Learning Sustainability: Families, Learning, and Next-Generation Eco-Feedback Technology

Michael S. Horn, Pryce Davis, Aleata K. Hubbard,
Danielle Keifert, Zeina Atrash Leong, Izabel C. Olson
Northwestern University
Learning Sciences and Computer Science
2120 Campus Drive
Evanston, IL 60208
michael-horn@northwestern.edu

ABSTRACT
Eco-feedback technology is a growing area of interest in interaction design research. From smart meters to ambient feedback displays, well-designed technology has the potential to help families cut costs, reduce waste, and increase environmental sustainability. In this paper, we reflect on this trend and pose two interrelated design challenges that we believe are important for the development and evaluation of next-generation eco-feedback technology. First, how can we design technology to encourage *entire families*, children as well as adults, to become meaningful and active participants in the management of household resource consumption? And second, how can we design interactive systems to engage families in *inquiry-based learning* around concepts of consumption and sustainability?

Categories and Subject Descriptors
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Human Factors

Keywords
Sustainability, interaction design, children, families, learning, design, eco-feedback technology.

1. INTRODUCTION
We live in a time of growing concern for environmental issues. From global warming to declining biodiversity, the evident impact of human behavior on the natural environment highlights the urgent need to adopt sustainable ways of being. We also live in a time when low-cost computational devices of every shape and size are commonplace. Surfaces such as pictures frames, coffee tables, and walls can double as interactive displays. More often than not, these devices have high-bandwidth connectivity to the Internet and an ever-growing cloud of data, allowing for the coordination of devices embedded throughout our homes, schools, and public spaces.

The convergence of these factors has contributed to recent interest from the human-computer interaction community in technology designed to help households monitor the use of resources such as electricity, water, and natural gas in real time [7],[14],[27]. The underlying assumption is that by increasing the visibility of consumption, such *eco-feedback technology* can motivate and empower families to reduce waste and shift toward more sustainable behaviors [11],[17],[27]. However, while there is encouraging evidence that such technology can make a positive difference [4], reduced consumption is by no means guaranteed [28]. Understanding how aspects of design influence behavior, therefore, is a paramount concern. Froehlich, Findlater, and Landy [11] argue that, "it is critical for the HCI community to step back and define an approach and theoretical foundation for the design and evaluation of eco-feedback technology" (p. 2000).

This paper addresses an area of interest that, while often considered implicitly in the interaction design literature on sustainability, has rarely been discussed directly. This area of interest is the role of learning: specifically, the process by which children and families learn sustainable behaviors and attitudes through the use of eco-feedback and management technology (eco-FMT). We use the phrase eco-FMT because it includes devices such as programmable thermostats that allow families to both monitor and manage their energy consumption. Building on the work of Sarah Darby [5], we see the goal of eco-FMT as more than a one-time change in individual behavior; rather the goal is to promote and facilitate a continuous process of *learning sustainability* through which families rethink their relationship with society and the environment by coming to understand how their choices affect consumption, and how their consumption, in turn, impacts the broader world.

The use of eco-FMT in homes is quickly becoming commonplace. For example, the California energy company, PG&E, plans to deploy smart meter technology to all of its customers by mid-2012[1]. As these forms of technology reach a broader audience, there are two design challenges that we argue successful eco-FMT should address. First, how can eco-FMT be designed to encourage *entire families*, children as well as adults, to become meaningful and active participants in the management of household resource consumption? And second, how can eco-FMT be designed to engage families in *inquiry-based learning* around concepts of consumption and sustainability?

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.
IDC 2011, June 20-23, 2011, Ann Arbor, USA.
Copyright 2011 ACM 978-1-4503-0751-2…$10.00.

[1] http://www.pge.com/myhome/customerservice/smartmeter/facts/

2. BACKGROUND

2.1 Eco-Feedback and Management Technology

Modern domestic infrastructure has done a remarkable job making the extraction, processing, transport, and consumption of natural resources largely invisible [3],[4]. Water flows when we turn on the faucet and disappears down the drain. Electricity "flows" when we flip on the light switch. The waste in these systems is displaced from the domestic setting. And, even though resources are precisely monitored and billed, households are largely unaware of the magnitude of their own consumption [3],[6],[19],[28],[29], nor of the energy used to produce and manage these resources.

Therefore, a basic goal of eco-feedback and management technology is to draw attention to consumption in terms of its magnitude and impact. One direction has been the development of inexpensive smart meters that can easily be installed into a building's existing infrastructure [12],[25]. These devices typically transmit resource consumption data wirelessly to stand-alone devices like the Energy Detective [9] and to computer-based services like Google PowerMeter [15]. Other devices are designed to visualize consumption at specific locations inside the home where resources are used [1],[16]. Beyond providing feedback on consumption, next-generation energy *management* systems such as the Ecobee programmable thermostat [8] enable consumers to "program" components of their homes, either through touch screen interfaces or through mobile devices connected to the Internet.

