Evaluation of a Pervasive Game for Domestic Energy Engagement Among Teenagers

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In this article, we present *Power Agent*—a pervasive game designed to encourage teenagers and their families to reduce energy consumption in the home. The ideas behind this mobile phone-based game are twofold; to transform the home environment and its devices into a learning arena for hands-on experience with electricity usage and to promote engagement via a team competition scheme. We report on the game's evaluation with six teenagers and their families who played the game for ten days in two cities in Sweden. Data collection consisted of home energy measurements before, during, and after a game trial, in addition to interviews with participants at the end of the evaluation. The results suggest that the game concept was highly efficient in motivating and engaging the players and their families to change their daily energy-consumption patterns during the game trial. Although the evaluation does not permit any conclusions as to whether the game had any postgame effects on behavior, we can conclude that the pervasive persuasive game approach appears to be highly promising in regard to energy conservation and similar fields or issues.

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1. INTRODUCTION

Recent reports from the United Nations on the changing climate set new demands on our society [Solomon et al. 2007]. It is clear that much needs to be achieved to reach the new targets towards sustainable living. Engaging people in making the, often small, behavior changes that are needed is crucial for fulfilling goals of energy reduction in the domestic sector. While most people tend to possess quite positive attitudes towards climate-saving actions, this is rarely enough to have any real impact on their behavior.

Additionally, there is also an educational problem: knowing what consumes a lot of electricity in the home, for example, is very difficult for most of us.

Large-scale information campaigns are frequently used to support learning and to create an awareness of pressing societal problems. Recently, companies and state authorities like the European Union have utilized simulation computer games targeting children in regard to domestic environmental issues like energy consumption [Kidscorner 2009]. While children and teenagers tend to respond to different motivating factors than adults—children, for example, rarely pay for their own energy usage—alternative approaches such as computer games make sense.

Hence, in our previous work, we suggested the use of pervasive games as an alternative approach to motivate teenagers towards energy awareness [Bang et al. 2007]. Pervasive games are very interesting from a learning perspective [Markovi et al. 2007], since they have the potential to better support what is known as transfer [Gagné et al. 1948]. In classic leaning theory, *transfer* refers to the situation when a learner must generalize and use abstract knowledge (i.e., learned from a book) and apply this knowledge to real-world problems and requirements. Pervasive games can minimize this contextual gap because the game can be situated in the real world with real hands-on tasks that require player engagement. Thus, from a research point of view, it is important to investigate what constitutes successful design components of pervasive learning games.

In this article we evaluate and analyze a pervasive game designed to motivate and educate teenagers towards energy conservation in the home, that is, encourage positive behavior change in the home regarding for example electricity usage. We particularly look into the social and motivational aspects of the design as well as the situational and contextual knowledge aspects of our approach.

2. POWER AGENT

Power Agent is a pervasive game for mobile phones that connects to the electric power meter in the home. The underlying design idea is to let players compete in teams and learn hands-on how to conserve energy in their homes. This design approach is based on the assumption that a change in behavior requires both motivation to act as well as knowledge of what to do. In *Power Agent*, motivation is achieved by utilizing the social aspects of a competitive multiplayer game at the same time as the player is educated through the contextual and situational aspects of a pervasive game.

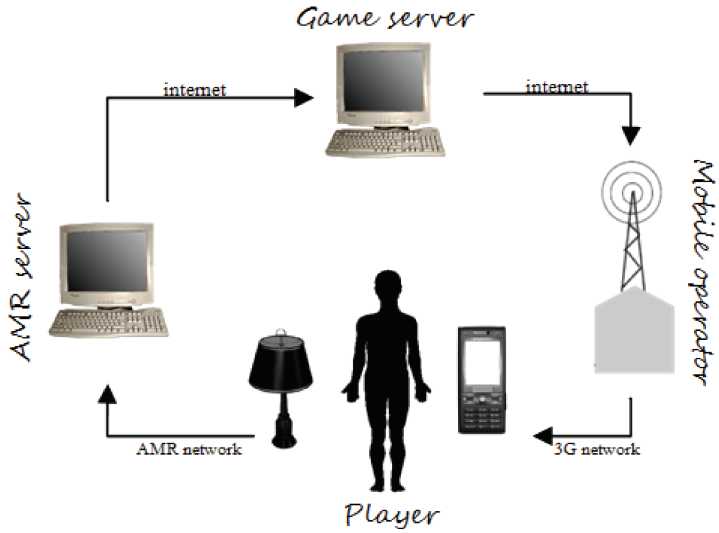

Fig. 1. System overview.

In order to be scalable, *Power Agent* was from the beginning designed on top of existing infrastructure such as the automatic meter-reading (AMR) system. An AMR system is basically networked power meters that are utilized by power companies to automatically measure their customers' consumption of electricity, remote heating or gas. The currently used AMR systems typically report on customers' consumption on an hourly basis, however due to cost, data is often only transmitted and updated to a central server once every 24 hours (during the early morning hours). In 2006 there were approximately 235 million AMR meters installed within the European Union. The AMR system in Sweden, where this project was carried out, is currently being expanded, and is expected to cover all households in the entire country by the summer of 2009.

