for attitude about sustainable energy in general and sustainability (macro-attitude), which ultimately leads to actual behavior change, in the form of energy conservation. A practical implication is that energy conservation is stimulated primarily by macro-attitude. So macro-attitude is more important for behavior change than micro-attitude as demonstrated by the Beta coefficients in the overall path diagram.

Limitations of this study are the start of the COVID-19 measures during the pre-intervention period and ending of the heating season in the post-intervention period, although this occurred equally in both conditions. Another limitation is the limited number of households participating in this study.

Despite the long intervention time, participants remained engaged during the whole intervention, because all households finished the game and the overall evaluation is positive. This suggests that the game is effective in stimulating participants long-term involvement in household energy conservation activities. Possible modifications for improvements are that the mission's texts and time can be shortened, and more attention can be given to adaptation features and the composition and appearance of game avatars. Adaptive or personalized game features could stimulate desired behavior (Bakkes et al., 2012), such as our competition feature design that incorporates both real-world behavior (energy conservation) and family name.

6.5 General conclusion and discussion value-added study

In previous research, using a media comparison approach, we conclude that *Powersaver Game*, which includes reality by using reality enhanced games principles, is effective in learning people to save energy in the household and to actually do that for the long term, in the weeks immediately following the intervention (see Chapter 5). In the present value-added study, the long-term effects of the persuasive features personal relevance using personalized avatars and social interaction by means of competition on participants' engagement, knowledge, attitude and behavior with respect to sustainable energy consumption with *Powersaver Game* are examined. For this approach, in two studies *Powersaver Game* including a feature is compared to the same game excluding this feature. In the first study, a pilot experiment, the aim is to examine the effect of personalized avatars and in the second study the competition feature is examined.

First, we can unfortunately not draw conclusions about the effect of personalization of avatars. Most participants from the pilot experiment dropped out before the end of the intervention. Because of this, no meaningful measurements on knowledge, attitudes and behavior could be collected, and as a result, we cannot draw any conclusions about the effect of personalization of avatars. Noticeable is that a weakness of the implementation of avatars in *Powersaver Game* is that they are static, meaning that their physical appearance and clothing are standard and their state/emotions are not dependent on game results and/or game narrative.

Second, we conclude from the results of the second value-added study that competition had a positive effect on behavior change. Noticeable is that participants in the control condition of the second study did not drop out, while the competition feature was absent as in the previous pilot experiment. A possible explanation that participants did not drop out is that the mission time had been shortened from 48 hours to 24 hours. This allows households to complete and start a mission every day, which is probably positive for integrating this activity into a daily routine. The decision to shorten the mission time is based on outcomes of previous evaluation measures.

Overall, it can be concluded that a reality-enhanced serious game that includes the feature social interaction by means of competition is, thus, effective in learning people to save energy in the household and is actually doing that in the long term, in the weeks immediately following the intervention, while the effects of the feature personal relevance using personalized avatars that are 'static', not responsive to gameplay, are still unclear. Also, it can be concluded from the results of the path analysis that knowledge about energy conservation that transfers from the game to the participants is a trigger for attitude about sustainable energy consumption in a household (micro-attitude). Subsequently, attitude about sustainable energy consumption in a household (micro-attitude) acts as a trigger for attitude about sustainable energy in general and sustainability (macro-attitude), which ultimately leads to actual behavior change, in the form of energy conservation.

Limitations of these studies are the limited number of households participating in these studies. In particular, the number of nine households in the pilot experiment is too small to draw firm conclusions. It is worthwhile to note that, significant differences are found in the second value-added study. Another limitation is the appearance of personalized avatars in the pilot experiment. The design of the avatars is not responsive to the situation in the game, such as the good and bad state of the in-game objects (see Figure 17 in Chapter 4). Responsiveness of avatars to the storyline and/or achievements of players can be more appealing and possibly influence engagement in the long term (Clark et al., 2019; Kang & Kim, 2020; Li et al., 2013).

Future research in reality-enhanced games should continue to focus on the game characteristics that contribute to the game's persuasiveness (Van 't Riet et al., 2018). To bring the research field on energy reduction games theoretically, but also practically further, it would be useful that in addition to competition and personalization of avatars the research question '*Which persuasive features of a reality enhanced game exactly promote lasting changes in knowledge, attitude and behavior regarding sustainable energy use of households?*' is also applied to other features. This is discussed in more detail in the next chapter.

Chapter 7

General Conclusions and Discussion

7. General Conclusions and Discussion

This chapter provides the answers to the central research question and sub-questions of this thesis. We evaluate the experiments and describe how they relate to the theory and our conceptual model. We also provide general conclusions, as well as a discussion of limitations and recommendations for future research.

7.1 Main conclusions

The main conclusion is that a digital energy conservation game for households with real energy conservation activities and feedback by monitoring real-life household energy consumption, which is developed in a thoughtful, iterative user-centered design process, can significantly reduce energy consumption by more than a third in the long term (in the weeks immediately following the intervention). Additionally, competition contributes to even more change in energy conservation.

With the research presented in this thesis we have reached our aim to contribute to the stimulation of individual sustainable behavior by studying how gamification, using a reality-enhanced computer game that takes several weeks to complete, can be a positive means for people to change their behavior on energy use at home. We decided to focus our research on examining the *basic* effects of a reality-enhanced game and its features, because this area of research is new. The scope is therefore primarily limited to the assumed chain of events that more accessible knowledge about energy conservation (higher awareness) leads to more attitude change towards energy conservation and sustainability, which subsequently leads to greater behavior change in energy conservation (see Section 2.2). In a reality-enhanced game the player's real-world activities, such as washing clothes on low temperatures, are integrated into a digital serious game (in this thesis *Powersaver Game*), so that players are immersed in real-life situations that are generated by user interaction with the game (see Section 1.2). Players experience a game in which real-life situations are integrated. We first examined the long-term effects (in the weeks immediately following the intervention) of game-relevant instructional techniques by comparing an energy game versus an energy dashboard. In the second study, we attempt to unravel the conditions under which learning is persistent by comparing an energy game with a specific game feature (e.g., the competition feature) to the basic version of this game without this game feature. To realize this, we introduced '*Powersaver Game*', a reality-enhanced serious game, and an energy dashboard (control condition) (Sahin & Ifenthaler, 2021) as instruments for research (see Chapter 4). By having an energy dashboard and the possibility to add the game features personalization of avatars and competition to the basic version of the game, it is possible to create multiple conditions for research purposes. In addition to the main conclusion as stated above, we also provide insight into the process, the design steps, of developing a reality-enhanced serious game which is an appropriate research tool for empirical randomized controlled trials (see Chapter 4). In the first design step the game prototype was designed based on effective designs in existing games that have similar purpose and energy saving activities in the real-world that are incorporated into the game. In the second design step the potential players evaluated the prototype on the match between in-game scenes and activities in the real-world, and design features.

In this thesis we empirically tested a number of (design-) principles for reality-enhanced games, in this case, to influence household energy conservation. For this purpose, we tested a set of (design-) principles through empirical studies aimed to enhance the instructional design of reality-enhanced games. Real-life energy consumption was monitored so that in this situation the transfer from the experimental situation to the real-life situation is possible. This is something we do not see in most research and can provide interesting new insights. We first examined the effects of the game and next the effects of individual game features. In the first study effects were examined with respect to energy conservation in the household of the energy conservation game compared to an energy conservation dashboard. In the second study effects were examined of the game including a feature, personalized avatars in the pilot experiment and competition in the main experiment, compared to a basic version of the game. The first study is a typical media comparison study (see Chapter 5). In a pretest-posttest design, an empirical study tested whether change in attitude, knowledge, engagement and behavior with respect to energy conservation in the household was different for participants playing *Powersaver Game* compared to a control condition where participants used an energy dashboard with the same content, but excluding game features. An online pretest as well as an online posttest questionnaire was used to assess, (1) participants' attitude towards sustainable energy consumption-related topics, and (2) their knowledge level towards household energy conservation. To assess participants' specific hierarchical attributes of the object of sustainable energy both micro-level attitude topics (about sustainable energy consumption in a household) as well as macro-level attitude topics (about sustainable energy and sustainability in general) were measured. To monitor engagement participants completed an online questionnaire in the second week and the last week of the intervention. Real-world behavior, in the form of real energy consumption of households, was monitored during 21 days right before the intervention, during the intervention, and 21 days right after the intervention. Energy data (real-life energy consumption) were retrieved from the smart energy meter of participating households (see Section 4.2: Topic 4. Technical Architecture).

