Pervasive Visual Interfaces to Change Energy Consumption Behaviour at the Workplace

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ABSTRACT
This position paper introduces pervasive interventions at a university campus to increase the pro-environmental awareness, consciousness, and learning of employees making use of different visual interfaces. We briefly present the design of three intervention iterations. While in the first intervention the focus was on increasing awareness through information distribution with ambient learning displays on the campus, the second iteration provided personalised feedback to employees with the help of a sensor network and different client applications. The third iteration then implemented a game-based learning concept. We found that these approaches are effective on different levels and that a combination of these effective elements can lead to a sustained behaviour change among the employees.

Categories and Subject Descriptors
H.5.2 [**INFORMATION INTERFACES AND PRESENTATION**]: User Interfaces

General Terms
Measurement, Design, Experimentation, Human Factors.

Keywords
Environmental Learning, Pervasive Education, Ambient Learning Displays, Game-based Learning, Design-based Research, Mobile Learning.

1. INTRODUCTION AND BACKGROUND
Several high-level studies have shown the effect of human energy consumption on pollution and climate change [3,6]. While in the home context monetary incentives are one of the main motivational aids to save energy, these incentives are not present at the workplace. In a formative study we have conducted it has been shown that only 25% of employees in an academic organisation are concerned about the financial consequences of their individual consumption for the organization [2]. Therefore, other initiatives are needed to increase pro-environmental awareness and behaviour change at the workplace. To approach this we conducted the three consecutive intervention studies briefly presented below. On a conceptual level these pervasive interventions are based on a complex model of pro-environmental behaviour [4]. The model integrates internal factors such as personality traits or environmental consciousness and external factors such as infrastructure or political context. Additionally the authors of the model investigated and incorporated possible barriers to pro-environmental behaviour. These barriers are mainly responsible for the gap between attitude and action, also referred to as engagement gap. Among others the identified barriers were lack of environmental consciousness and knowledge, negative or insufficient feedback about behaviour, as well as missing internal and external incentives. Our interventions are based on previous research done in this area. We acknowledge this work, but do not elaborate further on that within this paper.

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2. PUBLIC DISPLAYS TO INCREASE ENVIRONMENTAL AWARENESS
This study focused on an intervention that initiates environmental learning and facilitates pro-environmental behaviour at the workplace. Thereby the purpose of the study was to (1) use ambient displays as novel approach in presenting and dealing with energy consumption and conservation information, (2) assess and evaluate the respective learning outcome and the behaviour change. The utilisation of ambient displays in this context was motivated on the authors' underlying research project on the situated support of informal and non-formal learning scenarios in ubiquitous learning environments by enabling learners to view, access, and interact with contextualized digital content presented in an ambient way.

For the experimental variation two independent variables were used, i.e. the representational fidelity as well as the level of notification of the ambient learning displays, while each variable could take one of two distinct states. This resulted in four different treatments combining the two variables and their respective levels or a 2 x 2 experimental design with four groups covering all different treatments, i.e. ambient learning display prototype with either (1) blind notification and indexical representation, (2) blind notification and symbolic representation, (3) interruptive notification and indexical representation, or (4) interruptive notification and symbolic representation. As dependent variables the theoretical construct environmental learning and the pro-environmental behaviour have been measured. For environmental learning pre- and post-test questionnaires were used to measure the single components and apply respective statistical methods. In total three components were measured directly with the questionnaire, namely:

- Confidence to estimate individual and institutional consumption and conservation potentials,

- Awareness need and estimated effectiveness of higher awareness, as well as
- Environmental concern and conservational attitude.

For the experiment four prototypes were deployed in four chosen campus buildings. Corresponding to the main characteristic of ambient displays [1], i.e. deliver information out of the periphery of attention, while being able to move between the periphery and the focus of attention, the prototypes were used to emulate ambient learning displays. Each prototype consisted of a Dell M2010 notebook with built-in speakers and webcam but without attached keyboard or mouse. The speakers were used to send out audio notifications, while the webcam was used to enhance the functionality of the notebook with a custom-built movement/attention sensor. The sensor was built using the Processing[1] development environment and the open source computer vision library for Processing.

Figure 1. Deployed Ambient Display Prototypes.

The prototypes presented precompiled slides showing three types of information, divided into parts depicting information regarding energy consumption in the building, generic saving tips, and the overall conservation potential. On each slide the most important information was highlighted in red and contextual information, such as location or timeframe, was highlighted in blue. The first part contained information depicting the average electricity consumption per working day of each employee, the whole campus, and the building the display was located in. The respective numbers were calculated based on the actual consumption of the previous year.

