It doesn't matter, but: examining the impact of ambient learning displays on energy consumption and conservation at the workplace

DOI:
10.1080/13504622.2014.921804

Document status and date:
Published: 18/08/2015

Document Version:
Peer reviewed version

It Doesn't Matter, But: Examining the impact of ambient learning displays on energy consumption and conservation at the workplace

Dirk Börner*, Marco Kalz, Marcus Specht

Welten Institute, Open University of the Netherlands, Heerlen, The Netherlands

Postbus 2960, 6401 DL Heerlen, The Netherlands, Phone: +31455762506 Fax: +31455762800, E-mail: {dirk.boerner, marco.kalz, marcus.specht}@ou.nl

Dr. Dirk Börner is assistant professor at the Welten Institute at the Open University of the Netherlands. With a background in computer science he is conducting research on ubiquitous learning support. In particular he focuses on the utilisation of ambient information presentation in combination with mobile technology to support learners in authentic situations.

Dr. Marco Kalz is assistant professor at the Welten Institute at the Open University of the Netherlands. He is currently involved in several national and international research projects in the domain of technology-enhanced learning. His research focus is on the use of pervasive technologies for lifelong learning and new approaches for assessment and feedback that help learners to combine different learning contexts.

Prof. Dr. Marcus Specht is Professor for Advanced Learning Technologies at the Welten Institute at the Open University of the Netherlands and director of the Learning Innovation Labs. He is currently involved in several national and international research projects on competence based life-long learning, personalised information support and contextualised and mobile learning. His research focus is on Mobile and Contextualised Learning Technologies, Learning Network Services, and Social and Immersive Media for Learning.

* Corresponding author. Email: dirk.boerner@ou.nl

It Doesn't Matter, But: Examining the impact of ambient learning displays on energy consumption and conservation at the workplace

This study reports an intervention to initiate environmental learning and facilitate pro-environmental behaviour. The purpose was to examine the impact of ambient learning displays on energy consumption and conservation at the workplace, more specifically the evaluation of learning outcome and behaviour change. Using a quasi-experimental design, the empirical study was conducted among employees working at a university campus. For the experimental treatments ambient learning display prototypes were varied on two design dimensions, namely representational fidelity and notification level. The results do not provide clear evidence that the design of the displays influences learning outcome or that the displays lead to pro-environmental behaviour change. Nevertheless the sole deployment of the display prototypes eased the comprehension of the information provided and lowered the need for additional information. Thus ambient learning displays provide a promising framework in the context of environmental learning and beyond.

Keywords: Ambient learning displays; Empirical study; Energy conservation; Environmental learning; Pro-environmental behaviour

Introduction

This empirical study is the first in the research and development of ambient learning displays (Börner, Kalz, and Specht 2011). An initial literature review revealed a variety of application scenarios, designs, and evaluation methods of ambient displays, especially in a learning context (Börner, Kalz, and Specht 2013). However, no empirical studies evaluating the use of ambient displays for environmental learning (i.e. increasing knowledge and awareness about the environment and related challenges) were found. In this study the displays were applied in the context of environmental education and specifically with respect to energy consumption and conservation at the workplace. The overall goal was to raise employees' awareness on the topic, introduce relevant conservation strategies, and initiate environmental learning at the workplace.

The underlying assumption was that raised awareness on actual consumption fosters a change in behaviour among employees and thus leads to reduced total energy consumption for the employing organisation. In the long-term conservation opportunities should facilitate a change towards pro-environmental behaviour that ideally becomes a sustained habit. This assumption is based on a study by Siero et al. (1996) which showed that the offering of learning opportunities about pro-environmental behaviour has the potential to change the attitude and behaviour of employees.

Background

Several reports and studies have confirmed the need to decrease the human contribution to global warming and environmental deterioration on a global and local level (IPCC 2007; United Nations Environment Programme 2012). Besides changing behaviour and decreasing energy consumption in the domestic context, the workplace context offers huge potential to contribute to these goals. Earlier work showed that goal setting, information distribution, and the offering of learning opportunities can increase awareness about pro-environmental behaviour and energy conservation at the workplace (Siero et al. 1996). Several environmental education interventions have supported the connection between attitudes and pro-environmental behaviour. To explain pro-environmental behaviour, Kollmuss and Agyeman (2002) discussed linear models, pro-social behaviour models, and sociological approaches. Among theories they discuss the theory of planned behaviour (Ajzen 1991), in which attitudes influence behavioural intentions that shape in turn actions. The authors then synthesised their findings into a complex model that integrates internal and external factors. Personality traits or environmental consciousness can be described as internal factors, while the existing infrastructure or political context can be classed as external ones. In addition, Kollmuss and Agyeman (2002) investigated and incorporated possible barriers in their model to positively influence pro-environmental behaviour. These barriers are mainly responsible for the engagement gap between attitude and action. The most influential barriers were lack of environmental consciousness and knowledge, negative or insufficient feedback about behaviour, as well as the absence of internal and external incentives.