A general conclusion is that *Powersaver Game* is effective in transfer of energy conservation knowledge, which leads to energy saving behavior on the long term. Our energy conservation game that includes reality by using reality-enhanced gamification principles is, thus, effective in learning people to save energy in the household and to actually do that for the long term, while the energy dashboard does not change that behavior at all. The second study is a typical value-added study (see Chapter 6). We used the same measurements as in the previous media comparison study, to examine the effects of game features. First, in a pilot experiment the effect of standard avatars and personalized avatars was examined. In the next experiment we tested whether change in attitude, knowledge and behavior with respect to energy conservation in the household was different for participants playing *Powersaver Game* with or without competition. A general conclusion is that *Powersaver Game* is effective in transfer of energy conservation knowledge, which leads to energy saving behavior in the long term while competition additionally contributes to more change in behavior. We can unfortunately not draw conclusions about the effect of the feature personal relevance using personalized avatars, because most households stopped the intervention early, so that no measurements could be collected.

Before we could design and develop *Powersaver Game*, the research instrument in this research for conducting experiments, we described the following research gaps (see Section 2.2): First, it is not clear how reality-enhanced games are related to gamification process principles. Second, not much is known about the effectiveness of reality-enhanced games in the long term in the case of household energy conservation, and what the effects of *specific* game features are. Third, a description of a design strategy for reality-enhanced games is still not available, and, in addition, it is not known what the characteristics for evaluating a game design are, and how to implement these as features in a new game design. Fourth, it is not clear which features are key, and what their effects are. Based on the aim of this research to contribute to the stimulation of individual sustainable behavior by studying how gamification, using a reality-enhanced game, can be a positive means for people to change their behavior on energy use at home, and these research gaps, we presented the conceptual model (see Figure 5 in Section 2.2), and were able to formulate the central research question and related-sub questions. By studying three sub-questions we elaborated the central research question and were able to finalize the conceptual model. The central question of this thesis is:

'How can gamification, by means of reality-enhanced games, be used effectively to stimulate long-term sustainable energy use at home?'

Three sub-questions have been studied and reported in the previous chapters of this thesis, the results are summarized below.

Sub-question 1

'What are effective design principles for reality-enhanced household energy conservation games?'

The first sub-question is elaborated in Chapter 3 and Chapter 4. First, six goals were formulated based on the requirements of the design of the reality-enhanced serious game: (1) The game makes players aware of sustainability issues concerning energy use at home. (2) The game enables transfer of information about energy consumption. (3) The game influences energy consumption in real-life. (4) Real-life behavior is integrated into the game. (5) The game is played over a long period of time. (6) The game has a storyline (see Section 3.1.1). Next, a thoughtful user-centered game design methodology, including two design steps, was then used to design a reality-enhanced serious game (see Section 4.1). This approach basically answers the first sub-question. In the first step (design phase) reported effective design features for household energy conservation games such as competition, collaboration, gameplay (including game type, storyline, levels and game characters) and feedback, and empirical effects of household energy conservation games, that met the six goals, were reviewed based on nineteen characteristics (see Section 3.1). Also, household energy saving missions were formulated in this step. These include the approximately 50 activities that can be done to save energy in a household without having to buy any equipment, such as lowering the temperature of the thermostat for heating the household. Based on a novel gamification process these missions have been incorporated in a prototype game design as described in Section 4.2. The technical architecture to monitor real-life energy consumption using a real time connection between the household smart energy meter and game server has changed during the project. In the first study the connection was accomplished by using a datalogger with an Internet connection that is connected to the smart energy meter in a household that has a Wi-Fi network. In the last study the household energy consumption was monitored directly from the smart energy meter via a service provider without having to install a datalogger or any other monitoring equipment in the household (see Section 4.2: Topic 4. Technical Architecture). In the first part of step 2 (evaluation phase) potential players were involved to evaluate the implementation of household energy saving missions in the game. As a result, improvements in activities, scenes and objects in the prototype game design were made and described in Section 4.4. In the next part of step 2 potential players are involved to evaluate the complete design. As a result of this review improvements in artwork were made and described in Section 4.5. By formulating the six goals and using a thoughtful user-centered game design methodology, it was possible to successfully elaborate the first sub-question of this thesis.

Sub-question 2

'What is the long-term effectiveness of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players?'

The second sub-question is elaborated in Chapter 5 and Chapter 6. As for the *individual measures* (as opposed to dependencies between measures), the media comparison study and main value-added study present partly similar results. With engagement measures, by questionnaires in the second and last week of the intervention, we examined involvement of participants in playing *Powersaver Game* and whether this changes during a long-term intervention (see Appendix 1). Knowledge measures, by questionnaires before and after the intervention, assess information that is provided during gameplay, such as energy-efficient washing of textiles and clothing (see Appendix 3). It measures the present knowledge about household energy conservation before and after the intervention. Attitude measures, by questionnaires before and after the intervention, are about sustainable energy consumption in a household (micro-level attitudes) and sustainable energy and sustainability in general (macro-level attitudes). Behavior, in the form of real-life energy consumption of a household, was monitored from the household smart energy meter before, during and after the intervention. The monitoring started 21 days right before the intervention to set a good baseline of average energy consumption. During the intervention, energy consumption data provide feedback to the user on energy use, savings and in-game scores. During 21 days right after the intervention, energy consumption was monitored to examine the impact of the intervention (see Sections 5.4 and 6.4.4).

In Chapter 5, inspired by a media comparison approach (see Section 3.3), a reality-enhanced household energy conservation game (*Powersaver Game*) and a *specific* control condition (*Powersaver Energy Dashboard*) are compared. The control condition consisted of the same form, timing and content of information as the game condition, but with the exclusion of game features such as missions, quizzes, narrative, competition and rewards. It contained energy conservation recommendations, a timer, and in order to give feedback, energy consumption charts and energy conservation results from real-life energy consumption that is monitored from the smart energy meter (see Section 4.3). We conclude that there are differences in learning the same content of the game compared to the dashboard control condition (see Section 5.7). In the game intervention condition energy consumption changed significantly on the long term, while an energy dashboard does not change that behavior at all. From the beginning of the intervention, engagement of participants in the dashboard control condition decreased, resulting in delay in getting energy conservation recommendations, little or no energy conservation or quitting. In the game condition energy consumption (behavior) changed, knowledge about saving energy at home increased, and, despite the long intervention time, engagement remained high during the whole intervention. However, attitude change, about sustainable energy consumption in a household, and sustainable energy and sustainability in general, did not take place. It was high from the beginning and the intervention did not change it. Because of this, a ceiling effect regarding attitude could be the case, resulting in no-gain in attitude.

In Chapter 6, inspired by a value-added approach (see Section 3.3), a reality-enhanced household energy conservation game, '*Powersaver Game*', examines the effects of the features, personal relevance using personalized avatars and social interaction through competition, on involved engagement, knowledge, attitudes and behavior concerning energy consumption. The value-added study mainly elaborates the third sub-question (see below) regarding the long-term (in the weeks immediately following the intervention) effectiveness of *specific* game features, and it also elaborates the second sub-question regarding the long-term effectiveness of a reality-enhanced household energy conservation game in general. It should be noticed that no control dashboard condition, with the exclusion of game features, was present as in the previous study in the control condition. Instead, a base version of *Powersaver Game* was used as control condition. The main conclusion of a pilot experiment, where the effects of personal relevance using personalized avatars are examined, shows similarities to the dashboard condition in the previous study. From the beginning of the intervention, the engagement of participants decreased, resulting in delay, little or no energy conservation or quitting, and as a consequence no changes in knowledge, attitude and behavior could be detected, because unfortunately only a limited number of participants participated (see Section 6.3.7). Despite these results of the pilot experiment, the main study appears to show different results, which are much more expected and in line with the previous media comparison study. It should be noted that more participants were involved in this study (31 participants from 18 households) than in the pilot experiment (16 participants from 9 households). The main value-added study, where the effects of the competition feature are examined, showed generally similar results on individual measures as in the media comparison study on involved engagement, knowledge, attitude and behavior measures (see Section 6.4.7).