2.1 Gameplay

In *Power Agent*, the player takes the role of a special agent assigned the task of saving energy in the home. To be able to achieve this goal, he or she must cooperate with family members and also combine forces with other peer agents in a team. The team competes with another team of agents located in another town. A successful player persuades everyone in the household to conserve as much electricity as they can during the mission, which, on most days, takes place between 17.00 and 22.00. Throughout the mission, the game monitors electricity consumption in the participants' homes. The winning team is the one who made the combined largest relative decrease in energy consumption (in our case, electricity, and the consumption of remote heating, when present).

Mr. Q—the agents' boss—appears on the phone just before a mission starts and informs the player about the new assignment (voice and animation, see Figure 2(b)). At this point, a warm-up track for the mission—in the form of a small platform game—is unlocked in the phone (Figure 2(d)). At the

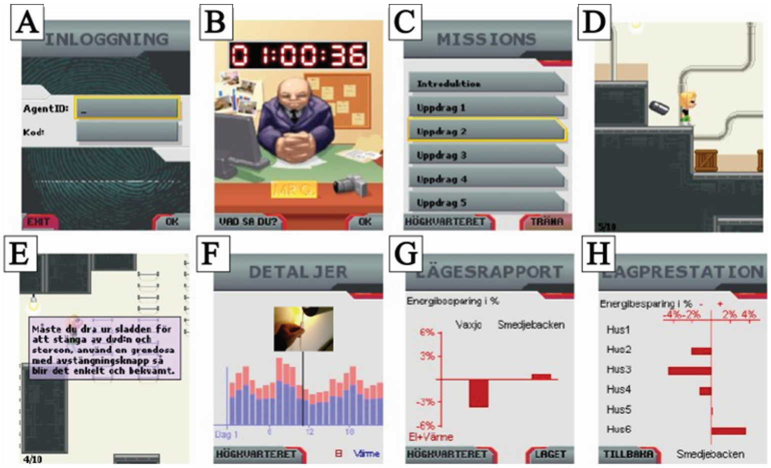

Fig. 2. Screen shots of game interface.

warm-up track, players can collect batteries. Each battery is associated with a clue (Figure 2(e)) on how to better succeed with the assignment during the evening's mission. A clue could for example be "Unplug wall sockets to prevent the DVD or the stereo from using electricity when not in use".

All the first six missions in the game have an energy-saving theme. The themes are (1) lamps; (2) activities in the kitchen; (3) entertainment equipment; (4) heating the house; (5) washing and cleaning; and finally (6) showering and bathing. In the final mission, players took on the task of lowering the *total energy consumption* of the household for a longer period of time, as this mission extended over the entire weekend.

The feedback after a mission is given by Mr. Q in the morning after it was preformed (Figure 2(b)). Mr. Q encourages the unsuccessful players to try harder and praises the successful ones. In addition to the voice responses from Q, a set of screens and bars visualize the result in more detail. These bars consist of (Figure 2(f)) a scrollable vertical chart with the players' personal home consumption; (Figure 2(h)) horizontal bars indicating the individual efforts within the team; and (Figure 2(g)) bars indicating the results during the latest mission for the two teams. In addition to this, a high-score list showing the winning team for all of the previously completed missions is also available.

At the end of the game (after the weekend final), all players receive a summarizing text message from Mr. Q on their phones. This message concludes the game by announcing the winners. In addition, it also provides feedback on how much the reduction in consumption achieved by the player during the final adds up to when translated into money and carbon emissions if the reduction were maintained over an entire year.

2.2 Interface

To strengthen the role of secret agent, we employed the mobile phone camera and encouraged players to take pictures of what they did to reduce energy consumption in their homes. When available, these pictures are superimposed on the personal energy consumption feedback chart (Figure 2(f)), which enables players to map actions to results. A message board was also included in the game to allow participants to send messages to each other.

All functions in the game are accessed by selecting the items behind Mr. Q on the main screen (Figure 2(b)). This is done by using the phone's navigation key. Selectable items include the camera (the agent camera function); the message board (message function to the other players); the computer (the warm-up tracks); the card index (brief information about the other players); the papers in front of Mr. Q (the missions); and the pictures and graphs (feedback and results).

2.3 Platform

Power Agent is played on standard Java-enabled mobile phones. Consumption data from the players' homes is collected via the ordinary and existing metering equipment used by the energy company to monitor the household consumption. This data is then relayed to our game server during the early morning hours. On the game server, data is processed and results calculated. The results are then sent to the Java client on the mobile phone where the information is transformed into feedback in the form of graphics and announcements from Mr. Q (see Figure 1).

3. RELATED WORK

The *Power House* is a traditional simulation-type computer game designed to stimulate teenagers towards energy awareness [Bang et al. 2006]. This conventional desktop game shares a lot of common ground with *Power Agent,* in that it aims to educate and motivate teenagers to conserve energy. *Power House*, however, does not incorporate the pervasive component of *Power Agent*.

The area of pervasive learning games is still quite unexplored. In "The ambient wood journals" [Weal et al. 2003], an educational system based on ubiquitous technology that is placed in a forest is described. The system delivers location-based experiences and simulation capabilities regarding biological functions in the forest. In this way knowledge is put in a context. Other than that, as far as we can judge, it lacks many of the basic qualities of a game.

In the article "Living on the edge" [Benford et al. 2005], a pervasive learning game called *Savannah* is described. It is a location-based pervasive game designed around the GPS system. It is played on a predefined open field where the participants take the role of a pack of lions hunting virtual animals. In doing this the teenagers are intended to learn about the life in the savannah. The work focuses primarily on the technical aspects of the implementation of the game prototype and the use of the GPS. Since the location of the players is about the only thing of the real world this game utilizes (everything else is fictive), this game does not in our view fully utilize the learning potential of a pervasive learning game. Although these kinds of games can still be successful in a school environment where reflection and debriefing can be provided, it is possibly only as efficient as the traditional type of educational program in terms of facilitating transfer between the game context and the real world.