Looking more into this process, pro-environmental behaviour can be understood as action directed at solving a problem by the individual who takes the action (Jensen

2002). Before taking the action individuals need to be conscious about the options available and the effects of their actions. Actions can be direct or indirect and they can be done on an individual level or collectively. Jensen stresses the role of knowledge in the awareness-building and decision-making process and proposes four knowledge dimensions, namely causes, effects, change strategies, and visions. While traditional environmental education initiatives mostly focus on effects, he proposes a holistic approach that integrates the four dimensions. Following this approach, Räthzel and Uzzell (2009) propose an action competence approach to avoid many problems that moralistic, value-driven environmental education approaches have. Instead they highlight the importance that learners understand of the problem to develop appropriate action strategies.

Regarding the motivation, it should be noted that the workplace context differs from the domestic one. The motivational factors are differently aligned and the conservation incentives vary. In a recent study we could show that only 25% of employees in an academic organisation were concerned about the financial consequences of their individual energy consumption for the organisation (Börner et al. 2012). In contrast financial incentives are currently one of the major driving forces in the domestic context. The employees surveyed reported that they felt unaware of the organizational and individual energy consumption and conservation possibilities. Moreover, around one third requested more detailed information as well as clearer incentives from the employing organisation.

These findings are in line with another recent study about energy-related behaviour in office buildings (Lo, Peters, and Kok 2012). The authors described two important differences between a domestic and an organisational context. The costs of energy consumption are not monitored or paid by the employee, whereas an organisation's structure, size, goals etc. do influence individual behaviour. Furthermore, they stressed the importance of understanding the psychosocial determinants of pro-environmental behaviour at the workplace, which differs from the domestic context. In conclusion, the authors presented a framework comprising individual and organisational determinants that can influence individual behaviour at the workplace, and identified five categories: attitude, awareness, self-efficacy, subjective norms, and habits.

Foster et al. (2012) took a similar approach by describing the interaction design for energy conservation at the workplace as a problem consisting of motivational, social, organisational, and technical issues. Further, they identified a "research knowledge gap present in understanding the end-users of energy in the workplace and, therefore, the design of appropriate and achievable workplace energy interventions, particularly those that encompass novel ways of encouraging people to adopt positive energy usage behaviour whilst at work."

Purpose

Designed to investigate parts of this identified research knowledge gap, this study focuses on an intervention that initiates environmental learning and facilitates pro-environmental behaviour at the workplace by presenting respective information. Although the use of information displays in environmental education contexts has been explored before, e.g. by introducing and evaluating visitors' technology use in zoos (Yocco et al. 2011), this study investigates an even more contextualised use and the actual impact on learning outcomes and behaviour. Thus 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 learning outcome and the behaviour change, as well as (3) address the barriers identified by Kollmuss and Agyeman (2002).

The utilisation of ambient displays in this context was motivated on the authors' underlying research project on the situated support of learning scenarios in ubiquitous learning environments by enabling learners to view, access, and interact with contextualised digital content presented in an ambient way. With the goal to examine the effects of ambient information presentation on learning in situated learning contexts, Börner, Kalz, and Specht (2011) outline their vision on ambient learning displays. This vision is based on Mark Weiser's outline of ubiquitous computing (Weiser 1991), the derived concept of ambient displays (Wisneski et al. 1998), as well as the concept of situated learning, i.e. learning that takes place in the same context as it is applied (Lave and Wenger 1991). The conceptual framework for ambient learning displays incorporated four design dimensions for ambient systems as defined by Pousman and Stasko (2006), namely information capacity, notification level, representational fidelity, and aesthetic emphasis. The influence and effectiveness of these dimensions on learning has not yet been examined. To do so, the learning outcome needed to be measured in a controlled study varying the manifestations of each dimension. A classification of existing ambient systems and prototypes (Börner, Kalz, and Specht 2013) revealed the most prominent manifestations as well as limitations and peculiarities to take into account when turning the dimensions into experimental variables. Information capacity and aesthetic emphasis have not been considered for experimental variation in this context. Information capacity is determined by the amount of information represented by the system, which needed to be consistent to measure a learning outcome reliably. The aesthetic emphasis is a highly subjective measure that heavily depends on the context in which the ambient system is used. Therefore this dimension fell outside the scope of a prototypical system. In contrast the remaining two dimensions were suitable for experimental variation. Pousman and Stasko (2006) described these dimensions as follows:

- The representational fidelity dimension describes how the data is encoded.
- The notification level dimension depicts the degree of user interruption.

Both dimensions covered a broad design spectrum ranging from indexical to symbolic representations and change blind to interruptive levels of notification. Using indexical representations data is almost not encoded, e.g. the visual output of measuring instruments. Symbolic representations instead use arbitrary encodings for the same data, e.g. color codes. When designing ambient system addressing a change blind notification level, status changes and transitions are subtle and almost invisible. An interruptive system instead actively alerts users regarding the status change. Consequently the extreme manifestations were used for the experimental variation. The possible combinations of the representational fidelity and notification level design dimension manifestations resulted in four experimental groups covering all different treatments.

To assess and evaluate learning outcome and behaviour change, the underlying concepts environmental learning and pro-environmental behaviour have been elaborated on the basis of existing models such as the model of pro-environmental behaviour presented by Kollmuss and Agyeman (2002). In this study environmental learning has been construed as a theoretical construct covering environmental awareness, confidence, knowledge about consumption, as well as concern and conservation attitude. Finally, pro-environmental behaviour has been defined as being determined by the conservation activities performed as well as the actual energy consumption data.