The following answer can be given to the second sub-question concerning individual measures. Both studies present long-term effectiveness of a reality-enhanced household energy conservation game. Real-life energy consumption (behavior) changed positively (more energy conservation) with 34% in the media comparison study and 48% in the value-added study. Knowledge about saving energy at home increased. Engagement remained high during the whole intervention, and as a consequence everyone was involved and finished the game. Attitude change did not take place because of a ceiling effect, attitude was already high from the beginning and the intervention did not change it.

As for the *dependencies between measures* (as opposed to individual measures), the media comparison study and main value-added study present partially complementary results. In the media comparison study only 15 participants filled out all questionnaires. With this limited amount of data, it is not prudent to perform complex statistical analyses, such as a path analysis. Though, a linear multiple regression analysis shows a significant model, indicating that more than 80% of the differences in behavior changes (energy conservation in the long term) are explained by the predictor variables 'behavior change during intervention' and 'attitude pre-intervention' (see Section 5.6.3). In the main value-added study 31 participants filled out all questionnaires. This is more than double the number of respondents compared to the previous media comparison study. The data is more robust allowing for more reliable interpretation of complex statistical analyses. Therefore, a path analysis technique is used to explore the directed dependencies among the selected variables. A path analysis method estimates both the magnitude and significance of relationships between a set of independent variables and the dependent variables, and between the independent variables. The path analysis shows that, first, more accessible knowledge (higher awareness) provided by *Powersaver Game*, is a significant predictor variable of micro-level attitude. Second, micro-level attitude is a predictor of macro-level attitude. Third, macro-level attitude is a predictor of behavior change as expressed in energy conservation (see Section 6.4.6.4). These results are incorporated in the conceptual model, that is explained in Section 2.2 (see Figure 5), and presented in the final conceptual model (see Figure 29).

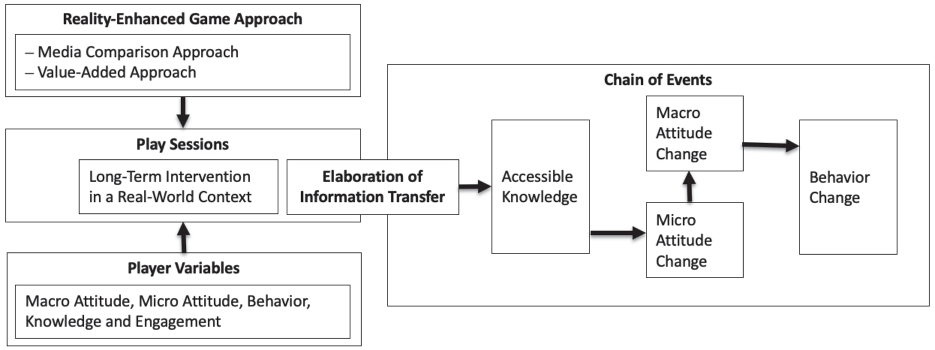


Figure 29. Final conceptual model.

The following answer can be given to the second sub-question concerning *dependencies between measures* (as opposed to individual measures): From the experiments with *Powersaver Game*, that is developed with a thoughtful, iterative user-centered design process and includes reality by using reality enhanced games principles, we conclude that, in a long-term intervention in a real-world context, knowledge about energy conservation that transfers from the game to the participants is a trigger for attitude about sustainable energy consumption in a household (micro-attitude). Subsequently, attitude about sustainable energy consumption in a household (micro-attitude) acts as a trigger for attitude about sustainable energy in general and sustainability (macro-attitude), which ultimately leads to actual behavior change, in the form of energy conservation. This answer is expressed as the 'Chain of Events' in the final conceptual model (see Figure 29).

Sub-question 3

'What is the long-term effectiveness of specific game features of a reality-enhanced household energy conservation game on involved engagement, knowledge, attitudes and behavior of players?'

To answer this sub-question, as described in Section 3.3, we decided, for theoretical and practical reasons, to focus on the game features personal relevance using personalized avatars and social interaction by means of competition. Both game features were expected to stimulate engagement in the long term and keep participants involved until the end of the game. Based on the possibilities, e.g., financial support, available capacity, timespan and technical architecture, both features were relatively easy to implement in a game design. Based on a pilot experiment and main value-added study, as described in Chapter 6, it can be concluded that a reality-enhanced household energy conservation game that includes the persuasive feature social interaction by means of competition is effective on involved engagement, knowledge, attitudes and behavior and is actually doing that in the long term. We can unfortunately not draw conclusions about the effect of the feature personal relevance using personalized avatars, because most households stopped the intervention early, so that no measurements could be collected. In a value-added approach (Mayer, 2014), the effects of the features, personal relevance using personalized avatars (in the pilot experiment) and social interaction through competition (in the main experiment) were examined, *on* involved engagement, knowledge, attitudes and behavior concerning energy consumption. In both studies, and therefore in all conditions (intervention and control), real-life energy consumption was monitored from the household smart energy meter. First, as described in Section 6.3, in a pilot experiment the basic version of the game, including standard avatars, was compared with a version of the game where avatars represented the participants. In both conditions the competition feature was absent. Despite a promotional campaign, unfortunately only a limited number participants were willing to participate. Most participants dropped out before the end of the intervention, and therefore no meaningful measurements on involved knowledge, attitudes and behavior could be collected. In the main study, as described in Section 6.4, the basic version of the game excluding the competition feature, was again compared with another condition, that is a version of the game including the competition feature. Both conditions had standard avatars. The results of this study show that energy consumption in both conditions changed significantly and positively with almost 48% in the long term. (The change in energy consumption is 34% in the media comparison study.) Furthermore, a significant difference of 8% in energy consumption between both conditions after the intervention was detected. Besides the difference in energy consumption, no further differences in involved engagement, knowledge and attitude were detected. Therefore, it seems that competition had a positive effect on energy consumption behavior change. Noticeable is that participants in the control condition, using the basic version of the game, of the second study did not drop out, while the competition feature and personalized avatars were absent as in the previous pilot experiment. A possible explanation that could make clear the fact that participants in the control condition of the main study did not drop out as the participants in the pilot experiment, is that based on the outcomes of previous studies, the mission time had been shortened from 48 hours to 24 hours. This allows households to complete and start a mission every day which is probably positive for integrating this activity into a daily routine (see Section 6.5).

7.2 General limitations of the research

In the first phase of the project when *Powersaver Game* was designed, it was only evaluated by using questionnaires on paper. A limitation in the design process is that after this evaluation, the game was not evaluated live with households before the media comparison study started. This would have taken too much time and effort (e.g., attracting participants and gathering results would take too long) compared to the expected outcomes. Therefore, to finetune the game, small adjustments have been made after each experiment: e.g., mission texts have been shortened, mission times have been shortened and updates have been made in the user manual.

Compared to previous studies, the experiments in this thesis involved many more households. However, for statistical reasons, there should have been more participants to ensure and optimize validity, reliability and accuracy so that the findings and conclusions can be generalized to a broader population. Therefore, the largest limitation of the project is the limited number of households participating in each study, despite the effort in campaigns that have been organized. This limitation also occurs in related studies (Fijnheer & Van Oostendorp, 2016) and points to the difficulties of this kind of research. It appears that the general public is rather reluctant to participate in this kind of study. Since the latest study it was possible to scale up the number of participants with the more user-friendly technical architecture. The smart energy meter can be monitored without additional hardware. However, a much larger campaign was needed to reach and convince potential households to participate. It should be noted that in correspondences with potential participants, we found that people experience some barriers to participating. First, some prefer to use the game right after signing up. This is not possible because it is necessary to monitor household energy consumption 21 days right before the intervention to set a baseline of average energy consumption. Second, people experience privacy-related issues when monitoring real-life energy consumption. Third, in the previous technical architecture a datalogger had to be installed to monitor household energy consumption, and in some cases also a device to connect the datalogger to the internet. We had to visit households to install and disconnect the dataloggers, or people had to do it themselves. Fourth, some households generate their own energy, e.g., with solar panels. Self-generation of energy is not integrated into the technical architecture. Fifth, people are not eager to fill in questionnaires. It is worthwhile to note that, although the number of households was limited, still significant differences are found.

