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Kilowh.at – Increasing Energy Awareness using an Interactive Energy Comparison Tool

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Abstract: Reducing the use of energy is important for several reasons, such as saving money and reducing impact on the climate. However, the awareness among non-experts of how much energy is required by different activities is generally low, which can lead to wrong prioritizations. In this study, we have developed an interactive tool to increase “energy awareness”. A group of 58 students first did a test to benchmark their current energy awareness, then tried the tool for 10 minutes, and then did the same test immediately after trying the prototype and one week after trying the prototype. In addition, they answered questions regarding which, if any, of the energy requirement of different activities surprised them, any thoughts about their own energy used aroused after using the prototype and what they thought about using the tool compared to more conventional methods of learning. The results showed a significant learning effect in energy awareness with a very strong effect size of 1.689, that they were most surprised by the energy required to produce a hamburger, 39 of 58 explicitly said they intended to change one or more aspects in order to improve their energy use, where 24 actions involved changing habits and 18 actions was of a one-time investment character. The attitude towards using such a tool instead of more conventional learning was very good and the words most frequently used to describe the tool was good, simple and easy to use, fun, and interesting, but five users also said they were bored after a while. In total the results indicate that using an interactive tool like this even for a limited time is a good way to in an efficient and fun way increase energy awareness.

Keywords: Energy awareness • Technology Enhanced Learning • Persuasive services • Sustainable HCI

1 Introduction

Energy use is an important topic for sustainability and climate change. While energy efficiencies can be created by optimization and dematerialization, promoting conservation behavior remains an important part of saving energy and avoiding rebound effects [1]. There has been much research during the last decade on using persuasive

technologies and eco-visualizations to promote energy conservation. Energy conservation is a dominant topic in using persuasive technologies for sustainability and Sustainable HCI research [2]. Technologies such as smart meters allow to measure and provide accurate feedback on energy consumption at both household level and appliance level. Different research activities have used this data with a persuasive intent to promote energy conservation. Many of the smart meters technologies, visualizations and applications created in this research area used quantitative data of energy using watt hour (Wh) or kilowatt hour (kWh) as main unit [3-8]

While kWh is a familiar term for everyone paying electricity bills or selecting an appliance, it is a fairly abstract unit that may be difficult to relate to, as explored in [9]. Even if abstract, it is still a relevant unit, Wood and Newborough have argued that “The kWh is already familiar to most consumers and although few understand this unit, thorough comprehension is not necessary for an effective display” [10]. However, this lack of understanding of qualitative information is a part of a general lack of energy literacy [11, 12]. While users know that having a lightbulb all the time, or charging their mobile phones requires energy, the lack of energy literacy or awareness needed to understand the differences in scale may lead to lack of or suboptimal conservation behavior.

This article explores the understanding of qualitative information of energy consumption and the use of simulation as a way of increasing awareness. A prototype called KiloWhat was created that uses simulation and play to practice and learn about energy consumption, exploring the following research questions:

- RQ1: What is the learning effect of using such a tool?
- RQ2: What energy comparisons surprised the respondents?
- RQ3: What thoughts about personal energy consumption were aroused?
- RQ4: What did they think about the tool compared to more conventional learning approaches?

An experiment was performed with 58 engineering students in four steps (see method chapter for more extensive description):

1. An assessment of their current energy understanding of kWh information.
2. Using and experimenting with the KiloWhat prototype during ten minutes.
3. A second test to evaluate the learning effect, insights and intentions to change as an effect of using the tool.
4. A final test one week later to see how much of knowledge had been lost.

This article presents the design of the KiloWhat prototype, the method and results from the test, and discusses the implications of the results for the design of persuasive energy services.

2 Design of the Prototype

The prototype is an online service available at <http://kilowh.at/>. The main goals of the design are to:

1. Make quantitative kWh information easier to relate to by providing a learning experience where the users can translate kWh into everyday activities
2. Help users to learn differences in scale between the energy consumption of different activities by allowing the users to play and compare between them.