Based on the purpose and objectives the following research questions and hypotheses were derived and tested in the following experiment:

(1) Does the design of an ambient learning display influence the environmental learning outcome?

Hypothesis #1. The environmental learning outcome is increased significantly when applying an ambient learning display design manifesting interruptive notification and symbolic representation. Thus the outcome within the group exposed to the respective design will be larger than within the other groups, while the group exposed to the change blind notification and indexical representation design will have the smallest outcome.

(2) Do the ambient learning display prototypes deployed lead to pro-environmental behaviour change?

Hypothesis #2. The sole deployment of ambient learning displays facilitates behaviour change. Thus there will be a significant increase in the measured pro-environmental behaviour for all participants in line with a decrease in energy consumption.

Method

The study was designed in the context of an institutional energy conservation project with the goal to promote conservation activities and reduce the overall energy consumption of the workplaces located at the main campus of a university. The study involved the four distinct experimental treatments with paired pre- and post-tests. The experiment was performed for four consecutive weeks during wintertime at the turn of the year. The pre-test questionnaire was launched one month before the experiment. The post-test questionnaire was launched one month after the experiment.

For the experimental variation two independent variables were defined, 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 manifestations or a 2 x 2 experimental design with four groups covering all different treatments: ambient learning display prototype with either (1) change blind notification and indexical representation, (2) change blind notification and symbolic representation, (3) interruptive notification and indexical representation, or (4) interruptive notification and symbolic representation.

The dependent variables measured were environmental learning and pro-environmental behaviour. For environmental learning the paired questionnaires were used to measure the individual components within this theoretical construct. Instead of analysing specific items statistical methods were applied to the latent components of interest in the subsequent analysis. 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 conservation attitude.

Each component was measured using several questions that were aggregated to form the composite scores within the pre- and post-test questionnaires using the means. Additionally one component was measured indirectly with the questionnaire, i.e. knowledge about consumption. For this purpose, several related open questions were recoded into comparable formats and then scored independently. The scoring was done by comparing the individual outcomes to the actual result and recoding this into values on an ordinal scale. These values were then aggregated using the mean. Finally the environmental learning outcome was calculated by summing the individual component gains in the following way: $|Gain_{Knowledge}| + Gain_{Confidence} + |Gain_{Awareness}| + Gain_{Concern}$. For the knowledge and awareness gain absolute values had to be used as negative values reflected positive component trends. For the knowledge component the trend was positive when participants received a lower score (i.e. better score) after treatment than before treatment. For the awareness component the trend was positive when participants reported a lower awareness need (i.e. better awareness) after treatment than before treatment.

The pro-environmental behaviour was determined by the conservation activities performed as well as the actual energy consumption data. The conservation activities performed were measured directly via the questionnaires. The item simply asked for the number of activities performed. The actual energy consumption data were obtained from the institutional facility management system on a daily basis.

Materials

For the experiment four prototypes emulating ambient learning displays were deployed in the entrance areas of four chosen campus buildings comparable in structure and size. The prototypes were deployed in such a way that everyone entering or leaving the buildings passed by the respective prototype. The prototypes corresponded to the main characteristic of ambient displays as defined initially by Wisneski et al. (1998), i.e. peripheral, unobtrusive, and embedded design addressing various senses, utilisation of subtle methods in the periphery of attention, and focus on ensuring awareness of mostly non-critical information. Consequently, the prototypes were designed to deliver information on the periphery of attention, while still being able to move between the periphery and the focus of attention. 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.

The prototypes presented pre-compiled slides showing three types of information, divided into parts depicting information regarding energy consumption, generic saving tips, and the overall conservation potential. The selection of information as well as the design of the presented slides was aligned with the four proposed knowledge dimensions by Jensen (2002) depicting on how to approach environmental problems with “action-oriented knowledge” in a more holistic approach. The causes and effects dimension was reflected by the provided energy consumption information, the change strategies dimension by the generic saving tips, and the visions dimension by the illustrated overall conservation potential. In this way the information delivered was adapted to the study context and institutional needs. 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 numbers were calculated based on the actual consumption of the previous year. Figure 1(a) shows one of these consumption

---

[1] http://processing.org

information slides that can be translated into: *Per working day as much electricity is consumed on the campus as by an average three-person household per year*. Figure 1(b) shows a generic saving tip and Figure 1(c) an illustrated conservation potential.

[Figure 1]

The slideshows presented by the prototypes consisted of 16 slides each, including three slides with energy consumption information, 11 slides presenting generic saving tips, and two slides informing on the overall conservation potential. The full screen slideshows were looped continuously showing each slide for 20 seconds. All four slideshows contained the same information, with the only exception that one slide per slideshow was adapted to inform about the respective building's energy consumption.

The prototype variation on notification level was implemented using the custom-built movement/attention sensor to trigger the notification as well as to activate the built-in speakers to play back audio files. 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. The audio notifications consisted of a short sample of clinking wine glasses (movement detection) and the fictive sound of a magic wand (user attention). For change 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. Therefore the raw data was encoded accordingly, i.e. light bulb icons representing an energy consumption of 5W each, person icons representing the annual energy consumption of households, as well as pie chart icons representing conservation potentials.