Related to the limited number of households is the limited diversity of households. Although various household types (single-person households, two-person households and family households) are equally represented in each condition, it would be more adequate to have more of each type. Also, the biased selection of participants is potentially a threat to the validity of the studies. All participants had from the beginning a high positive attitude towards reduction of energy consumption, which made it difficult to find changes in attitude and it restricts the range of participants to which we can generalize.

The research topics ‘game usability’ and ‘collaboration’ were not extensively included in our experiments. If we had included these topics, it would have provided insights into participants’ interaction with the game and collaboration within the household. We decided to focus our research on examining the *basic* effects (involved engagement, knowledge, attitude, behavior and evaluation measures) of a reality-enhanced game and its features, because this area of research is new. It was not possible to monitor players during the intervention, as there are no tools for monitoring interaction and collaboration incorporated into the game’s technical architecture. It was also not feasible to add more questionnaires. The participants already had to fill in many questionnaires.

Another limitation of the studies is that they all took place in spring. It could be that other effects are detected when it takes place in the winter period when more energy is consumed by households. However, still significant differences were found between intervention and control conditions.

7.3 Efficacy Guidelines, Implications and Future research

In the first experiment of this research, using a media comparison approach, we concluded that there are differences in learning the same content of a reality-enhanced energy conservation game, developed by using a thoughtful, iterative user-centered game design methodology, compared to an energy dashboard control condition. Furthermore, we concluded that energy consumption changed significantly in the long term. In the second experiment of this research, using a value-added approach, we concluded that social interaction by means of competition, when competition is simulated by using virtual competitor households to stimulate high scores, significantly improves energy conservation even more.

Guidelines

As a result of the research outlined in this thesis, we propose the following guidelines to enhance the efficacy of reality-enhanced serious games on household energy conservation:

Guideline 1. A thoughtful, iterative user-centered game design methodology including two design steps, can lead to a high-quality reality-enhanced serious game that is effective in changing knowledge, attitude, energy conservation behavior, and engage players during playing in the long term. In step 1 a game prototype is constructed by combining design principles and energy saving missions. In the first part of step 1 the design of a game prototype is established by analyzing the designs and empirical effects of existing games that have a similar purpose. In the second part of step 1 energy saving activities are formulated and are incorporated in the game design. In step 2 potential players evaluate the prototype. In the first part of step 2 the match between in-game scenes and activities in the real-world is evaluated, and in the second part of step 2 design features of the complete system are evaluated.

Guideline 2. Implementing real-world processes into a game design stimulates the transfer of knowledge between the game world and the real-world and thus changes behavior related to energy consumption.

Guideline 3. Social interaction by means of competition, when competition is simulated by using virtual competitor households to stimulate high scores, improves behavior change with respect to energy consumption.

Guideline 4. Daily interaction with the game, as a design principle, can probably stimulate engagement in the long term as it is incorporated into the player's daily routine.

Implications

The results of the studies in this thesis can have considerable implications for policymakers, e.g., related to the energy transition (European Commission, 2021), and companies in the field of smart energy meters, e.g., energy providers and Smart Home service providers. Currently in practice, only dashboard designs (Sahin & Ifenthaler, 2021) are used to give feedback on energy consumption (e.g., Google Nest Thermostat), and the media comparison study (see Chapter 5), and also other research, indicate that these dashboard designs are probably not effective in the long term (Geelen et al., 2019; Hargreaves et al., 2010). A recent publication by PBL Netherlands Environmental Assessment Agency, the national institute for strategic policy analysis in this field, also confirms the limited effects of energy dashboards (Vringer et al., 2021). These results are in line with the main conclusions of a meta-analysis of Clark et al. (2016). Their first conclusion is that games enhance learning relative to nongame conditions, such as our dashboard control condition. Their second conclusion is that games that incorporate reality, such as real household energy consumption, enhance learning even more.

Future research

The results can be used in the development of effective, future games, especially in the field of household energy conservation. There still remain several research gaps in this area of research, because little empirical research has been done so far on the effectiveness of reality-enhanced games in the long term. Even after our research project, gamification by applying reality-enhanced games still has a great potential for behavior change and attitude change in novel and engaging ways. Stimulation of individual sustainable behavior is still an important topic in the field of sustainability, both from a social perspective (European Commission, 2021; Vringer et al., 2021) and a scientific perspective (Douglas & Brauer, 2021; Gustafsson et al., 2009b). Our research provides insight in the effectiveness of reality-enhanced games in the long term, both in general, and specifically in the case of household energy conservation, but more empirical research is necessary to attain more knowledge and to be able to generalize our findings. Also, more empirical research is needed to study the empirical effects of several (key-)game features of household energy conservation games on player's engagement, knowledge, attitudes and behavior.

To bring the research field on reality-enhanced energy conservation games theoretically, but also practically further, future research should continue to focus on the game characteristics that contribute to the game's persuasiveness (Van 't Riet et al., 2018). It would be useful that in addition to competition and personalization of avatars (see Chapter 6) the research question '*Which persuasive features of a reality enhanced game exactly promote lasting changes in knowledge, attitude and behavior regarding sustainable energy use of households?*' is also applied to other features. For that purpose, in next research, researchers should thus continue with a 'value-added' approach (Mayer, 2014). As in this thesis, the effects of persuasive features - separately and combined - on participants' engagement, knowledge, attitude and behavior with respect to sustainable energy consumption should be examined, with new innovative reality-enhanced household energy games. These games should be developed by using a thoughtful, iterative user-centered game design methodology as explained in Chapter 4. Also, it is recommended to implement the nine effective or promising instructional techniques in terms of learning and/or motivation that are suggested in the meta-analysis of Wouters and Van Oostendorp (2017): content integration, context integration, assessment and adaptivity, level of realism, narration-based techniques, feedback, self-explanation and reflection, collaboration and competition, and modeling. Unfortunately, this meta-analysis was published after we developed *Powersaver Game*. For research purposes, and as a follow-up to this thesis, special attention should be given to three features that are based on these instructional techniques. First, *personal relevance* by means of *adaptive* personalized avatars. As a follow-up to our pilot experiment, these avatars should be adaptive and responsive to participants and gameplay (e.g., narrative and results). Avatars will represent the residents of the household, including physical appearance and clothing, and their state will depend on the game results of the player (Clark et al., 2019; Kang & Kim, 2020; Li et al., 2013). This feature can enhance considerably the engagement of users in the long term. Second, more personalized *feedback*. The game will present simulations of future scenarios to players, such as how much energy and money will be saved if conservation measures are continued. Adaptive algorithms should be integrated in the technical architecture, so that player data (e.g., household characteristics, appliances and historical energy consumption) can be used in forecasting to create realistic simulations of future scenarios. Personalized feedback then gives players more insight into future effects of behavioral changes (Dennis et al., 2016; Pham et al., 2020). It is then also possible to personalize instructions. For instance, energy conservation missions can then be adjusted to household characteristics and performance (Johnson et al., 2017; Johnson & Priest, 2014). Third, *collaborative-competitiveness* by means of competing groups of households while collaborating within groups. As a follow-up to the second value-added study, in addition to collaboration within the household, also collaboration between households can be possible. Collaboration within teams of households can be stimulated, facilitated and monitored by providing in-game communication tools. Competition is then stimulated by forming groups of households based on location (e.g., neighborhoods or city). The benefits of putting together both collaboration and competition are not yet completely clear. However, it is promising, because collaboration seems to have a greater impact on social skills, whereas competition seems to have greater influence on motivation to spend more effort and concentration on an activity (Buchinger & Da Silva Hounsell, 2018). It is expected that in our situation both features will reinforce each other (Chen et al., 2018).

It should be noted that a new game for future research could be more automated and should require less external monitoring. The current version requires a lot of manpower, e.g., for registering participants, monitoring the progress of players and extracting data for research. It is also recommended to add more tools to monitor players, e.g., in-game communication tools, in-game questionnaires and information about game usage.

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Appendices

1. Engagement questionnaire

The statements below (originally in Dutch) are rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree.

1. Powersaver Game challenges me to save energy.
2. I am involved in saving energy through Powersaver Game.
3. I enjoy saving energy with Powersaver Game.
4. Using Powersaver Game is an intense experience.
5. Seeing the new results, I have achieved with Powersaver Game motivates me.
6. I am involved in using Powersaver Game.
7. I find the information that Powersaver Game provides interesting.
8. I would like to continue with the Powersaver Game.