The prototype is based on the code and idea of <http://carbon.to> which explored the same concept for increasing carbon literacy [13]. The prototype provides the possibility of exploring and comparing the energy use of sixteen different activities such as driving an electric car or having a TV on. The activities are divided in five different categories. The values provided were average values gathered from a search in research databases and should only be seen as rough estimates since there can be large differences within one category.

- *Energy generation*: hours of solar panels, kg of coal, hours running in a treadmill.
- *Home and appliances*: washing machine loads, hours with a LED lamp on, hours with a incandescent light bulb on, hours with a fridge on, hours with Wi-Fi on, mobile phone charges, hours watching television.
- *Transportation*: km driving a gasoline car, km driving an electric car, km driving an electric assisted bike.
- *Heating*: hours heating a house with electric heaters, hours heating a house with geothermal pump.
- *Food*: hamburgers (energy needed to produce).

When accessing the site, it shows by default 1kWh compared to one of the activities selected randomly (figure 1).

The users can change the unit in the right side for comparing 1kWh to other activities and increase or decrease the amounts using the plus and minus buttons on the top-right corners. The users can also change the unit on the left side to compare different activities against each other (figure 2) or to see what would be needed to generate that amount of energy (figure 3).

The main persuasive strategy used in this prototype is simulation, “enabling users to observe immediately the link between cause and effect” [14]. The intent is that by comparing kilowatt hours against different everyday units, and those units against each other, the users can simulate the energy use of those everyday actions and gain knowledge about them.

Fig. 1-3.

The software is a fork of the aforementioned carbon.to. It is developed using Ruby on Rails and JavaScript, the code is available as open source in GitHub (<https://github.com/zapico/kilowhat>)

As a first design iteration, the prototype was tested with 20 users. The users tested the site and answered provided feedback. From this feedback, several improvements were added, including a better grouping of activities using colored categories, a unification of time units to hours and the inclusion of several extra activities.

3 Method

In order to evaluate the effect of the prototype, an experiment was designed. The respondents were 58 first-year engineering students who had recently started a five year long educational program within media technology. As part of an introductory course module about “introduction to scientific research” they were required to participate in one scientific experiment. Out of the 58 students, 53 participated fully in the four parts of this experiment. In order to check which students had participated, the participation was not anonymous, but the students were informed that the email addresses collected would not be used to identify individuals. The students were also informed that the results would be used for research, and that they would be presented with the resulting paper with comments as a part of the course module.

The respondents were given instructions by email, and they could do the assignment anywhere and anytime within the given time window. The email told the students about the aim of the prototype, “to increase energy awareness”, an introduction to why increasing energy awareness is important, and the setup of the study.

Their first assignment consisted of three tasks that they were required to complete in a sequence within a window of two days, and that the expected total time requirement was 30 minutes. The first task was to answer a questionnaire where they should give their best guess what 100 kWh corresponded to for 16 different activities, for examples “How many kilometers ride with an electric bike”, “how many hours powering at TV” or “how many charges of a mobile phone”. In order to help the students understand roughly how much 100 kWh corresponds to, they were informed that the price of 100 kWh electricity is roughly 100 Swedish crowns or about €10. The coincidence that 1 kWh roughly equals 1 Swedish crown makes it easy for users to assess

if an estimate is reasonable since money is more easy to relate to. They were instructed not to look up the answer anywhere while answering the questionnaire. The second task was to try out the prototype for exactly 10 minutes after watching a short screen-cast introducing the prototype. The third task was then to answer a copy of the first questionnaire but where a three free-text questions about whether they were surprised by any of the comparisons, if using the prototype had given them insights/ideas about their own energy use in a short and long perspective, and how they perceived using the prototype as a learning tool compared to other methods of learning.

Finally, after one week they were required to answer the first questionnaire one final time in order to evaluate how much of the learning effect was lost after one week.

The first part of the analysis was to evaluate the learning effect. After receiving all responses to the questionnaire, the answers were edited [15], where respondents we had good reasons to believe that they had just provided random answers were removed from the analysis. Criteria for removing answers were where it would be obvious for anyone that the answer was not correct. For example, any answer where the students estimated that an electric car would travel longer on 100 kWh than an electric bike. A total of 19 responses were removed in this process.