Instrument

The used questionnaire took about 15 minutes to complete and was not anonymous which allowed detailed pair-wise data comparison. The questionnaire was constructed specifically for this study and contained demographic questions, such as year of birth, gender, period of employment, workplace location, as well as individual activity and awareness. Further, the questionnaire contained the questions tapping actual knowledge about consumption, attitude towards conservation, and individual actions performed. Each part comprised several questions; for instance, knowledge was measured by asking the participants to estimate the energy consumption of the campus, the building, and the workplace. The questionnaire was used for the pre- and post-test. The selection of components was supported by a correlation matrix based on the pre-test, which revealed correlation coefficient clusters indicating that the respective questions measure the same aspect/component. A reliability analysis revealed the selected components had acceptable reliabilities, with Cronbach's $\alpha >= .701$. Most questions used 5-point or 7-point rating scales. The 5-point scales provided a distinct range of choices covering 1 (not at all), 2 (poorly), 3 (fairly), 4 (good), and 5 (perfectly) to express the participants' agreement regarding a personal ability, while the 7-point scales provided an open range of choices from 1 (not at all) to 7 (completely) to express the participants' agreement regarding a statement. Other questions elicited multiple answers or open answers. The different types of questions were not mixed when forming components to allow a consistent analysis. Table 1 lists the components, the questions used in the questionnaire, and their type. As the components confidence, awareness, and concern aggregate several scaled items, the mean has been used as central tendency measurement for the following analysis. The post-test questionnaire also contained questions related to the individual perception of the ambient learning display and comprehension aspects. The data was mainly collected quantitatively with only some qualitative data to collect generic comments and feedback. This study used only the quantitative data for analysis.

[Table 1]

Participants

A total of 563 university employees (i.e. faculty members and administrative staff) were asked to participate in the study. Of these, 190 employees responded to the pre-test. Due to the ambient nature of the learning displays, the employees were not asked directly to participate in the experiment or watch out for the treatment. Instead, all employees that responded to the pre-test were asked to respond to the post-test. In total 101 employees responded to the post-test. The prototypes were only deployed in the four main buildings of the university site. Only employees working in one of these main buildings were considered as participants of the experiment, yielding 94 post-test respondents for analysis. The buildings are comparable in function and allocation of faculty members and administrative staff. Although the different buildings host different faculties, the employees' membership, profession, or discipline was not enquired nor considered in the following analysis. The participants were divided into groups depending on the building they are working in.

The 94 participants (37 females and 57 males) were aged between 26 and 65 and had been working for the university for between two and 26 years. Of these, 12 participants were exposed to the prototype with the change blind notification and symbolic representation treatment (N=12), 35 to the prototype with the change blind notification and indexical representation treatment (N=35), 12 to the prototype with the interruptive notification and indexical representation treatment (N=12), and 35 to the prototype with the interruptive notification and symbolic representation treatment (N=35). Table 2 outlines the four treatments, the prototype variations, and the number of participants exposed to them.

[Table 2]

Results

The first hypothesis was related to the environmental learning outcome, which was calculated by summing the individual component gains. In total the mean environmental learning outcome was $M_{\text{Total}} = 0.61$ ($SD = 1.61$). The group with interruptive notification and symbolic representation had the largest environmental learning outcome ($M_{\text{Group 4}} = 0.90$, $SD = 1.56$) and the group with interruptive notification and indexical representation the smallest ($M_{\text{Group 3}} = -0.17$, $SD = 2.14$). Subsequently, the individual component gains were examined to gain more insights. In total the mean knowledge gain was $M_{\text{Total}} = 0.22$ ($SD = 0.75$). The largest knowledge gain was observed in the group with change blind notification and indexical representation ($M_{\text{Group 1}} = 0.31$, $SD = 0.76$). The largest confidence gain ($M_{\text{Group 4}} = 0.21$, $SD = 0.83$) as well as the largest awareness gain ($M_{\text{Group 4}} = 0.49$, $SD = 0.91$) was noted in the group with interruptive notification and symbolic representation. In total the mean confidence gain was $M_{\text{Total}} = 0.12$ ($SD = 0.70$) and the mean awareness gain was $M_{\text{Total}} = 0.36$ ($SD = 0.97$). The largest concern gain was observed in the group with change blind notification and symbolic representation ($M_{\text{Group 2}} = 0.22$, $SD = 0.98$) compared with a mean total loss of $M_{\text{Total}} = -0.09$ ($SD = 1.05$). A Kruskall-Wallis test was conducted to explore the influence of the different treatment conditions on the environmental learning outcome as well as the individual component gains. This non-parametric test allows comparison of several conditions with different participants. The test does not require the group samples to be the same size. The test did not show significant differences between the treatment conditions.