2. Evaluation questionnaire

The statements, nr.1 to nr.11, below (originally in Dutch) are rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree. The last question, nr.12, is an open-question.

1. Powersaver Game has made me more aware of energy consumption at home.
2. With Powersaver Game I save a lot on my energy consumption at home.
3. Using Powersaver Game has made the sustainability theme more important to me than before I used Powersaver Game.
4. Joining Powersaver Game was helpful.
5. The information Powersaver Game provided was credible.
6. The information Powersaver Game provided was relevant to me.
7. I found it interesting to use Powersaver Game.
8. I'm sad that Powersaver Game has ended.
9. I will continue to follow Powersaver Game's savings tips now and in the future.
10. Powersaver Game's content was appealing for me.
11. The way Powersaver Game helped me save energy at home was appealing for me.
12. Do you have any tips to improve Powersaver Game?

3. Knowledge questionnaire

This questionnaire (originally in Dutch) consists of twelve multiple choice questions. The correct answer is presented in bold for each question.

1. Because chargers remain in the socket after use, they use per year in an average household:

A. No electricity
B. 5 Euro in electricity
C. 8 Euro in electricity
D. 40 Euros in electricity

2. Many people leave lights on unnecessarily because they make the following fallacy:
A. It takes very little power.
B. Lamps are using extra power at start-up each time they turn on.
C. When lamps are on, they have warmed up and then use less power.
D. Lamps hardly wear out and therefore last a very long time.

3. Which statement is TRUE about the use of computers.
A. It makes no difference to the computer's energy use where it is located in the home.
B. By keeping the filters and coolers of computers clean, you can save 5 Euros per year.
C. By playing games one evening a week where no computer, laptop and/or tablet is used and all unnecessary devices are switched off, you can save more energy than removing devices from Standby mode.
D. Using the power save mode on the computer saves more energy than turning off the computer screen when you are not using it for a while.

4. Which statement is FALSE.
A. Taking a bath takes more energy than taking a shower.
B. On average, shower time is twice as long as necessary.
C. Shorter showers per year saves just as much money as setting the temperature of the boiler at 60 degrees, namely 60 Euros per year.
D. By closing doors in the house, you can save 20 Euros per year.

5. Which saving measure saves the most energy/money.
A. Lower the temperature in the house to a maximum of 18 degrees.
B. Keeping doors closed.
C. Turn the thermostat at a lower temperature an hour before going to bed or before you leave.
D. Turning off the radiators in rooms where no one is.

6. Which statement is FALSE.
A. By keeping the radiators clean and not putting anything on top or against them, you can save 140 Euros per year.
B. By opening a window in rooms for 10 minutes every day, you can save 60 Euros per year.
C. By closing windows when the heating is on you can save 300 Euros per year.
D. By opening all curtains during daytime and closing curtains at nighttime, you can save 25 Euros per year.

7. Which statement about television is FALSE.
A. We spend almost a quarter of our 'awake' lives in front of the television.
B. A third of the energy use of a television is required for the decoder to make the TV signal from the cable ready for the television.
C. By setting the brightness of your television as low as possible, you can save 25 Euros per year.
D. By not watching television for one evening every week and switching off all unnecessary devices, you can save 75 Euros per year.

8. Energy-efficient washing of textiles and clothing is done as follows:
A. Always fill the washing machine to 75% of its maximum capacity, use a low spin speed and set the temperature at 30 degrees.
B. Always fill the washing machine to its maximum capacity, use a low spin speed and set the temperature at 30 degrees.
C. Always fill the washing machine to its maximum capacity, use a high spin speed and set the temperature at 30 degrees.
D. Always fill the washing machine to 75% of its maximum capacity, use a high spin speed and set the temperature at 30 degrees.

9. Which statement is TRUE.
A. Energy-efficient drying can save you more energy than making tea energy-efficient.
B. The washing machine uses 40% more energy than the dryer.
C. By using the oven energy-efficiently, you can save more than by energy-efficient drying of the laundry with a dryer.
D. The dryer consumes 40% more energy than the washing machine.

10. What is FALSE about the energy-efficient use of the refrigerator and freezer.
A. The optimum temperature of the refrigerator is 6 degrees (position 2 or 3) and the optimum temperature of the freezer is -18 degrees.
B. Many households have products in the refrigerator that can simply be stored outside the refrigerator.
C. Frozen foods are best thawed on the counter.
D. By regularly cleaning the freezer and avoiding a 'freeze layer' you can save 8 Euros per year.

11. Which statement is FALSE.
A. Household appliances that produce warmth consume the most energy.
B. If you want to save energy when watching television, you can do more than just watch television less often and/or for less time.

C. The average laundry gets just as clean at lower temperatures as it does at higher temperatures.
D. The back of the refrigerator should always be as close to the wall as possible.

12. Energy-efficient cooking goes like this:
A. When cooking, always use large size pans and always put the lids on the pans. Preheat the oven, keep the oven door closed as much as possible. When cooking, do not set the extractor hood to a higher setting than necessary. Only switch on the dishwasher when it is really full, use the lowest temperature of the eco program and first remove the largest food residues from the dishes using a basin with cold water.
B. When cooking, always use the correct size pan and always put the lids on the pans. Do not preheat the oven, keep the oven door closed as much as possible and turn the oven off just before the end of the cooking time. When cooking, switch on the extractor hood to a middle setting. Only switch on the dishwasher when it is really full, use the lowest temperature of the eco program.
C. When cooking, always use the correct size pan and always put the lids on the pans. Do not preheat the oven longer than necessary, keep the oven door closed as much as possible and turn the oven off just before the end of the cooking time. When cooking, set the extractor hood to the highest setting and turn it off shortly after cooking. Only start the dishwasher when it is really full, use the highest temperature and choose the shortest program.
D. When cooking, always use the correct size pan and always put the lids on the pans. Do not preheat the oven longer than necessary, keep the oven door closed as much as possible and turn the oven off just before the end of the cooking time. When cooking, do not set the extractor hood to a higher setting than necessary. Only switch on the dishwasher when it is really full, use the lowest temperature of the eco program and first remove the largest food residues from the dishes using a basin with cold water.

4. Macro-attitude questionnaire

The statements below (originally in Dutch) are rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree.

1. It is important that homeowners and housing associations are encouraged to generate their own energy with, for example, solar panels, heat pumps and/or solar boilers.
2. It is important that people are encouraged to purchase energy-efficient appliances.
3. It is useful if people are encouraged to use sustainable green energy.
4. It is important that public buildings should only use sustainable green energy.
5. I do not find it a problem if taxes were to be increased in order to make the transition from fossil energy to sustainable energy in the Netherlands as quickly as possible.
6. It is important that nuclear and coal-fired power stations are closed as soon as possible, even if it costs taxpayers a lot of money.
7. It is important that the appearance of a building is affected by solar panels.
8. Everyone should burden the environment as little as possible by using energy efficiently.
9. It is important that homeowners and housing associations are encouraged to insulate houses.
10. It is important that the government helps by means of subsidy measures to generate your own energy, for example by means of solar panels, solar boilers and heat pumps.
11. It is important that the polluter should pay.
12. I think the environment is more important than the economy.
13. It is important that primary school children learn to live sustainably.
14. It is important that the government and companies invest in recycling.
15. It is important that global warming and climate change are the main themes of politics.

5. Micro-attitude questionnaire

The statements below (originally in Dutch) are rated on a 7-point Likert-scale ranging from strongly disagree to strongly agree.

1. It is important to turn off lights when I leave a room/space where no one else is.
2. It is important that devices are completely turned off (including from the standby mode) when they are not in use.
3. It is important that I don't shower for more than 5 minutes at a time.
4. It is important to close doors in the house to save heat.
5. It is helpful to lower the thermostats temperature an hour before going to bed or leaving home.
6. It is important to wash textiles and clothing that are not extremely dirty at low temperatures.
7. It is helpful to open the refrigerator and freezer doors for as short a time as possible.
8. It is important to first measure the amount of water that is really needed to heat up in a kettle.
9. It is good to use the eco program or a lower temperature of the dishwasher.
10. It is important that I do my best to use as little electricity and gas as possible at home.
11. It is important that I do my best to waste as little electricity and gas as possible at home.
12. A lower energy bill is the most important for me to save electricity and gas at home.
13. Commitment to the environment is the most important for me to save electricity and gas at home.
14. Sustainable use of electricity and gas is more important than my comfort at home.
15. Saving energy at home takes a lot of effort for me.