The answers from the remaining 35 respondents were then analyzed where both p-value and effect size of the learning was calculated. The relevant measure was the order of magnitude the responses were distant from the correct value. I.e. a response 10 times higher than the correct response is as good or bad as a response 10 times lower. Therefore, and also in order to reduce skewness of the data distribution, a transformation was performed on the responses, where the values of the student response were divided by the correct answer if the student answer was lower than the correct answer, and 1/that value if the student answer was higher than the correct answer. This results in a number between 0 and 1 on a ratio scale, where 1 means the answer was exactly correct and 0 means it was infinitely incorrect. For example, if the correct answer was 10 hours, then a student answer of 5 or 20 hours both would have yielded a value of 0.5, and student answers of 1 or 100 hours both would have yielded a value of 0.1. Finally, the results of all 16 questions were averaged for each student. The resulting distributions were tested for normality using the Anderson-Darling normality test and were found to be roughly normally distributed and therefore paired t-tests could be used for analysis.

For analyzing the three free-text answer questions, a-priori codings were used as described in the corresponding sections in the results.

4 Results

The four different research questions were closely associated with specific parts of the study, and the results are accounted for below.

4.1 RQ1: What is the learning effect of using such a tool?

The results from the first questionnaire showed that the energy awareness was low, as expected. The respondents' estimates were most incorrect for the activities that consumed least energy, such as Wi-Fi and charging mobile phones. The median estimation among the 848 data points generated by the 53 students who answered all three questionnaires was 15.7 times off the correct value, and when removing respondents who had given one or several unreasonable responses the remaining 560 data points generated by the remaining 35 students the median value was 11.8 times off the correct value. Their estimates were improved substantially in the questionnaire answered immediately after trying the prototype the median estimate was instead only 1.2 times off the correct value in the 560 data points from the 35 respondents. A paired-samples t-test indicated that scores were significantly higher immediately after trying the prototype ($M = 0.651$, $SD = 0.034$) than before ($M = 0.208$, $SD = 0.017$), $t(34) = -13.688$, $p < .001$, Cohen's $d = 2.775$.

The median results after one more week was 2.89 times off the correct value which was a significant improvement compared to the first questionnaire, but also a significant drop compared to the results of the second questionnaire. A paired-samples t-test indicated that scores were significantly higher one week after trying the prototype ($M = 0.423$, $SD = 0.025$) than before trying the prototype ($M = 0.208$, $SD = 0.017$), $t(34) = -9.350$, $p < .001$, Cohen's $d = 1.698$.

Finally, there was a significant decrease of test scores between the second questionnaire and the third questionnaire. A paired-samples t-test indicated that scores were significantly lower one week after trying the prototype ($M = 0.423$, $SD = 0.025$) than immediately after trying the prototype ($M = 0.651$, $SD = 0.034$), $t(34) = 6.366$, $p < .001$, Cohen's $d = 1.292$. These statistics are presented in Table 1.

Table 1. Results of paired t-tests for the three different questionnaires.

Paired Samples Statistics					
Sample	N	Mean	Std. Error Mean	Std. Deviation	Median
Q1	35	0.208	0.017	0.102	0.176
Q2	35	0.651	0.034	0.202	0.704
Q3	35	0.423	0.025	0.147	0.433

Paired Samples Correlations			
	N	Correlation	Sig. (2-tailed)
Q1 & Q2	35	0.350	0.040
Q1 & Q3	35	0.452	0.006
Q2 & Q3	35	0.293	0.088

Paired differences							
	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)	Cohen's d
Q1 - Q2	-0.443	0.198	0.032	-13.688	34	0.000	2.775
Q1 - Q3	-0.215	0.136	0.023	-9.350	34	0.000	1.698
Q2 - Q3	-0.228	0.212	0.036	6.366	34	0.000	1.292

4.2 RQ2: What energy comparisons surprised the respondents?

For RQ2 and RQ3 the results are presented by first showing a number of sample answers, and then presenting the result of the data encoding.