4. METHOD

Two teams (*Team Smedjebacken* and *Team Växjö*) each consisting of three players and their families played the game for ten consequent days in two small cities in Sweden during the spring of 2008. Energy consumption data for the participating households was collected before, during, and after the game trial. By means of the existing AMR system and the local energy company database, we acquired the hourly consumption rates for both electricity and, when present, remote heating. The total period monitored after the gaming sessions extended to a total of 57 days for the three players on Team Smedjebacken. During the entire trial the participants had the ability to contact evaluators by means of instant messaging (MSN, Skype, etc.). All IM conversations were logged. The game trial was followed by semi-structured interviews with the players and their families. These conversations were transcribed, analyzed, and categorized into the following classes:

- player actions taken to reduce energy;
- motivating factors;
- situated learning; and
- user feedback on the game design.

Pictures taken by the agent camera provided yet another source of information on the actions users took to reduce energy consumption.

To estimate the efforts taken by each household regardless of preconditions for the families—we primarily investigated the relative change in consumption. This measurement was calculated by comparing consumption during the game with a period of normal consumption preceding gameplay (i.e., a reference period). Due to cyclic behavior in the consumption pattern of most households, we compared consumption during a certain hour during the game to the average consumption during the same hours in the reference period.

A source of error in the players' consumption data could be attributed to changing outdoor temperatures. Lower outside temperatures meant significantly higher energy consumption for the households (in warmer countries this might of course be the opposite when using air-conditioning). For test participants with remote heating, this effect will be isolated to the readings of remote heating. For participants not having remote heating, a reference group of six households not participating in the game test was employed.

5. RESULTS

In this section we present the outcome of the game play sessions in terms of renewed energy conservation patterns, behavior changes, and participant learning. Moreover, we report on how social interactions were shaped between the players in the teams and between the players and their families. Finally, we summarize a set of comments from the players on the game and its design.

Table I. Relative Electric Consumption Agent 101

Mission	**1**	**2**	**3**	**4**	**5**	**6**	**Final**
Change	0.1%	–14.1%	–60.9%	–	–42.7%	–42.7%	–36.0%

Table II. Relative Electric Consumption Agent 102

Mission	**1**	**2**	**3**	**4**	**5**	**6**	**Final**
Change	–72.6%	–27.6%	–14.3%	–16.6%	–51.2%	–30.6%	–30.5%

Table III. Relative Electric Consumption Agent 103

Mission	**1**	**2**	**3**	**4**	**5**	**6**	**Final**
Change	+17.5%	–7.3%	–34.0%	–62.5%	–48.3%	–7.3%	–35.6%

5.1 Behavior Change—Player Actions

5.1.1 *Individual Efforts.* The first four agents presented below had remote heating installed in their households (and outdoor temperature changes could therefore be ignored regarding the electricity data). Since we chose to focus on electricity, efforts made by lowering temperature for these participants will not be visible here. For the remaining two participants, results from electric metering in terms of relative change were subtracted by the savings of the reference group, to remove the outdoor temperature bias. Original values for these agents are found inside brackets below the corrected number. The summary of ìmeasures takenî by the agents is based on the interviews as well as the pictures taken by the agent's camera.

Agent 101's house was heated by remote heating. During the game, the agent and his family tried to use only one of the TV sets as much as possible, started washing with a full machine, and turned the lights off more frequently. They also lowered room temperature with 3°C down to 19°C. During the mission that involved lamps, this agent approached the problem by turning all lamps off and used candles for illumination.

Agent 102's house was also heated by remote heating. During Mission One, the family attended a party and was away during most of the evening. The family reports that they kept turning lights off during the entire game, and the agent said he adjusted the refrigerator temperature. The family felt, that they achieved great results, even though their efforts were perceived as small.

Agent 103's house was heated by remote heating. Actions taken to reduce energy consumption included turning lights and appliances off, unplugging standby equipment, as well as lowering temperature for a couple of days. The father in the family estimated that he—during the light mission—replaced standard light bulbs with low-energy ones for about €80.

Agent 204's house was heated by remote heating. Based on the interview and pictures taken by the agent camera, we identified several energy conservation measures that had been taken by the family. The agent had for instance turned down the room thermostat, adjusted the refrigerator temperature, tuned lamps off, disconnected the TV from standby mode, and avoided using the tumble dryer, the computer, and hot water. The agent explained that the family was already quite good at saving energy. From the start, the temperature in the

Table IV. Relative Electric Consumption Agent 204

Mission	1	2	3	4	5	6	Final
Change	+55.3%	−44.6%	−49.9%	−23.6%	−31.5%	+34.3%	−17.3%

Table V. Relative Electric Consumption Agent 205

Mission	1	2	3	4	5	6	Final
Change	−17.4%	−15.3%	−29.6%	−28.8%	−12.9%	−4.6%	−11.4%
	(−20.7%)	(−35.0%)	(−50.2%)	(−41.3%)	(−30.9%)	(−27.8%)	(−32.4%)

Table VI. Relative Electric Consumption Agent 206

Mission	1	2	3	4	5	6	Final
Change	−72.4%	−45.2%	−52.5%	−55.6%	−41.5%	−46.9%	−32.3%
	(−75.7%)	(−64.9%)	(−73.1%)	(−68.1%)	(−59.5%)	(−70.1%)	(−53.3%)

house was set low and the fridge was already set to the temperature suggested by one of the clues in the game.