6. Final improvements prototype *Powersaver Game*

This appendix is an addition to Section 4.6, where artwork improvements in the prototype game that are suggested in the two evaluations from step are presented. As described in Section 4.6, the artwork of the plant in scene 4 is improved and presented in Figure 30. The improved plant is drawn in more detail and has more facial expression. Dust clouds and daylight have also been added to the background of the plant to give more expression to the atmosphere.

Figure 30. In-game objects: original plant (on the left) and improved plant (on the right).

The improvements in artwork of the state of the house of the professor are presented in Figure 31. The art style has been changed with the result that the difference between the bad and good state of the house has been expressed more expressively. In the bad state (see Figure 31 left), the new version of the house has broken windows and a thunderstorm in the background compared to the original house. In the good state (see Figure 31 right), festive flags have been added in the new version of the house to indicate the celebration of the game's good end.

Figure 31. Original house (above) and improved house (below).

The improvements in artwork of the art style of the computer in the study-room are presented in Figure 32. Although the facial expressions are presented quite simply, emotions are expressed very clearly.

Figure 32. Original computer (on the left) and improved computer (on the right).

The improvements in artwork of the evil state of the professor are presented in Figure 33 and Figure 34. The designers have put a lot of thought into designing the angry, neutral and happy facial expression of the new professor, manipulating the mouth, eyes, eyebrows and skin colour.

Figure 33. Original professor (on the left) and improved professor (on the right).

Figure 34. Facial expressions professor.

The lamps that are the in-game objects in the first scene (see Figure 35) are changed in art style for consistency reasons.

Figure 35. Original lamps (on the left) and new lamps (on the right).

7. Comparison pretest measures media comparison and pilot experiment

As presented in Table 22, average knowledge scores are low and all attitude scores are high in both media comparison study and pilot experiment. An independent-samples *t*-tests is performed to test if these similarities on knowledge and attitude measures are significant. As expected, there are no differences: Knowledge: $t(29) = 0.49$, $p > 0.05$; Attitude total: $t(29) = 0.24$, $p > 0.05$; Attitude at micro-level: $t(29) = 0.36$, $p > 0.05$; Attitude at macro-level: $t(29) = -0.07$, $p > 0.05$. A major difference between the studies is detected in the engagement scores, measured in the third week of the intervention. There is a significant difference of 1.9 points between groups. The average score in the pilot experiment is 3.5 (SD = 1.3, N = 13) and 5.4 (SD = 0.9, N = 15) in the media comparison study. An independent-samples *t*-test is performed to test if this difference between the two studies on engagement measures is significant. As expected, the difference is significant: $t(28) = 5.18$, $p < 0.05$.

Table 22. Knowledge pretest, attitudes pretest, evaluation and engagement third week measures in the media comparison study and value-added pilot experiment: means, standard deviations, t-statistic and significance level of difference.

	Personalization Pilot Experiment		Media Comparison Study		Difference		
	M	SD	M	SD	M	*t*	*p*
Knowledge* Pretest	4.0	1.4	4.3	1.6	0.3	0.49	ns
Attitude Pretest							
Total Pretest	5.3	0.4	5.4	0.9	0.1	0.24	ns
Micro-level Pretest	5.3	0.5	5.4	0.9	0.1	0.36	ns
Macro-level Pretest	5.4	0.5	5.4	0.9	0.0	-0.07	ns
Engagement third week	3.5	1.3	5.4	0.9	1.9	5.18	< 0.05

* Maximum score = 12 ns—not significant at 0.05 level

Appendices

8. Curriculum Vitae

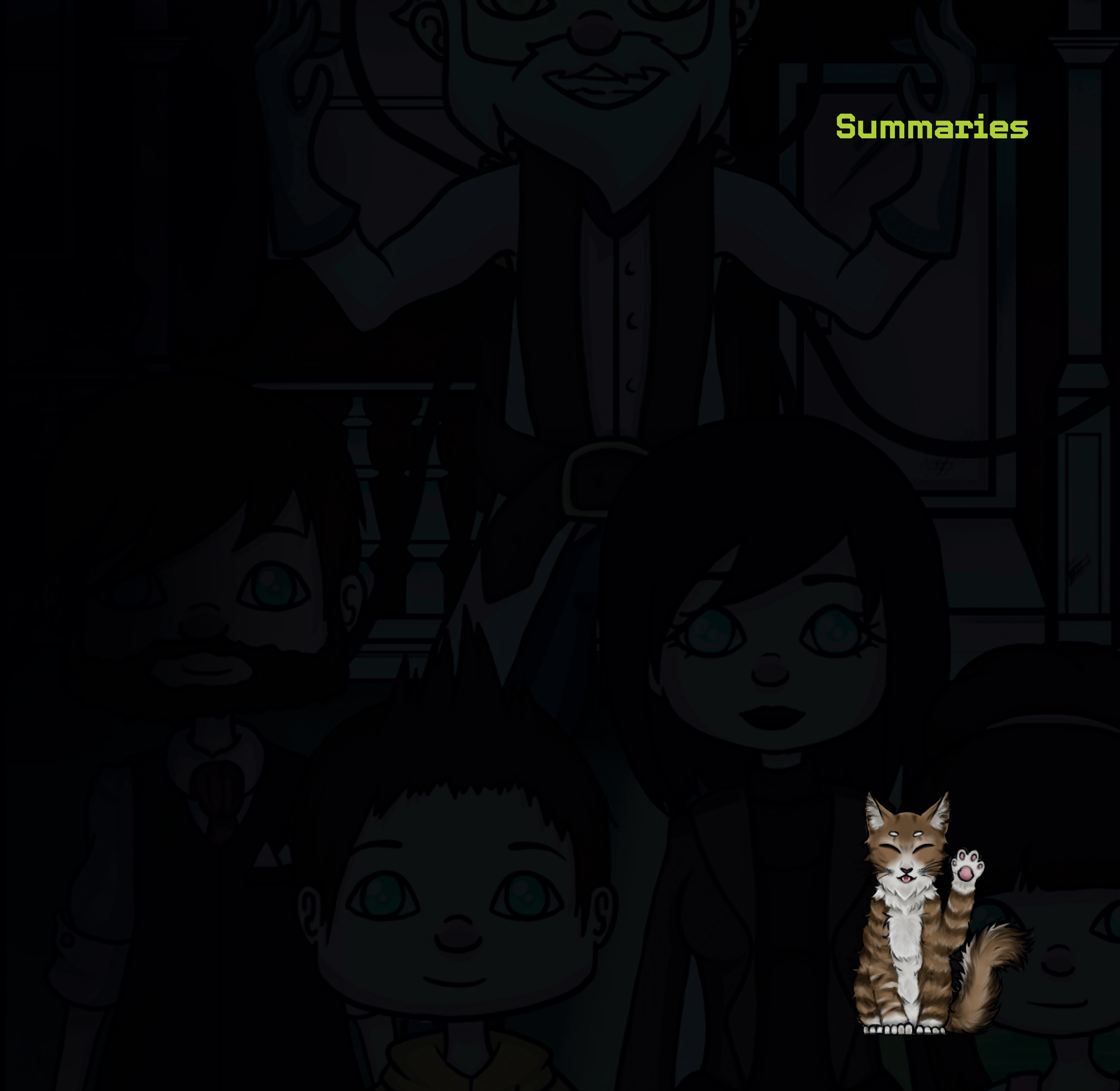
After elementary school Jan Dirk Fijnheer followed General Secondary Education (MAVO) and Intermediate Vocational Education (MBO) (1988 - 1996). He holds a bachelor degree in Business Administration and Economics (HEAO), specialization Marketing at Alkmaar University of Applied Sciences (1998 - 2002). During this study he followed a traineeship at Ford Motor Company at the fleet marketing department at the United Kingdom head office, and wrote his bachelor thesis for the supply chain management department at Epson Europe in Amsterdam. He has a master degree (Doctorandus) in Business Economics, specialization Services & Retail Marketing at the University of Tilburg (2002 - 2004). He wrote his master thesis for the membership recruitment department at Amnesty International in Amsterdam. He was a senior lecturer marketing and research fellow in the research group Digital World, both at Inholland University of Applied Sciences (2005 - 2021). He taught 20 courses (in Dutch and English), was consultant of bachelor thesis projects and student group projects, coordinated and developed several educational programs and courses, and was member of the Central Curriculum Committee Marketing and National Domain Commerce in The Netherlands. In 2014 he started his doctorate project as parttime PhD candidate at the Department of Information and Computing Sciences at Utrecht University. Besides the research project, he taught the courses Applied Games, which he also co-developed, and Persuasive Technologies at Utrecht University. In 2022 he received a grand from the Dutch Research Council (NWO) of 1.5 million euros to continue his research as a post-doctoral researcher at Utrecht University. He has broad interests in gamification and persuasive technology (applied to sustainability and health), influence of digitization on society and the individual, spirituality and spiritual traditions, electronic music and society from a historical perspective.