In a second step a number of Wilcoxon signed-rank tests were conducted. This non-parametric test allows comparison of individual component means before and after the treatment from the same participants. Table 3 lists the descriptive statistics used for the comparison of each component. In total participants scored significantly better on the knowledge component after the treatment ($M_{\text{Total}} = 5.07$, $SD = 0.72$) than before the treatment ($M_{\text{Total}} = 5.29$, $SD = 0.54$), $z = -2.60$, $p = .009$, $r = -.19$. The effect size is small. Participants felt a significant lower awareness need after the treatment ($M_{\text{Total}} = 4.29$, $SD = 1.34$) than before ($M_{\text{Total}} = 4.65$, $SD = 1.39$), $z = -3.33$, $p = .001$, $r = -.24$. The effect size is again small. The results for the components depicting the estimation of individual and institutional consumption and conservation potentials (confidence) as well as of the environmental concern and conservation attitude (concern) were not statistically significant. The individual component means of the different groups before and after the treatment were examined using Wilcoxon signed-rank tests. The group with change blind notification and indexical representation scored significantly better on the knowledge component after the treatment ($M_{\text{Group 1}} = 5.11$, $SD = 0.66$) than before ($M_{\text{Group 1}} = 5.42$, $SD = 0.43$), $z = -2.14$, $p = .032$, $r = -.26$. The effect size is small. The group with interruptive notification and indexical representation scored significantly worse on the concern component after the treatment ($M_{\text{Group 3}} = 3.53$, $SD = 0.99$) than before ($M_{\text{Group 3}} = 4.00$, $SD = 1.26$), $z = -2.01$, $p = .045$, $r = -.41$. The effect size is medium. The group with interruptive notification and symbolic representation scored significantly better on the awareness component after the treatment ($M_{\text{Group 4}} = 4.49$, $SD = 1.36$) than before ($M_{\text{Group 4}} = 4.98$, $SD = 1.35$), $z = -2.99$, $p = .003$, $r = -.36$. The effect size is again medium.

[Table 3]

The second hypothesis was related to the pro-environmental behaviour change. In total the mean activities gain was $M_{\text{Total}} = -0.11$ ($SD = 1.57$). The largest activities gain was observed in the group with change blind notification and indexical representation ($M_{\text{Group 1}}$ = 0.37, *SD* = 1.14). All other groups had a negative gain. The group with change blind notification and symbolic representation had the lowest gain ($M_{\text{Group 2}}$ = −0.58, *SD* = 1.38). The Kruskall-Wallis test did not show a significant influence of the different treatment conditions on the activities performed. Wilcoxon signed-rank tests were conducted to compare the conservation activities before and after the treatment. Table 4 lists the descriptive statistics of the conservation activities. In total participants performed fewer conservation activities after the treatment (M_{Total} = 4.76, *SD* = 1.85) than before the treatment (M_{Total} = 4.86, *SD* = 1.86). The effect is not statistically significant.

[Table 4]

The buildings total energy consumption decreased during the treatment (M_{Total} = 361.88, *SD* = 219.53) when compared with the consumption beforehand (M_{Total} = 372.35, *SD* = 219.77). After the treatment the total consumption decreased further (M_{Total} = 335.55, *SD* = 181.28). Figure 2 illustrates the consumption data for 12 consecutive weeks before, during, and after the experimental treatment for each building and in total. A Friedman test was conducted to compare the consumption means before, during, and after the treatment. This non-parametric test allows comparison of more than two means. The test revealed that the consumption changed significantly over time, χ^2 (2, 4) = 6.00, p = .050. Wilcoxon signed-rank tests were conducted to follow-up this finding, controlling for Type I error across tests by using the Bonferroni approach. The test did not show significant results.

[Figure 2]

Discussion

According to our first hypothesis, using interruptive notification and symbolic representation should result in a significantly larger environmental learning outcome than using change blind notification and indexical representation. The between-subjects tests results show no evidence to support this hypothesis. Although on average the group with the interruptive and symbolic prototype design had the largest outcome, the design variations have no significant influence on this. The group with the interruptive notification and indexical representation had the smallest outcome. Again this does not support the hypothesis that the group exposed to the change blind notification design and indexical representation should have the smallest outcome.

When investigating the construct's single components, namely the participants' environmental awareness, confidence, knowledge about consumption, as well as concern and conservation attitude, some supporting evidence for the hypothesis can be found. The group with the interruptive and symbolic design showed the largest gain in confidence and awareness, indicating that this design lowers the awareness need and builds up confidence to estimate the actual consumption and conservation potentials. On the other hand the group with the change blind and indexical design showed the largest gain in knowledge, suggesting that this design supports the examination and comprehension of the consumption information provided, saving tips, and conservation potentials. The group exposed to the change blind and symbolic design showed the largest gain in concern and conservation attitude.

Overall, within-subjects tests of the single component means of all participants show that the prototypes significantly influence awareness and knowledge. Generally speaking the prototypes help to examine and comprehend and lower the awareness need. The effect sizes are small with the highest magnitude on awareness. At the level of the different groups, the tests show that the group exposed to the prototype with change blind and indexical design significantly gained knowledge. Similarly the largest gain in awareness for the group with interruptive and symbolic design is also significant. It should be noted, however, that one group also showed a significant negative trend. The group exposed to the interruptive and indexical design showed significantly less environmental concern and conservation attitude after the treatment.