This agent seems to have followed the clues from the instructional part of the game quite exactly, however, the agent admits that she—during the first mission that involved cooking food efficiently, skipped dinner altogether because she was home alone. During the final session she said that she “let things be”; didn’t use the computer as often, didn’t watch TV much, turned off almost all the lights and avoided using the shower.

Agent 205’s house was heated by electricity. Just as agent 204, she (205) also couldn’t lower the room temperatures that much since it was already set low. The fridge was also already set to the values suggested by the game.

Other measures taken by 205 involved turning off the electric lights. She said that the family kept the whole house in the dark and lit only one lamp or used candles if they absolutely had to have some light. She also disconnected all standby equipment and ensured that the washing machine was filled more than it usually was. The family also tried to use the microwave oven instead of the stove for certain meals. On the initial assignment, the agent went and bought pizza instead of cooking at home. Moreover, the mother of the family expressed concerns that she ruined the results for her daughter by performing some slow cooking during the weekend of the final.

Agent 206’s house had a flexible heating system; it could be heated by electricity or wood either by a boiler in the basement or two old tile stoves and a huge baking oven in the kitchen. Normally, the family primarily used electricity to support the tile stove heating system. The tile stove on the second floor was only used when it was extremely cold (−30°C or so), since it would otherwise became too hot. Before the game, hot water in the building had been produced by an electric heater.

The clues for energy-saving from the batteries in the platform game were followed partially, even though they were not always applicable. One example is the clue to put the dishwasher in eco-mode. The washing machine in this particular home was too old and lacked such a mode. At one point the family began to turn all the lights off. A picture of a burning candle can be found in 206’s agent camera. This ascetic strategy was abandoned after about two days.

Table VII. Relative Changes in Consumption for the Teams

	Smedjebacken		Växjö	
Mission	**Electricity**	**Heat**	**Electricity**	**Heat**
1	−13.6%	−7.0%	**−18.3%**	**−15.1%**
2	**−48.2%**	**−12.6%**	−16.4%	−10.3%
3	**−57.7%**	**−11.2%**	4.1%	−11.4%
4	−44.3%	−15.3%	**−39.5%**	**−21.2%**
5	−40.6%	−11.2%	**−47.4%**	**−32.8%**
6	−21.2%	−11.2%	**−26.9%**	**−26.8%**
Final	−34.3%	−12.1%	**−34.0%**	**−35.3%**

The father in 206 put a lot of effort into the task of lowering heat consumption. The first measure was to use a lot more wood for heating. This resulted in a warmer indoor temperature than the family normally had. He also partially reconnected the water piping in the house so that hot water could be obtained from the boiler in the basement instead of the electrical boiler.

5.1.2 *Team Effort.* The results after each accomplished mission were normalized and augmented to include heat consumption from houses with remote heating. The results presented to the players were based on the calculated outcomes in Table 7.

The red color in the table indicates the winning team. The numbers denote averages of the players' relative change in energy consumption. Each player's relative consumption was calculated by comparing his or her energy consumption during the mission to the average consumption during the same hours during the five weeks prior to the test. In other words, this table does not take outdoor temperature biases into account. It merely serves to show the kind of feedback (positive or negative) each team got from the game after each mission.

5.1.3 *Overall Results.* Most game missions took place between 17:00 and 22:00. It is during these hours that our homes consume the most electricity. This short five-hour period, in which the missions must be carried out, makes it possible for players to move energy consuming activities outside the missions (displacement). To not affect gameplay, the washing machine, for example, must be done after 22:00. Hence, even though everything looks good in the game score, due to displacement the family may have the same rate of energy consumption total as before. In this section we will therefore take a closer look at displacement effects and overall consumption change during the entire game period.

To the right in Figure 3 (blue bars), we can see a detailed plot of the electricity consumption one week before the gameplay for one of our players. To the left in the same figure, we provided the gamers with a plot for the first mission during the game evaluation. The gray bars indicate average consumption for the specific hour during a normal day. The pink area in the right plot indicates the mission time. It is clear that consumption is a lot lower during mission time; but we can also see a clear case of displacement, since the bars prior to the mission are a lot higher than at the same time the previous week. This kind of behavior by the participants was anticipated. To get an idea of the magnitude

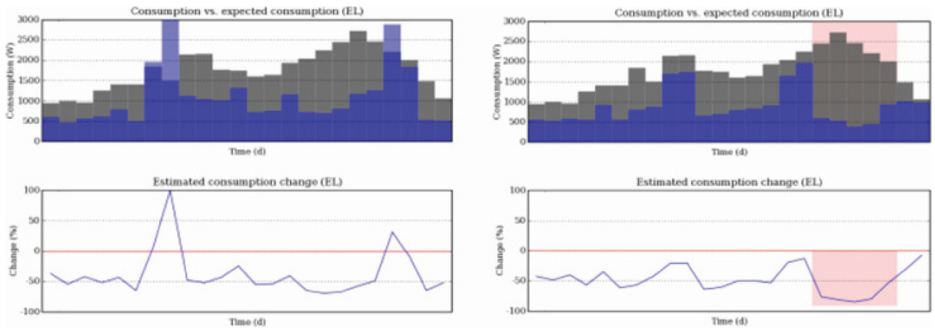

Fig. 3. Illustration of displacement occurring during mission one for agent 206.