9. Assessment Committee

The five appointed members of the assessment committee are:

- **Prof. dr. Sara De Freitas**, executive director of Learning Effectiveness at StudyGroup, Brighton, United Kingdom, and governor on the board of Sunderland University, London, United Kingdom.
- **Prof. dr. Dirk Ifenthaler**, professor Design and Technology at University of Mannheim, Germany.
- **Prof. dr. Jeroen Jansz**, professor Communication and Media in the Department of Media & Communication at Erasmus University Rotterdam, The Netherlands.
- **Prof. dr. Joost Raessens**, professor Media Theory at Utrecht University, The Netherlands.
- **Prof. dr. Wilfried Van Sark**, professor Photovoltaics Integration at the Copernicus Institute of Sustainable Development at Utrecht University, The Netherlands.

Summaries



English Summary

In a reality-enhanced game player's real-world activities, such as household energy saving activities, are integrated in the gameplay of a digital serious game (Chapter 1). Players are then immersed in real-life situations that are generated by user interaction with the game. The aim of this 'reality-enhanced games' approach is to stimulate the transfer of information between the game world and the real-world. When the transfer is stimulated, the game is expected to be more effective in change of behavior. Implemented real-world processes, such as washing clothes on low temperatures, are the core of the game design. For this purpose, household's real-life energy consumption is monitored. This characteristic is lacking in most research and provides important new insights.

With the research presented in this thesis we contribute to the stimulation of individual sustainable behavior by studying how gamification, using a reality-enhanced computer game that takes several weeks (long-term duration) to complete, can be a positive incentive for people to change their behavior on energy use at home (Chapter 2). This thesis presents empirical tests that enhance the instructional design of reality-enhanced games, in this case, to influence household energy conservation. Our research is inspired by *cognitive constructivist learning theory*, which focuses on assumptions regarding teaching and meaningful learning at a distance. In contrast to most studies, we pay special attention to: (1) long-term interventions, (2) relevant control conditions, (3) a thoughtful, iterative game design process where potential players are involved, (4) changes that endure over time of the depended variables involving engagement, knowledge, attitude and behavior, (5) and last, monitor and incorporate real-life behavior. We address the following research gaps: First, it is not clear how reality-enhanced games are related to gamification principles. Therefore, we introduce a taxonomy of the following five gamification approaches based on main characteristics and game features: Playful persuasive element, Feedback systems, Learning systems, Serious (simulations) games and Reality-enhanced games (Chapter 3). Second, not much is known about the effectiveness of reality-enhanced games in the long term in the case of household energy conservation. We present several experiments and provide interesting new insights. Third, a description of a design strategy for reality-enhanced games is still unknown, and, in addition, it is not clear what the characteristics for evaluating such a game design should be, and how to implement these in a new game design. We present a design strategy for a game as an instrument for our research and give a description how it is applied in the development of our game. Therefore, we identified nineteen characteristics, such as storyline, competition and game characters, for evaluating a game design. Fourth, it is not clear which game features are key, and what their effects are. Key features for

household energy conservation games considered effective include competition, collaboration, gameplay (e.g., levels and progression, etc.) and feedback. We selected competition for an empirical experiment.

For our research project *Powersaver Game* is designed (Chapter 4). We present a user-centered game design methodology including two design phases. This methodology provides insight into the development of a reality-enhanced serious game, which is an appropriate research tool for empirical randomized controlled trials. In design phase 1, principles are formulated to design a game prototype, and in design phase 2 potential users evaluate this prototype. The design principles concern: (1) effects that the game will generate, such as awareness of sustainable energy use at home, (2) the game stimulates information transfer about energy conservation measures, so that players acquire more knowledge, and (3) the game focuses on behavior change related to energy conservation in real-life. They involve game characteristics such as integration of real-life behavior (in our case by monitoring the smart energy meter in a household), a long-term duration of minimum three weeks and presence of a storyline. Based on a novel gamification process fifty household energy saving activities that have to be carried out in real-life, have been incorporated in the game design. Implementing real-world processes in a game design is still an emerging principle in research, and represents an important step to stimulate the transfer of knowledge between the game world and the real-world to change attitude and behavior.

We present two studies with *Powersaver Game*. In the first study we examine the effects of the game and in the second study the effects of an individual game feature (competition). In a pretest-posttest design, both studies test whether change in involved engagement, knowledge, attitude and behavior with respect to energy conservation in the household is different for participants playing *Powersaver Game* compared to a control condition (energy conservation dashboard or a basic version of the game). Families play *Powersaver Game* for more than three weeks in their own household. Every day energy saving missions are provided by the game. The main goal is to reduce energy consumption. Behavior in real-life, by means of electricity and gas use of the household, is integrated into the gameplay. A real time connection between the household energy meter and game server is accomplished. A pretest as well as a posttest questionnaire is used to assess participants attitude towards sustainable energy consumption and knowledge level towards household energy conservation. To assess participants' attitude, attributes of the object of sustainable energy, both on micro-level (about sustainable energy consumption in a household) as well as on macro-level (about sustainable energy and sustainability in general), were measured. To monitor engagement, participants complete an online questionnaire in the second week and the last week of the intervention. Real-world behavior, in the form of real

energy consumption of households that is retrieved from the smart energy meter, is monitored during 21 days right before the intervention, during the intervention, and 21 days right after the intervention.

In the first study, using a media comparison approach, which investigates whether people learn better from serious games than from conventional media, effects were examined with respect to energy conservation in the household of the energy conservation game compared to an energy conservation dashboard (Chapter 5). The form, timing and content of the information that the control condition receives from the energy conservation dashboard are as similar as possible as in the game condition, but excluded game elements. *Powersaver Game* appears to be effective in transfer of energy conservation knowledge, which leads to energy saving behavior on the long term (in the weeks immediately following the intervention). Our energy conservation game that includes reality by using reality-enhanced gamification principles is, thus, effective in learning people to save energy in the household and to actually do that for the long term, while the energy dashboard does not change that behavior at all.

In the second study, by using a value-added approach, which questions how *specific* game features foster learning and motivation, effects were examined of the game including a feature compared to a basic version of the game (Chapter 6). The effects of the persuasive features personal relevance using personalized avatars and social interaction by means of competition on participants' engagement, knowledge, attitude and behavior with respect to sustainable energy consumption with *Powersaver Game* were examined.

We decided to first conduct a pilot experiment with a small group of households to examine the effects of personalized avatars, because it takes researchers a lot of effort to adapt the appearance of the avatar's head in the game to a player. Based on the outcomes of the evaluation of the first study, we also decided in this pilot study to test the effect of (1) shorten the mission time to 48 hours, and (2) let households install the datalogger to the household smart energy meter themselves to monitor energy consumption. In this pilot experiment, the competition feature in *Powersaver Game* is absent because the aim is to focus the experiment only on the effects of the personalized avatars without the influence of competition. Unfortunately, we cannot draw conclusions about the effect of personalization of avatars, due to the fact that most participants from the pilot experiment dropped out before the end of the intervention. Thus, it is not possible to measure effects on engagement, energy conservation, knowledge and attitude within or between conditions. Based on this pilot experiment, we changed the following in the next experiment: First, the avatars were not personalized to participants, because it takes a lot of effort from both the participants and researchers and, as the pilot demonstrates, it has no effect. Second, we reduced the mission time from 48 hours to 24 hours, so participants can integrate the use of the game within normal daily household routines and practices. Third, we provided notifications when participants forget to proceed in the game. Fourth, we monitored the household smart energy meter without hardware to be installed in the households.