The reasons for the observed lack of evidence for the primary hypothesis are manifold. Beside the possible imprecision of the construct measured, some of the inherent issues when evaluating ambient displays and/or the insufficient variation in design might account for this lack. Furthermore novelty effects and the effect of small, partial, or no attention need to be prevented. This is also related to the general limitations of this study, mainly due to the exclusiveness of the experimental setting. On the one hand the setting offers a high degree of authenticity; on the other it provides challenges regarding the span between unobtrusiveness and user attention, e.g. how to measure and guarantee attention over time. The longitudinal effects need to be investigated from different perspectives. Both the display as well as the information provided need to be able to retain the participants' interest. Another limitation of the study in this context is the missing evaluation of the design dimensions information capacity and aesthetic emphasis. As explained both dimension were not taken into account for the experimental variation. Clearly these dimension also have an influence on the effectiveness of ambient learning display designs, which opens future research opportunities.

The second hypothesis stated that, independent of the display's design variation, the sole deployment of ambient learning displays should facilitate a pro-environmental behaviour change. Ideally the effect should be sustainable after the treatment. There is no supporting evidence that the prototypes have an influence on the conservation activities performed. Again the results suggest that the prototypes deployed have an opposite effect. Shen et al. (2008) reported similar findings in their study. Although the comprehension for the display increased over time, the user interest decreased. Consequently, the commitment to perform conservation activities might decline. However, there is some supporting evidence when comparing the consumption during the treatment with the consumption after the treatment, but no evidence for the secondary hypothesis in general. The previously mentioned novelty effect can partly explain this. There might also be a general problem with the kind of study conducted. Kenis and Mathijs (2012) observed that many respondents were opposed to being conditioned by educational or awareness-raising campaigns rather than being truly convinced.

Conclusions

In this paper we described a study to evaluate the effect of different variations of ambient learning displays to initiate environmental learning. As a first empirical study into the research and development of ambient learning displays, the study makes an important contribution to the field of technology-enhanced learning in general and environmental education specifically. We see the approach presented as a promising way to increase awareness, initiate pro-environmental behaviour, and point out alternative behaviour at the workplace and the possible future impact on different levels (individual, institutional, societal). It is essential to employ ambient learning displays in the future not only in a corrective way, but also in support of the development of employees' visions about possible futures (Hicks and Holden 1995). The findings extend the state of the art for sustainability initiatives on a university campus and can also influence both the incorporation of sustainability knowledge into several disciplines and a more adaptive way of knowledge production targeted at addressing "wicked" environmental problems (Miller, Muñoz-Erickson, and Redman 2011).

The results provide relevant insights and reveal several challenges future research has to cope with when applying technology in a learning context. As the variation on the prototypes' representational fidelity and notification level proves to be inconclusive, future designs should be balanced following successful approaches elaborated (e.g. Kim, Hong, and Magerko 2010; Kuznetsov and Paulos 2010). Recently Alt et al. (2012) also provided guidelines for the evaluation of public displays that could also be applied for ambient learning displays. The authors suggested setting a clear focus on internal, external, or ecological validity. With the aspiration to evaluate in realistic settings, confounding variables need to be somehow controlled and generalisability reduced to reach the desired goal. Instead of aiming too much on design factors, the context in which the ambient learning display is used and the contextualised information provided need more focus.

One claim of environmental education is to change consumption and conservation behaviour and eventually form pro-environmental habits. A variety of factors influence the pro-environmental behaviour. Especially in a workplace context the barriers need to be identified and respective determinants (Lo, Peters, and Kok 2012) incorporated to create a successful model. From an ambient learning display perspective, the study's results revealed different effective design strategies depending on the purpose of the educational initiative – from raising awareness, through confidence building, to the transfer of knowledge. To form habits the results call for a provision of (direct) feedback reflecting individual behaviour. This is also mentioned by Kollmuss and Agyeman (2002) as one of the barriers towards pro-environmental behaviour. Corresponding feedback characteristics and research variables of interest have been defined by Mory (2004). Another solution might be the use of alternative motivational designs, such as gamification (Werbach and Hunter 2012). This approach proved to be successful to close engagement gaps, progress towards a specific goal, and form sustained habits. Furthermore it has been applied for social good making use of game elements like rewards, feedback, or competition as motivational factors. We plan to build on these concepts in our future research.

References

Ajzen, Icek. 1991. "The Theory of Planned Behavior." *Organizational Behavior and Human Decision Processes* 50 (2): 179–211.

Alt, Florian, Stefan Schneegaß, Albrecht Schmidt, Jörg Müller, and Nemanja Memarovic. 2012. "How to Evaluate Public Displays." In *Proceedings of the 2012 International Symposium on Pervasive Displays - PerDis '12*, 1–6. New York, NY: ACM Press. doi:10.1145/2307798.2307815.

Börner, Dirk, Marco Kalz, and Marcus Specht. 2011. "Thinking Outside the Box - A Vision on Ambient Learning Displays." *International Journal of Technology Enhanced Learning* 3 (6): 627–642.

Börner, Dirk, Marco Kalz, and Marcus Specht. 2013. "Beyond the Channel: A Literature Review on Ambient Displays for Learning." *Computers & Education* 60 (1): 426–435. doi:http://dx.doi.org/10.1016/j.compedu.2012.06.010.

Börner, Dirk, Jeroen Storm, Marco Kalz, and Marcus Specht. 2012. "Energy Awareness Displays: Motivating Conservation at the Workplace through Feedback." *International Journal of Mobile Learning and Organisation* 6 (3/4): 189–203.

Campbell, Donald Thomas, Julian C. Stanley, and Nathaniel Lees Gage. 1963. *Experimental and Quasi-Experimental Designs for Research*. Boston, MA: Houghton, Mifflin and Company.