Table VIII. Team Smedjebacken: Electricity Consumption

ID	Entire game period		
	Expected	Measured	Change
204	110 kWh	99 kWh	−12,1%
205	570 kWh	398 kWh	−11,1%
206	345 kWh	164 kWh	−24,0%
Med			−15,7%

Table IX. Team Växjö: Electricity Consumption

ID	Entire game period		
	Expected	Measured	Change
101	104 kWh	—	—
102	310 kWh	240 kWh	−26,1%
103	256 kWh	169 kWh	−31,5%
Med			−28,8%

of the displacement, we present the overall savings for the entire game week for both mission and nonmission times in Tables 8 and 9.

For Agents 205 and 206, the savings were adjusted in relation to the reference group (which had a reduction of 22 percent in electricity usage for the entire week). The table has an incomplete entry for Agent 101 since a faulty AMR meter caused an incomplete data set for this participant at some instances during the week. The tables show that the net effect on the entire week was clearly positive in terms of savings for all of the participants.

5.1.4 *Postgame Observations.* Postgame observations include the Smedjebacken team and the reference persons only. Here we present the average consumption change relative to consumption before the game, where the consumption changes for players 205 and 206 have been subtracted from the results of the reference group.

The postgame consumption is illustrated in Figure 4. The line in boldface shows the average for all players. The players' individual consumption is shown by colored lines (blue 206, green 205, and red 204). Player 204 shows a significant peak in consumption the second week after the game, reaching a 46.2%

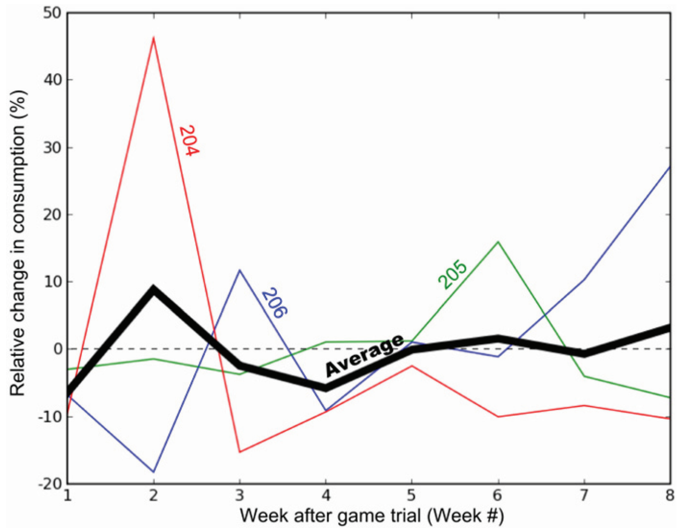

Fig. 4. Postgame consumption.

increase in consumption compared to the period prior to the game. This increase can be located as occurring at two specific times during the week, namely on Friday between 11.00 and 22.00 and on Sunday between 06.00 and 21.00, when a peak in consumption of 2 to 6 times higher than normal can be found (about 3000W more than normal). Average consumption for all players during the entire eight weeks after the game test was −0.2%.

5.2 Social Motivation

The level of involvement by family members in the game varied a great deal. In all families, except agent 204's, the parents appear to have been involved in saving energy. Agent 204 lives with her older sister and father, and said she mostly carried out the missions herself. The sister and father appeared to have been away quite often during the period when the agent 204 was playing. Where the agent had younger sisters or brothers, as in the case for agents 101, 103, and 206, the siblings, in addition to the parents, were often also involved in game tasks.

The form of involvement also varied among the families. In some cases, as in that of agent 206, the family members (in this example the younger brother) interacted just as actively with the game as the player herself, playing the "warm-up tracks" (see game play). In most cases, however, family members (especially the parents) only occasionally interacted directly with the game console, and for the majority of the time participated in the game using their teenagers as mediators.

Regardless, the content of the game (clues, missions, and feedback) seem to have been effectively conveyed among the members of the family. The joint mission of reducing energy usage in many families became a task of guarding and reminding each other to turn off lights and other appliances. In some cases,

Table X. Involvement by Family Members

	People in the family	Involved in the game	Kind of involvement
101	Parents and a sister	Everyone	Player read clues out loud so that everyone could participate.
102	Parents brother, sister	Parents	Turning off lamps. Tacking part of the feedback. The father also used the actual application once.
103	Parents, several smaller brothers and sisters	Everyone (but mostly parents)	Tacking part of the feedback. Buying and replacing lights with low-energy ones.
204	Father and older sister	No one except player	—
205	Parents and two older brothers	Parents	Guarding and turning lights off after one another.
206	Father, stepmother, and little brother	Father and brother	Brother played both warm-up tracks and final mission. Father took extensive energy-saving measures.

we saw parents taking quite extensive and ambitious measures to lower energy consumption in the home. Examples can be found in the families of agents 103 and 206. The father in agent 206's house, for example, rerouted heating pipes to make the heating system more effective, and the father in family 103 replaced most of the filament light bulbs with low-energy ones.

Most players reported that getting cooperation from the family was quite easy.