RQ2 was included because we for future work wanted to identify areas where the difference between facts and beliefs were large, since these are promising candidates for behavior change interventions. The question “Did any energy comparisons surprise you? Give examples and describe briefly” was coded using an a-priori coding. The 58 respondents who answered this question generated a total of 78 different coding units. Two answers were “No, I was not surprised” and 14 were unclear or unrelated. The remaining 62 answers were coded as follows using three categories.

Category 1: Much energy required/generated for one activity (absolute value), 28 encoded units

Sample answers: “I had no idea how much energy was required to make a hamburger”, “Solar panels were much more effective than I thought”, “That so much energy was required to heat a house”.

- Hamburger (20 encoded units)
- Solar panels (3)
- Heating (3)
- Washing machine and car (1 each)

Category 2: Little energy required/generated for one activity (absolute value), 14 encoded units

Sample answers: “That charging your phone too often does not make a big difference in the big picture”, “That Wi-Fi could be turned on for such a long time”, “That you could drive very far with an electric car”.

- Mobile charges (6 encoded units)
- Wi-Fi (4)
- Electric car, refrigerator, solar panels and LED (1 each)

Category 3: Two items compared with each other (much energy - little energy), 21 encoded units.

Sample answers: “How big a difference there was between those requiring little [energy] and those requiring more [energy], especially LED vs light bulb”, “I was very surprised by the difference between an electric car and a gasoline car”, “How much better geothermal heating was than electric heating”.

- Light bulb vs LED (7 encoded units)
- Car vs electric car (6)
- Electric heating vs geothermal heating (3)
- LED vs Wi-Fi , hamburger vs mobile charges, hamburger vs car, hamburger vs electric bike, refrigerator vs light bulb (1 each)

4.3 RQ3: What thoughts about personal energy consumption were aroused?

For the analysis of the question “Did you get any thoughts about your own energy consumption? Please describe briefly” we also used an a-priori coding with the categories

1. No, I did not get any thoughts
2. Increased energy awareness
3. Plan to change behavior (in most all but one case including explicit increased energy awareness). These were then further categorized as “habits”, “one-time investments” and “other”.

The 58 answers were categorized using one of the categories above resulting in the following coding of the answers:

Category 1: “No, I did not get any thoughts”, 7 respondents

Sample answers: “No”, “I don’t think I have such a good idea about my own energy consumption so I really, unfortunately, don’t know”, “No, I have the same thoughts as before. To turn off everything that isn’t used and travel as little as possible by car “.

Category 2: Increased energy awareness, but no explicit indication of intention to change, 20 respondents

Category 3: Plan to change, 39 respondents explicitly mentioning energy-related actions of which 38 also indicated increased energy awareness

These 39 respondents indicating they planned to change their behavior generated a total of 45 answers about what they wanted to change, of which 41 were specific and 4 were only general intentions. They 41 specific actions were categorized as follows:

Habits

Sample answers: “Yes, the way I eat. I never knew that meat production could have such a huge energy consumption and therefore affect the environment. That has made me more inclined to review my eating habits”, “Yes, I now have more insight in what consumes much electricity at home. I can for example start turning off the TV when I am not watching”, “Foremost, I thought about how much energy is required for heating homes. Something I will think about is to maybe lower the temperature in the flat and instead put on more clothes”

- Change eating habits (reducing amount of meat) (10)
- Turn things off (light, TV...) (10)
- Decrease temperature at home and put on more clothes (2)
- Reduce use of washing machine, not use tools using much energy unnecessarily (1 each)

One-time investments

Sample answers: “In the short term I think I will exchange more light bulbs to LED lights”, “If I ever buy a new car it will probably be an electric car. If Sweden does the same thing as Germany it will also be the only alternative”, “As a long term goal, that perhaps not was aroused now but has been there for a while but now received more fuel, was to live and use solar energy and at some time in the future have an electric car - if a car is needed. It was impressive to see how much energy solar panels could generate, and how far an electric car could travel on one charge, especially compared to normal cars”

- Change to LED (8)
- Invest in electric car (5)
- Install solar panels (2)
- Choose more energy efficient products (2)
- Geothermal heating (1)

4.4 RQ4: What did they think about the tool compared to more conventional learning methods?

Finally, for analyzing the question “What was your experience of using this tool for learning about energy awareness compared to more conventional learning methods”, a basic coding was used where the answers were categorized as

Only positive (35), Mixed (16), Only negative (0), Neither (3) and Other/unclear (2).