The prototype variation on notification level was implemented using the custom-built movement/attention sensor to trigger the notification as well as the built-in speakers to play back a respective audio file. For the interruptive treatments one audio notification was played when the sensor detected movement and another one when the sensor detected that someone turned towards the display. For blind treatments any notification was omitted. The variation on representational fidelity was implemented as two distinct means of information presentation. For the indexical representation raw data facts were used to communicate consumption information, saving tips, and conservation potentials. In contrast, topic-related icons were used for the symbolic representation of the data, e.g. light bulb icons representing 5W each. Due to the ambient nature of the deployed learning displays the employees were not asked directly to participate in the experiment and watch out for the treatment. Instead the prototypes were deployed in the entrance areas of the four buildings and all employees that responded to the pre-test were asked after the treatments to respond to the post-test assuming that they did notice the deployed ambient learning display.

Analysing the results of the pre-test and post-test data showed the following results. The group with interruptive notification and symbolic representation had the largest gain within the construct environmental learning and the group with interruptive notification and indexical representation the smallest. The largest knowledge gain could be measured for the group with blind notification and indexical representation. The largest confidence gain as well as the largest awareness gain could be measured for the group with interruptive notification and symbolic representation. The largest concern gain could be measured for the group with blind notification and symbolic representation. Furthermore the influence of the different treatment conditions on the environmental learning outcome as well as the individual component gains was explored. None of the effects were significant to demonstrate the superiority of the one prototype design against the other. Across all groups a comparison showed that the deployed prototypes significantly influenced awareness and knowledge. In total participants scored significantly better on the knowledge component and felt a significant lower awareness need after the treatment. This revealed that the deployed prototypes helped to examine and comprehend and lower the awareness need of employees. The qualitative results of the post-test also showed that there is a need for alternative ways to motivate employees to save energy at the workplace, as for instances clear incentives were missed or the provided information was to generic.

3. PERSONALISED FEEDBACK TO INCREASE ENVIRONMENTAL CONSCIOUSNESS AND KNOWLEDGE

The presented project elaborated and developed an infrastructure that supports the concept of “Energy Awareness Displays” in office buildings with the following functionality:

- Inclusion of individual energy consumption information (device specific or personal level of detail).
- Aggregation of available information extending and enriching the overall energy consumption picture.
- Sensoring and logging to measure the effectiveness in terms of energy conservation and enable the prototypical evaluation.

Based on the supporting infrastructure respective display prototypes have been developed upon the following characteristics:

- Public interactive representation of the overall and individual energy consumption in several levels of detail.
- Explorative comparison of the consumption information in relation to fellow employees, departments, and/or floors.
- Motivating and persuading conservation facilitation patterns based on the presented information, such as visual incentives.

The described approach required accessing and using external services offering the needed functionality, i.e. inclusion of individual energy consumption information, aggregation of this information, and logging. For the inclusion of individual energy

[1] http://processing.org

consumption information the Plugwise[2] system was chosen. The system provides the needed sensor hardware to manage appliances and get access to energy consumption details. Furthermore the included software allows configuring the informational access via web services. The result is a wireless smart meter plugs network that can be accessed using the bundled software. The system was set up in such a way that individual appliance, room, and group information could be accessed. A basic application programming interface (API) can be used to access this information. The existing API was slightly adapted and enhanced to deliver all needed information in the right format. All changes are implemented based on the existing Plugwise Source[3] software template engine. When requesting information from the API, the information is returned in a simple XML[4] structure that can be incorporated into applications.

For the aggregation of available information respectively the logging of sensor data the Pachube[5] system was used. The system offers a free real-time open data web services that allows to aggregate, store, and access all kinds of sensor data, e.g. energy, home automation, and weather data can be aggregated, enriched, and accessed utilising different means. The system was set up to aggregate all the available sensor data for each room, i.e. (daily) total power usage and additionally the occupation.

On top of the outlined infrastructure a mobile and a web/desktop end-user application have been developed. The applications visualise the gathered information within the infrastructure. Thus the information can be accessed and explored online or with existing institutional or personal devices, including desktop computers, tablets, smartphones, and so on. The developed mobile application is shown in Figure 2. The developed web/desktop application is shown in Figure 3.

Figure 2. Mobile Application.

As part of the design cycle the developed display prototypes and used visualisation techniques have been evaluated in user-studies to reveal which are most effective in communicating energy consumption data and motivating energy conservation. Furthermore surveys have been conducted to assess whether dynamic visual feedback and the provided facilitation patterns can promote the conservation of electricity at the workplace and measure the increased awareness on the topic as well as changed attitudes and/or changes in behaviour. Furthermore the user acceptance and interest have been measured.

[2] http://www.plugwise.com/

[3] http://www.plugwise.com/idplugtype-f/source

[4] http://www.w3.org/XML/

[5] https://pachube.com/

The deployment of the feedback intervention in the subgroup made them aware that they are not active enough and need more information and knowledge about energy conservation at the workplace. In addition most participants of this intervention communicated the need for incentives to save energy. Results show that although the display prototypes have not been used extensively the information presented was perceived well and understood. Information granularity of the visualization has satisfied the needs of employees.