Interviewer: "How did you do to get the family to cooperate? Did you use any special kind of tricks?"
102: "No it was more like . . . Now I'm going to do this, we can win this and they understood."
Interviewer: "They wanted to be in on it?"
102: "Yes, yes. They thought it was interesting as well. How it worked and so on, that it was a game where you save electricity. They also thought it was interesting."

Although in most cases the players were wholeheartedly supported by their families, some conflicts did occur from time to time. Players 204 and 205, for example, reported arguments with older sisters and brothers, who, at times, found it difficult to adjust to not using computers (204) or TVs (205). Turning off all the lights could also lead to complaints from family members. According to agent 206, her stepmother complained about the darkness. Agent 205's mother worried that she might have ruined the results for her daughter by doing some slow cooking during the weekend final.

Team member interaction was greatest among those who already knew each other. Two of the players in the Växjö team (101 and 102) were in the same class in school, and in team Smedjebacken one of the girls, agent 205, knew both of the other players on her team. The other two girls in team Smedjebacken, however, were not familiar with each other.

Agents 101 and 102 in the Växjö team reported that they discussed the game when meeting at school as well as using the game's built-in chat board. In the Smedjebacken team, agents 205 and 206 reported having discussed the game frequently at school. Agents 205 and 204, said they discussed the game occasionally when they met.

Communication in the Växjö team seems not to have covered specific details about game strategy. On the question whether they exchanged any clues, 102 said:

102: "No, we just said that just to try to turn off things and keep the electricity down and so we did. That's about it."

The only communication with the third member of the team was initiated because agent 103 got a really bad result in one mission. Agent 102 then sent him a message on the discussion board, telling him to "pull himself together".

For Agents 205 and 204 on team Smedjebacken, the conversations seem to have been about *"How it was to play the game"* (204). Agent 204 appears to have been unclear about certain things in the game, and consequently asked for agent 205's help in understanding the game.

Agents 205 and 206 seem to be the only ones who exchanged specific strategies.

206: "Then later when I got back to school we talked about it all the time".
Interviewer: "You did!"
206: "Yes, and gave each other clues and talked about it and so".

In the Växjö team the participants clearly felt obligated to contribute to the team effort and said that, to a degree, they also competed against each other, even though they belonged to the same team.

Interviewer: "Do you feel that you did more than the others for your team in order to save energy? "
101: "No ... David (agent 102) did very much, he saved a lot, you could really tell, you could see it on those bars. Each time it was David that was best almost all the time. So ... ".
Interviewer: "What did you think then?"
101: "Well, I guess I thought that then we have to work some more so that we become ... ".

No instances of communication seem to have occurred during the game between the two teams.

Interviewer: "Did you talk about the other team at all? You, girls, did you talk about them?"
206: "No"
Interviewer: "Or was it just of what you did?"
206: "Yes, that we were going to win over them."
Interviewer: "Ok!"
206: "He he"
Interviewer: "So you where very motivated to win then at least?"
206: "Yes"

5.3 Learning

To structure learning analysis, we categorized the knowledge gained by the participants who we identified in the interviews according to (1) aspects of knowledge suggested by the game; (2) situational knowledge gained from applying measures; (3) information the players were forced to acquire consciously or unconsciously to solve the mission at hand; (4) aspects of knowledge learned from discussing strategy with parents and teammates; and finally (5) aspects learned from the feedback mechanism in the game. Here we will give examples from all of these categories.

In the first category, we can put the clues provided by the game's warm-up track (see Section 2.1 Gameplay) where the players collect batteries. Some of the players commented that these clues were often quite obvious, implying that they had acquired the knowledge previously. Nevertheless, it seems that it was these particular clues that they applied the most during the missions, or at least remembered using. The clues with some degree of humor appear to have been the easiest to remember.

In some player contexts the very explicit nature of the game clues sometimes made them useless, for instance in adjusting the temperature for the refrigerator if it was already adjusted correctly. In other cases, lack of knowledge prohibited the players from applying the clues from the game, as in the example below on applying the eco program to the dishwashing machine.

206: "Yes, but we couldn't, or Marion (the stepmother) didn't know any functions on it so it was the same old usual".

The most prominent example of situational knowledge gained from this evaluation was regarding the experience of turning off lights. To the question of how they behaved before they started playing the game, all the players answered that they turned off the lights. This was also probably the most common measure taken during the game sessions. Many families took this to the absolute extreme by turning off all the lights in the house for a long period of time. In the interviews, many informants reflected with amusement on this dramatic experience:

101: "We had everything turned off until it was dark outside. Then we started lighting some candles .... But it was actually really dark here, hehe".

Or with insight:

Father of 206: "I don't think you could stand it having that dark all the time".

In another case of situational knowledge, the father of agent 206 also reflected on other measures taken by the family:

"But the kind of larger change, the thing with the hot water and so on, that I kind of thing that we could ... live with".

He explained that they were all surprised at how long the hot water lasted after a fire in the basement boiler was lit, which had not been used until then.

We often found very practical discoveries for category 3, such as locating the temperature control for the fridge, the location of a room and working out how it functions, or identifying and locating standby equipment in the home.

Category 4 often also involved tasks in resolving practical issues in the home. Parents, when available, were frequently made use of, as can be seen in the example with the dishwasher from earlier on. As for information exchange between team members, this appears to have been very limited, with agents 205 and 206 as the only examples.

When looking at the personal feedback mechanism of the game (category 5), we asked what the player and his family thought about the consumption bars.