Foster, Derek, Shaun Lawson, Jamie Wardman, Mark Blythe, and Conor Linehan. 2012. "'Watts in It for Me?': Design Implications for Implementing Effective Energy Interventions in Organisations." In *CHI '12 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2357–2366. New York, NY: ACM Press. doi:10.1145/2207676.2208396.

Hicks, David, and Cathie Holden. 1995. "Exploring the Future: a Missing Dimension in Environmental Education." *Environmental Education Research* 1 (2) (January): 185–193. doi:10.1080/1350462950010205.

IPCC. 2007. "Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." In *Climate Change 2007*, edited by B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer. Cambridge and New York, NY: Cambridge University Press.

Jensen, Bjarne Bruun. 2002. "Knowledge, Action and Pro-Environmental Behaviour." *Environmental Education Research* 8 (3) (August): 325–334. doi:10.1080/13504620220145474.

Kenis, Anneleen, and Erik Mathijs. 2012. "Beyond Individual Behaviour Change: The Role of Power, Knowledge and Strategy in Tackling Climate Change." *Environmental Education Research* 18 (1) (February): 45–65. doi:10.1080/13504622.2011.576315.

Kim, Tanyoung, Hwajung Hong, and Brian Magerko. 2010. "Designing for Persuasion: Toward Ambient Eco-Visualization for Awareness." In *Persuasive Technology*, edited by Thomas Ploug, Per Hasle, and Harri Oinas-Kukkonen, 6137:106–116. Berlin, Heidelberg: Springer. doi:10.1007/978-3-642-13226-1_12.

Kollmuss, Anja, and Julian Agyeman. 2002. "Mind the Gap: Why Do People Act Environmentally and What Are the Barriers to Pro-Environmental Behavior?" *Environmental Education Research* 8 (3): 239–260. doi:10.1080/13504620220145401.

Kuznetsov, Stacey, and Eric Paulos. 2010. "UpStream: Motivating Water Conservation with Low-Cost Water Flow Sensing and Persuasive Displays." In *Proceedings of the 28th International Conference on Human Factors in Computing Systems*, 1851–1860. New York, NY: ACM Press. doi:10.1145/1753326.1753604.

Lave, Jean, and Etienne Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press. doi:10.2307/2804509.

Lo, Siu Hing, Gjalt-Jorn Y. Peters, and Gerjo Kok. 2012. "A Review of Determinants of and Interventions for Proenvironmental Behaviors in Organizations." *Journal of Applied Social Psychology* (November 1): 1–35. doi:10.1111/j.1559-1816.2012.00969.x.

Miller, Thaddeus R., Tischa Muñoz-Erickson, and Charles L. Redman. 2011. "Transforming Knowledge for Sustainability: Towards Adaptive Academic Institutions." *International Journal of Sustainability in Higher Education* 12 (2): 177–192. doi:10.1108/14676371111118228.

Mory, Edna Holland. 2004. "Feedback Research Revisited." In *Handbook of Research on Educational Communications*, 745–784.

Pousman, Z., and J. Stasko. 2006. "A Taxonomy of Ambient Information Systems: Four Patterns of Design." In *Proceedings of the Working Conference on Advanced Visual Interfaces*, 67–74. New York, NY: ACM Press. doi:10.1145/1133265.1133277.

Räthzel, Nora, and David Uzzell. 2009. "Transformative Environmental Education: a Collective Rehearsal for Reality." *Environmental Education Research* 15 (3) (June): 263–277. doi:10.1080/13504620802567015.

Shen, Xiaobin, A. Vande Moere, Peter Eades, and Seokhee Hong. 2008. "The Long-Term Evaluation of Fisherman in a Partial-Attention Environment." In *Proceedings of the 2008 Conference on BEyond Time and Errors: Novel evaLuation Methods for Information Visualization*. New York, NY: ACM Press. doi:10.1145/1377966.1377979.

Siero, Frans W, Arnold B Bakker, Gerda B Dekker, and Marcel T C Van Den Burg. 1996. "Changing Organizational Energy Consumption Behaviour through Comparative Feedback." *Journal of Environmental Psychology* 16 (3): 235–246. doi:10.1006/jevp.1996.0019.

United Nations Environment Programme. 2012. “GEO-5. Global Environment Outlook”. New York, NY.

Weiser, M. 1991. “The Computer for the Twenty-First Century.” *Scientific American* 265: 94–104.

Werbach, Kevin, and Dan Hunter. 2012. *For The Win: How Game Thinking Can Revolutionize Your Business*. Wharton Digital Press.

Wisneski, C., H. Ishii, A. Dahley, M. Gorbet, S. Brave, B. Ullmer, and P. Yarin. 1998. “Ambient Displays: Turning Architectural Space into an Interface Between People and Digital Information.” In *Proceedings of the First International Workshop on Cooperative Buildings*, 1370:22–32. New York, NY: Springer.

Yocco, Victor, Elizabeth H. Danter, Joseph E. Heimlich, Betty A. Dunckel, and Chris Myers. 2011. “Exploring Use of New Media in Environmental Education Contexts: Introducing Visitors’ Technology Use in Zoos Model.” *Environmental Education Research* 17 (6) (December): 801–814. doi:10.1080/13504622.2011.620700.