The results provided direction for further research, based on a value-added approach. This is why in the next phase of the value-added study the effects of the competition feature have been examined. Research provides limited explanation of how competition, a key game feature, influences learning in this type of setting. Therefore, each household in the intervention condition is in competition with 9 virtual (computer-based) households, but assumes to play against 9 real households. The energy conservation data of virtual households follow a logical pattern based on the real-time energy conservation results of the real household. Competition is simulated to stimulate households to achieve high scores. The scores of the top 4 ranking households, including the real household, are close to each other, and therefore should stimulate desired behavior. This way positive influences of social comparison opportunities are stimulated and negative influences prevented like frustration, discouragement and potentially dropping out of less-able players who always lose while more-able players always win. It appears that competition contributes to more change in energy saving behavior in the long term. We applied a path analysis technique and conclude that knowledge about energy conservation is a trigger for attitude about sustainable energy consumption in a household (micro-attitude). Subsequently, attitude about sustainable energy consumption in a household (micro-attitude) acts as a trigger for attitude about sustainable energy and sustainability in general (macro-attitude), which ultimately leads to actual behavior change, in the form of energy conservation. It is important to note that both knowledge and micro-attitude are playing an indirect role; the influence on energy conservation runs via the macro-attitude. So, there is no direct link between micro-attitude and energy conservation, and no direct link between knowledge and energy conservation. We conclude that higher awareness (more accessible knowledge) for a longer period leads to attitude change, which in turn results in behavior change in the long term; particularly the macro-attitude plays here a significant role.

In general, we conclude that a digital energy conservation game with real energy conservation activities by monitoring real-life household energy consumption, which is developed in a thoughtful, iterative user-centered design process, significantly reduces energy consumption in the long term (Chapter 7). In addition, competition

contributes to even more change in energy conservation. Knowledge about saving energy at home increased. Engagement remained high during the whole intervention, and as a consequence everyone was involved and finished the game. Attitude change did not take place because of a ceiling effect; attitude was already high from the beginning and the intervention did not change it.

The results of the studies in this dissertation have considerable implications for policymakers (e.g., related to the energy transition) and companies in the field of smart energy meters. Now in practice only dashboard designs are used to give feedback on energy consumption, and research indicates that these dashboard designs are probably not effective in the long term. Instead, our results can be used in the development of effective, future games, especially in the field of household energy conservation.

Gamification by applying reality-enhanced games still has a great potential for behavior change and attitude change in novel and engaging ways. Stimulation of individual sustainable behavior is an important topic in the field of sustainability, both from a social and scientific perspective. More empirical research is necessary to attain more knowledge and to be able to generalize our findings, and to study the empirical effects of other (key-)game features of household energy conservation games.

Nederlandse samenvatting

In een reality-enhanced game worden activiteiten van spelers in de echte wereld, zoals energiebesparing in het huishouden, geïntegreerd in de gameplay van een digitale serious game. Spelers worden betrokken in activiteiten uit de echte wereld door de interactie met de game, wat de overdracht van kennis uit de game naar de echte wereld stimuleert.

Dit proefschrift presenteert empirische onderzoek dat bijdraagt aan het ontwerpen van 'met door realiteit verrijkte digitale spellen' (reality-enhanced games) om energiebesparing in het huishouden te beïnvloeden. Voor dit onderzoek is '*Powersaver Game*' ontwikkeld. We hebben een user-centered game design methodologie gevolgd die twee ontwerpfasen omvat. In ontwerpfase 1 worden principes geformuleerd om een spelprototype te ontwerpen, en in ontwerpfase 2 evalueren potentiële gebruikers dit prototype.

We hebben twee studies uitgevoerd. In een pretest-posttest design, werd in beide studies getest of verandering in betrokkenheid, kennis, houding en gedrag met betrekking tot energiebesparing in het huishouden anders was voor deelnemers die '*Powersaver Game*' speelden in vergelijking met een controleconditie (energiebesparingsdashboard of basisversie van de game). Huishoudens speelden '*Powersaver Game*' meer dan drie weken (lange duur) in hun eigen huis. Elke dag werden door de game energiebesparende opdrachten gegeven met als hoofddoel het energieverbruik te verminderen. Er is een real-time verbinding tussen de energiemeter in het huishouden en de gameserver tot stand gebracht.

In de eerste studie werden de effecten onderzocht van het energiebesparingsspel op energiebesparing in het huishouden in vergelijking met een energiebesparingsdashboard. De vorm, timing en inhoud van de informatie die de controleconditie ontvangt van het energiebesparingsdashboard zijn zoveel mogelijk gelijk aan die in de gameconditie, maar het energiebesparingsdashboard heeft geen spelelementen. Ons energiebesparingsspel is effectief om voor de lange termijn energie te besparen in het huishouden, terwijl het energiedashboard dat gedrag in het geheel niet verandert.

In de tweede studie werden effecten onderzocht van het energiebesparingsspel inclusief de feature competitie in vergelijking met een basisversie van de game. Als eerste concluderen we dat competitie extra bijdraagt aan meer energiebesparend gedrag op de lange termijn. Ten tweede concluderen we dat meer beschikbare kennis gedurende een langere periode leidt tot attitudeverandering, en dat deze attitudeverandering vervolgens resulteert in gedragsverandering op de lange termijn; voornamelijk de macro-attitude speelt hierbij een belangrijke rol.

De hoofdconclusie is dat een digitaal energiebesparingsspel inclusief echte energiebesparingsactiviteiten en het monitoren van het echte energieverbruik, dat is ontwikkeld in een doordacht, iteratief gebruikersgericht ontwerpproces, het energieverbruik op de lange termijn significant vermindert. Bovendien draagt het spelelement competitie bij aan nog meer energiebesparing. De kennis over energiebesparing nam toe en de betrokkenheid bleef hoog gedurende de hele interventie. Er was echter geen verandering van attitude, omdat die vanaf het begin al hoog was.

Gamification door het toepassen van reality-enhanced games is nog steeds opkomend in onderzoek. Het heeft een groot potentieel voor gedragsverandering en attitudeverandering op een nieuwe en boeiende wijze, en onze resultaten kunnen gebruikt worden bij de ontwikkeling van effectieve games.

Short English Summary

In a reality-enhanced game player's real-world activities, such as household energy saving activities, are integrated in the gameplay of a digital serious game. Players are then immersed in real-life situations that are generated by user interaction with the game, which stimulates the transfer of information between the game world and the real-world.

This thesis presents empirical tests of principles that enhance the instructional design of reality-enhanced games to influence household energy conservation. For this research *Powersaver Game* is designed. We followed a user-centered game design methodology including two design phases. In design phase 1, principles are formulated to design a game prototype, and in design phase 2 potential users evaluate this prototype.

We conducted two studies. In a pretest-posttest design, both studies tested whether change in involved engagement, knowledge, attitude and behavior with respect to energy conservation in the household was different for participants playing *Powersaver Game* compared to a control condition (energy conservation dashboard or a basic version of the game). Families played *Powersaver Game* for more than three weeks (long-term duration) in their own household. Every day energy saving missions were provided by the game. The main goal was to reduce energy consumption. A real time connection between the household energy meter and game server was accomplished.

In the first study, effects were examined with respect to energy conservation in the household of the energy conservation game compared to an energy conservation dashboard. The form, timing and content of the information that the control condition receives from the energy conservation dashboard are as similar as possible as in the game condition, but excluded game elements. Our energy conservation game is effective in learning people to save energy in the household and to actually do that for the long term, while the energy dashboard does not change that behavior at all.

In the second study, effects were examined of the game including the feature competition compared to a basic version of the game. We conclude that competition contributes to more change in energy saving behavior in the long term, and that higher awareness (more accessible knowledge) for a longer period leads to attitude change, which in turn results in behavior change in the long term; particularly the macro-attitude plays here a significant role.

In general, we conclude that a digital energy conservation game with real energy conservation activities by monitoring real-life household energy consumption, which is developed in a thoughtful, iterative user-centered design process, significantly reduces energy consumption in the long term (in the weeks immediately following the intervention). In addition, the game feature competition contributes to even more change in energy conservation. Knowledge about saving energy at home increased, and engagement remained high during the whole intervention. In contrast, attitude change did not take place because it was already high from the beginning.

Gamification by applying reality-enhanced games is still an emerging principle in research. It has a great potential for behavior change and attitude change in novel and engaging ways, and our results can be used in the development of effective games.