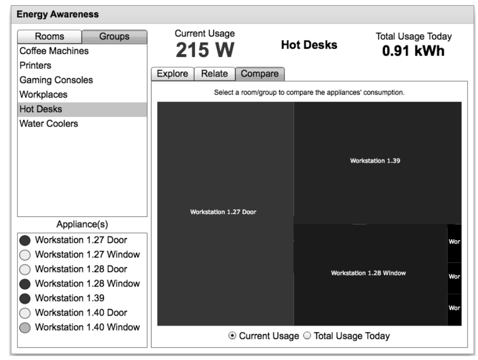

Figure 3. Web/Desktop Application.

4. GAME-BASED LEARNING TO INCREASE ENVIRONMENTAL CONSCIOUSNESS AND BEHAVIOUR CHANGE

In this study we had the goal to go beyond increasing awareness and providing personalized information and we focused on the potential of a pervasive game to increase knowledge, pro-environmental consciousness and last but not least change consumption behaviour. Our research questions for the pilot study have been the following:

- Which aspects of a pervasive game have the most potential for improving energy consumption behaviour at the workplace?
- Which aspects of a pervasive game have the most potential for improving environmental consciousness?
- Do rewards in the form of digital badges and prizes have a positive impact on consumption behaviour and environmental consciousness?

To answer these questions we have integrated different technologies. The design of the pervasive game has been done using ARLearn. ARLearn is a platform for location-based mobile learning. The platform consists of an authoring interface that enables game-designers to bind a number of content items and task structures to locations and to use game-logic and dependencies to initiate further tasks and activities [5]. Figure 4 shows the developed game-based learning application. Besides ARLearn we have used a signage solution to display content on existing displays on the campus and recruit participants for the game. For the incentive component we have integrated and used the Mozilla Open Badge Infrastructure[6]. At the end of the game the participants were asked to evaluate the game and provide qualitative feedback. The results showed that participants were highly concerned about the amount of energy they are using at the workplace, especially regarding the environmental costs, such as

[6] http://openbadges.org

higher environmental pollution. They were also highly concerned with what they can do personally to reduce their energy consumption and performed the suggested energy saving tips. When asked why they were not doing more to reduce their energy consumption the participants opted again for more information and detailed feedback on their personal consumption. Compared to the second iteration less participants stated that they need more incentives to save energy thus emphasising the influence of the gamification as incentive mechanism. The majority of participants was highly motivated to take more actions to further reduce their energy consumption.

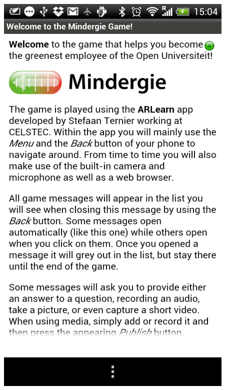

Figure 4. Game-based Learning Application in ARLearn.

When asked to evaluate the game the participants stated that the gamification was appealing. Overall the participants liked "active" game elements most. The "informational" elements were less popular, while the given rewards in form of badges ranged in between the two. Regarding the expected behaviour change, participants stated that the game in general changed their energy consumption behaviour, while the "informational" and the "active" elements were assigned with the highest potential to do so. Regarding the environmental consciousness, participants stated that the game enhanced their environmental consciousness. In this regard the "informational" elements were assigned with the highest potential to do so. Participants stated that the "active" game elements had a slighter higher potential to change energy consumption behaviour compared to the "informational" elements and vice versa for enhancing the environmental consciousness. The badge and the prizes element were in general assigned with the lowest potential, while the potential to change the consumption behaviour was higher compared to the potential to enhance environmental consciousness.

5. DISCUSSION AND CONCLUSIONS

We presented different pervasive interventions to increase pro-environmental awareness, consciousness, and learning of office employees making use of different visual interfaces. The first intervention introduced public displays at the workplace to increase the awareness for pro-environmental behaviour and energy saving potential. The results revealed the influence on awareness, confidence, and knowledge, but also asked for more personalised and direct feedback. Consequently the second intervention fostered personalised feedback about individual energy consumption at the workplace using different means. On the one hand the results showed the effectiveness and revealed the favoured kind of feedback, on the other hand participants asked again for more information and instructions to initiate conservation activities combined with the need for more incentives to sustain this behaviour. The third intervention then focused more on behavioural approaches combined with a motivational and social influence approach utilising gamification and clear incentives. The results underpinned the role and impact of these mechanisms. In sum, the results of the three interventions have provided information on different levels: For the organization the pilots have provided a good guideline how effective energy conservation at the workplace can be enabled and rewarded for employees. For our research we could collect feedback about important design decisions that will influence a large scale pilot, combining the most promising components of the single iterations, i.e. public displays to distribute information, individual displays with personalised feedback, gamification to sustain behaviour change, clear incentives and active game elements, etc.

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