Father of 102: "You put it in relation to what has happened during the day. What was it that made such an effect .... Perhaps you are away one evening ... which we perhaps are normally as well, but it becomes special now when you are thinking that, aha that made that big difference ... and that perhaps doesn't make much overall difference".

In this case, the anticipated outcome was of being away from the house was expected but obviously became a bit more dramatic than initially predicted by the father. This provided new insights for the father as well as the rest of the family causing reflection and discussion. When on the other hand the feedback from the game, from the player's perspective, was contradictory to what was expected, a degree of speculation as to the cause could be anticipated. In these cases, however, as far as we could tell from our investigation, discussion went only as far as to conclude that it was strange.

101: "Then one other time when we were away from half past two until midnight. Still there where red bars there and then we thought, well that's strange".

We conclude that players did not learn much from this negative feedback, since the energy-saving measures taken were often maintained and enforced, regardless whether they registered well on the bars or not.

5.4 The Game

One of the most critical bugs in the game prototype used in the trial was the game's inability to handle delayed data transfer from the AMR system. At one point this caused a lot of confusion among the players, due to a mission first presented by Mr. Q and later changed during the same day. To avoid all delays in data transfer, measures were taken prior to the game to eliminate players with bad reception on their AMR equipment. Nevertheless, one of the players experienced a delay during one of the missions. Regarding the overall game experience, reactions were generally very positive from both players and their families, and all of the participants were very positive about trying similar games in the future.

Interviewer: "If you got the opportunity would you want to play something like this again in the future?"
205: "Yes ... I would. I thought it was quite OK. I am a quite competitive person so it's fun when you compete against others and things like that".
Interviewer: "Did it feel like a true competition would you say?"

205: “Yes, it became just like a competition. Sure it didn’t feel exactly like regular competitions I compete in otherwise, but still . . . . I thought it was fun. It was quite alright”.

However, the two oldest boys among the participants (101 and 102)—both 17 years old—remarked that the game might be more suitable for someone a bit younger than them. Most participants also agreed that, in order for the game to last longer, the missions needed a greater degree of variation.

101: “Yes but you learnt quite much . . . kind of about how you save and so on . . . Having gotten clues and applying it in practice and seeing what happened and so on . . . if you then do this . . . perform those tasks right and how much you save and . . . So, well I think it is a quite fun way to learn. But . . . it might not last for several months or so to play with but . . . Because its still, you still keep a lot of the clues so maybe, one got too see then that it saved thirty percent and . . . during one day . . . and that becomes quite a lot of money in the long run”.

6. DISCUSSION

Changing energy consumption patterns in the home requires both knowledge and motivation. The approach taken in our game demonstrates a significant decrease in energy usage by the participants. This indicates a change in behavior, which in turn implies the presence of both knowledge and motivation. The actions taken to reduce energy consumption by the participants involved several measures that clearly infringed on their normal level of comfort. This fact gives us reason to believe that the degree of motivation was very high in this game.

Based on an analysis of the interviews, it is clear that the number one factor behind the motivation was the *competitive aspect* of the game. The outspoken ambition to win the competition was stated explicitly by team as well as family members on several occasions during the game. It seems that in this game design the competitive factor was twofold: players competed both against the opposing team as well as with and against their own team mates.

The second most important motivational factors were *social demand and peer pressure* between team and player. It is clear that players in the trial felt obliged to increase their efforts if their results were not as good as those of the other team members. Players who did not go along with this social dynamic received verbal and written reprimands from fellow team members. The effects of peer pressure in the game was—just like the competitive aspect—present in several layers, since each participating family constituted a team within the team. Peer pressure within the family was manifested as a kind of “meta-game,” that of *watching closely* and *reminding* each other to turn off appliances.

Given that the teams have such an important role in motivating play, it is important to identify factors that are consequential to team performance. The first of these factors seems to be *how well the team members knew each other* before the game. We also identified that *age difference* could be a factor that might affect the teams’ dynamics. This factor could be seen when older sisters and brothers did not cooperate with younger players (although this could also be interpreted in several other ways). Expanding on this issue, we believe that when designing this type of game it is important to let users form their own teams and natural social groups to maximize motivation and to support communication within the game.

From the start, the current game prototype was developed to support one team in Smedjebacken and one team in Växjö. By coincidence, all members in the Växjö team were boys, while all members of the Smedjebacken team were girls. Moreover, some of the team members in each group already knew each other from school. These circumstances may have contributed in strengthening the teams' identities as well as the motivation to win.

Considering learning in the game: it seems that energy-conservation strategies and knowledge of what constitutes energy-conserving behaviors were gained both directly and indirectly through the game sessions. Not only did the participants learn hands-on *what* they should do via the pervasive game approach, but also *how* they should do it. Perhaps the most intriguing aspect here was how in this pervasive process they were able to gain unique contextual knowledge and experience in applying a certain energy- saving strategy. This led to insights by the participants as to which strategies and behaviors could perhaps be sustainable over time in their everyday lives.

Interestingly, families appear to have employed a joint strategy to reduce the negative effects of extreme energy-saving and a low comfort level by transforming it into a social event (for example, lighting candles, making things cozy, buying pizza or attending a party).