Next, all descriptive words or units used for describing the tool or its use were collected from the responses, coded so that similar words were grouped and then used for calculating word frequencies. The results were “good” (23), “simple or easy to use” (17), “fun” (15), “interesting” (7), “clear or good overview” (6), “tiring or boring” (5), “effective” (4), “aesthetic” (3), “difficult to memorize” (2) and one each of “rewarding”, “insightful”, “interactive”, “concrete”, “easy to memorize”, “unhelpful”, “unspecific”, “pedagogical”, “relevant” and “difficult to understand”. Three respondents expressed uncertainty about what “more conventional methods” meant.

5 Conclusion and Discussion

In this paper we have implemented and tested a tool for increasing energy awareness. We set up four main research questions:

5.1 RQ1: What is the learning effect of using such a tool?

The results first confirmed our view that energy awareness in general was very low. However, spending 10 minutes with the tool developed increases energy awareness significantly, with an effect size after one week of 1.698. Cohen classifies an effect size of at least 0.8 as large, and an effect size of 1.698 should therefore be considered very large. Effect sizes for learning interventions were studied by Hattie [16], who in a study of more than 800 meta analyses about learning the conclusion was that the average learning intervention had an effect size of 0.4.

5.2 RQ2: What energy comparisons surprised the respondents?

The high amount energy required to produce a hamburger clearly was what most surprised the respondents, whereas they were also surprised by the low amount of energy required by a Wi-Fi router or to charge a mobile phone. All these three were things easy to relate to for students. For pairs of comparisons, they were most surprised by the high difference of pairs with the same functionality such as light bulb vs led light, gasoline car vs electric car, and electric heating vs geothermal heating, indicating that comparing similar activities were easier than comparing apples and oranges.

5.3 RQ3: What thoughts about personal energy consumption were aroused?

When asked about if any thoughts were aroused, 39 of 58 mentioned that they now intended to change something in their life in order to improve their energy use and of these 38 also indicated they had increased their energy awareness, 20 more indicated they had increased their energy awareness but did not explicitly mention intentions in changing behavior, and 7 said no thoughts were aroused. The most popular habits to change was to eat less meat and to turn off electric equipment when they were not used. It is interesting to note high interest to eat less meat since that is indirect energy, and not something that will save money for the individual, indicating saving money is not the prime concern for these respondents.

5.4 RQ4: What did they think about the tool compared to more conventional learning approaches?

The general attitude was positive, where 35 respondents gave only positive feedback, 16 gave positive feedback but with some reservation, 5 were neither positive or negative or gave unclear answers and finally 0 were purely negative. Analyzing the free text answers showed the most common words used to describe the tool was good (23), simple or easy to use (17), fun (15), interesting (7), clear or good overview (6) and tiring or boring (5). Of the 82 words identified 72 were positive and 10 were negative.

5.5 Limitations and Further Research

One limitation of this study is that the users were not representative of society in general. They were young and many of them lived with parents and/or did not pay for energy use. Most also run on a tight student budget where major investments are not realistic at the time. They were also relatively well educated and could be expected to have a better knowledge about energy than most other people in their age group.

Further research includes performing another test after 6 months. The respondents will then again answer the questionnaire in order to measure if any learning effect was maintained after 6 months. They will also be reminded of the (possible) actions they said they would take in order to see if the good intentions turned into outcomes.

To sum up, the use of feedback and other persuasive technologies for energy conservation rely on the use of technical units such as kWh which are abstract and not well understood. This study confirms this lack of understanding, both of quantitative energy information and of the ability to compare the energy use of different activities against each other. The results indicate that an interactive tool like the one presented in this article can be an efficient and fun way increase energy awareness.

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