Table 1. Questionnaire used to measure environmental learning and pro-environmental behaviour: components, questions, and type of questions.

Component	Question	Type
Knowledge	Please estimate how much energy (electricity) is consumed entirely on the campus per working day.	Open
	Please estimate how much energy (electricity) is used in the building you are located in per working day.	Open
	Please estimate how much energy (electricity) you use individually at your workplace per working day.	Open
	How much energy do you think the OU could save each year if more general energy efficient measures were employed, such as installing solely energy saving lamps?	Open
	How much energy do you think the OU could save each year if the employees would employ more individual energy efficient measures, such as switching off appliances rigorously during lunch breaks?	Open
Confidence (Cronbach's α = .701)	To which degree can you estimate the entire energy consumption (electricity) on the campus?	5-point Scale
	To which degree can you estimate how much energy (electricity) is used in the building you are located in?	5-point Scale
	To which degree can you estimate how much energy (electricity) you use individually at your workplace?	5-point Scale
Awareness (Cronbach's α = .934)	Would you like to be more aware of the entire energy consumption on the campus?	7-point Scale
	Would you reduce your energy consumption if you were more aware of the entire energy consumption on the campus?	7-point Scale
	Would you like to be more aware of how much energy is used in the building you are working in?	7-point Scale
	Would you reduce your energy consumption if you were more aware of how much energy is used in the building you are working in?	7-point Scale
	Would you like to be more aware of how much energy you use individually at your workplace?	7-point Scale

	Would you reduce your energy consumption if you were more aware of how much energy you use individually at your workplace?	7-point Scale
	Would you like to receive more information on how to save energy at your workplace?	7-point Scale
	Would you reduce your energy consumption if you would receive more information on how to do it?	7-point Scale
Concern (Cronbach's α = .710)	Are you concerned about the amount of energy you are using at your workplace?	7-point Scale
	Are you concerned with what you can do personally to reduce the energy consumption at the OU?	7-point Scale
	Are you planning to take more individual actions to reduce your energy consumption at your workplace?	7-point Scale
Activities	Are you doing any of the following activities to reduce your energy consumption at your workplace?	Multiple Answer

Table 2. Treatments and assigned groups of the 2x2 experimental design covering the two independent variables “Representational Fidelity” and “Notification Level”.

Treatments		Representational Fidelity	
		indexical	symbolic
Notification Level	change blind	Group 1 N = 35	Group 2 N = 12
	interruptive	Group 3 N = 12	Group 4 N = 35

Table 3. Group and total descriptive statistics for the components depicting environmental learning before and after the treatment

	Component	Pre			Post		
		Mean	SD	SE	Mean	SD	SE
Total (*N*=94)	Knowledge	5.29	0.54	0.06	5.07	0.72	0.07
	Confidence	1.56	0.61	0.06	1.68	0.72	0.07
	Awareness	4.65	1.39	0.14	4.29	1.34	0.14
	Concern	3.63	1.21	0.13	3.55	1.14	0.12
Group 1 (*N*=35)	Knowledge	5.42	0.43	0.07	5.11	0.66	0.11
	Confidence	1.54	0.55	0.09	1.70	0.62	0.11
	Awareness	4.55	1.49	0.25	4.27	1.43	0.24
	Concern	3.57	1.09	0.18	3.42	1.05	0.18
Group 2 (*N*=12)	Knowledge	5.23	0.56	0.16	5.28	0.61	0.17
	Confidence	1.56	0.82	0.24	1.58	0.74	0.21
	Awareness	4.30	1.16	0.33	3.88	1.20	0.35
	Concern	2.78	0.72	0.21	3.00	0.62	0.18
Group 3 (*N*=12)	Knowledge	5.30	0.52	0.15	5.07	0.78	0.22
	Confidence	1.53	0.63	0.18	1.42	0.67	0.19
	Awareness	4.31	1.35	0.39	4.14	1.15	0.33
	Concern	4.00	1.26	0.36	3.53	0.99	0.29
Group 4 (*N*=35)	Knowledge	5.18	0.62	0.10	4.97	0.81	0.14
	Confidence	1.59	0.60	0.10	1.80	0.82	0.14
	Awareness	4.98	1.35	0.23	4.49	1.36	0.23
	Concern	3.87	1.34	0.23	3.87	1.33	0.23

Table 4. Group and total descriptive statistics of the conservation activities performed before and after the treatment

	Pre			Post		
	Mean	SD	SE	Mean	SD	SE
Total (*N*=94)	4.86	1.86	0.19	4.76	1.85	0.19
Group 1 (*N*=35)	4.43	1.74	0.29	4.80	1.86	0.31
Group 2 (*N*=12)	4.92	1.98	0.57	4.33	2.10	0.61
Group 3 (*N*=12)	4.92	2.28	0.66	4.67	1.61	0.47
Group 4 (*N*=35)	5.26	1.77	0.30	4.89	1.88	0.32

Figure 1. Sample presentation slides used during the experiment: a. consumption information (left); b. saving tips (top right); c. saving potential (bottom right)

Figure 2. Energy consumption (in kWh) before, during, and after the treatment per building. Each period covers four weeks. The single bars represent the average consumption per week.