However, one important question about the persuasive pervasive game approach that needs to be answered is: do people that play pervasive learning games *retain* the behaviors that they had acquired in the game over time? In this study we have not been able to show any conclusive long-term effects of our approach. When interviewed, several of the participants assured us that they still conserved energy and were committed to continue doing so. For the Smedjebacken team, however, energy consumption seems to have returned to normal within a few weeks after the game ended. One of the team members (agent 204) did have a slightly lower consumption level after the game, if we disregard an initial peak during the second week after the game (see Figure 4). Since we were unable to measure the Växjö team's postgame consumption, we don't know if the postgame trend for this team (who won the game) was the same. Some households made permanent changes in lightning and heating, and these measures should naturally have an impact on their long-term energy consumption.

Nevertheless, to reinforce behavior change over time, we suggest three different strategies that are worth exploring. The first could be to prolong the actual gameplay. This could be achieved by providing additional game content, preferably by building on the social aspects of the game. For example, we could set up leagues where the different teams fight against each other for a place in a final, or adding missions that, in line with strategies in this game, encourage energy-saving social activities such as taking the family to cultural events like a movie or a concert.

A second design strategy could be to expand, based on a real-time sensor system, on the pervasive interaction component of the game. In this way—when the player is using different home appliances—the game could provide immediate energy consumption feedback from those particular devices. This strategy would strengthen learning and enable other forms of less event-based forms of games.

A third approach worth considering is to append the current game experience with a low-intensity kind of postgame information service to sustain some of the motivation for energy conservation, as well as provide feedback on the participants' postgame energy- saving strategies.

Of these three strategies, the second one (investigating how a game design on top of a real-time sensor system can be done) is currently being investigated in an ongoing project at the Interactive Institute [Bång et al. 2009; Gustafsson et al. 2009].

In this project however the use of existing platforms such as the AMR systems, Java-enabled phones, as well as the HSDPA network was a deliberate choice in order to provide a concept with real-world feasibility, which at a later stage can be implemented and introduced on a larger scale.[1] Hence, in this sense, the technical development and evaluation can also be said to be part of the results of this project. The problems mentioned earlier, with delays in data transfer, are examples of unexpected difficulties that arise with a novel system such as the AMR. Despite this problem, which could be accounted for in the design, the overall success of the game prototype gives us the confidence to say that it is feasible to build an engaging and *scalable* mobile pervasive game for energy conservation based on existing AMR infrastructure. A game that, despite the limitations of a slow feedback loop, can both motivate and educate on the topic of energy conservation, through what appears to be an enjoyable and interesting experience for both indirect and direct participants.

7. CONCLUSION

This study indicates that mobile pervasive games can be an effective way to *motivate* teenagers and their families to lower energy consumption in their homes. The participants were highly engaged in the game and accepted levels of comfort in the home way below normal standards. Moreover, the study indicates that pervasive games can also be great tools to *educate* people about energy consumption in the home. In this trial, however, we were not able to show any indication of long-term reduction in energy consumption, and more research is clearly needed in this regard. Nevertheless, we believe that pervasive learning games that have a pronounced social component like the *Power Agent c*an be a very successful tool for behavioral change and learning in related domains such as lifestyle-induced health problems, and other complex real-world issues close to the domestic and personal domain.

[1]During 2010 a commercial project based on Power Agent and these findings will be tested on 150 households.

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REFERENCES

BÅNG, M., SVAHN, M., AND GUSTAFSSON, A. 2009. Persuasive design of a mobile energy conservation game with direct feedback and social cues. In *Proceedings of the 3rd International Conference of the Digital Games Research Association* (DiGRA 2009).

BÅNG, M., GUSTAFSSON, A., AND KATZEFF, C. 2007. Promoting new patterns in household energy consumption with pervasive learning games. In *Proceedings of Persuasive 2007*. LNCS 4744, Springer, Berlin, 55–6.

BÅNG, M., TORSTENSSON, C., AND KATZEFF, C. 2006. The PowerHouse: A persuasive computer game designed to raise awareness of domestic energy consumption. In LNCS 3962, Springer, Berlin,123–132.

BENFORD, S., ROWLAND, D., FLINTHAM, M., DROZD, A., HULL, R., REID, J., MORRISON, J., AND FACER, K. 2005. Life on the edge: Supporting collaboration in location-based experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '05), ACM, New York, 721–730.

FORMAN, G. 2003. An extensive empirical study of feature selection metrics for text classification. *J. Mach. Learn. Res. 3* (Mar.), 1289–1305.

GAGNÉ, R. M., FOSTER, H., AND CROWLEY, M. E. 1948. The measurement of transfer of training. *Psychological Bull. 45*, 97–130.

GUSTAFSSON, A., BÅNG, M., AND SVAHN, M. 2009. Power Explorer—A casual game style for encouraging long term behavior change among teenagers. *In Proceedings of the ACM ACE 09.*

KIDSCORNER. 2009. http://www.managenergy.net/kidscorner/.

MARKOVI, F., PETROVIC, O., KITTL, C., AND EDEGGER, B. 2007. Pervasive learning games: A comparative study. *New Rev. Hypermedia and Multimedia 13,* 2 (Jan.), 93–116.

SOLOMON, S., QIN, D., AND MANNING, M. (EDS.). 2007. *Climate Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

WEAL, M. J., MICHAELIDES, D. T., THOMPSON, M. K., AND DEROURE, D. C. 2003. The ambient wood journals: Replaying the experience. In *Proceedings of the Fourteenth ACM Conference on Hypertext and Hypermedia* (HYPERTEXT '03), ACM, New York, 20–27.

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