2.2 Sustainability

Central to our arguments in this paper is a definition of sustainability itself. One common definition, originating from the 1987 report from the World Commission on Environmental Development, frames sustainability as the ability to "meet the needs of the present without compromising the ability of future generations to meet their own needs" [33] (p. 24). This definition, while providing a broad goal for sustainability, says nothing about what sustainability means in the day-to-day context of household activities. And, as Hirsch and Anderson [18] point out in their study of water use in central New Mexico, "using terms like 'sustainability' in an uncritical manner elides serious and difficult questions about human relationships with nature, and implies consensus where none exists." Thus, part of our rationale for focusing on learning is to emphasize that eco-FMT will be most successful if it helps families build an understanding of sustainability on their own terms in light of their own unique circumstances.

2.3 Pro-Environmental Behavior

Research in environmental psychology, environmental education, and, more recently, human-computer interaction has sought to understand the factors and motivations that influence pro-environmental behavior in homes (e.g. [18],[26],[28],[32]). The good news is that as early as the 1970s researchers have demonstrated through controlled studies that direct feedback on resource consumption can result in savings in the range of 5-15% [4]. Despite these findings, sustained behavioral change as the result of eco-FMT is by no means guaranteed [28]. Results depend on the form of direct feedback and the specific resource being monitored [23],[24]. Likewise, subtle changes in the design of devices and their placement in the home can have dramatic effects on conservation outcomes (e.g. [23]). Many of the designs emerging from the human-computer interaction community are artistic and compelling, yet there is relatively little empirical evidence supporting their effectiveness [11]. Habits and social norms also play important roles [6],[11],[17],[31],[32], and researchers acknowledge that we are only just beginning to understand how complex social interactions among family members affect pro-environmental behavior and attitudes [2],[6],[26],[29]. Put simply, the existence of advanced technology does not imply that those who dwell in "smart" homes will possess the knowledge or motivation to reduce wasteful consumption.

2.4 Learning and Sustainability

Darby [5] argues for a focus on understanding social learning processes as part of a research agenda on sustainability in homes. In particular, she points to social constructivism—a perspective on learning that emphasizes social processes in the construction of knowledge through shared experience—as a framework for understanding the process of behavior change in homes. Darby sees a central role for eco-feedback technology in this learning process, and she provides evidence that "people build up their energy knowledge over time through a combination of taking action, monitoring usage, and absorbing information from many sources in their environment" (p. 2936).

3. DESIGN CHALLENGES

3.1 Engaging Entire Families

Echoing calls from the HCI community for a focus on families in the design of domestic technology [29], our first design challenge involves creating eco-feedback and management technology to encourage entire families, children as well as adults, to become meaningful and active participants in the management of household resource consumption. This goal is important because just as all members of a household contribute to resource consumption, so too might they contribute to the resource conservation. When the use of eco-FMT is thought of as part of a broader social learning process, thoughtful designs could have the potential to both help family members contribute to and benefit from that learning. In contrast, designing for a single user misses out on potentially valuable interactions between family members that could contribute to the success of a design. For example, consider home thermostats. In interviews that we are conducting with families, children report that they rarely, if ever, touch their family's thermostat. One woman, reflecting on her childhood, mentioned:

> *"Daddy took care of the temperature in the house, and it's still that way. My dad ... mama doesn't mess with the thermostat. Daddy sets it. And that's it."*

The idea that eco-feedback and management technology can become *adult-only* is troubling for several reasons. First, children are often more savvy than adults when it comes to the use of household technology [20],[30]. Thus, a segment of the population that could meaningfully contribute to resource management is potentially being excluded—the segment that will grow into the next generation's adults. By the same token, while adolescents might be more adept at interacting with eco-FMT, parents might provide needed structured guidance to support the process of exploring alternative strategies to conserve energy based on the output of an eco-feedback device [10],[13]. Second, children often develop pro-environmental viewpoints in school, yet can feel powerless to bring about positive change [2]. By limiting their role in household energy management we not only miss out on an opportunity to transfer environmental viewpoints from children to adults, we also miss an opportunity to build a sense of optimism and empowerment among youth. Third, habits of resource consumption in homes are the result of complex social and cultural dynamics involving entire families [2],[26],[31]. Designs that recognize and embrace this complexity might stand a better chance of promoting lasting behavior change by encouraging intergenerational collaboration.

3.2 Supporting Inquiry Learning

Our second design challenge involves creating eco-FMT to engage families in *inquiry-based learning* around concepts of consumption and sustainability. There are many ways to motivate behavior change in homes. For example, Kirman, Linehan, Lawson, Foster, & Doughty [21] make an appeal to behavioral psychology in support of designs that modify behavior through operant conditioning and "aversive feedback". While their position is intentionally provocative (and humorous), the underlying assumption is that learning is limited to conditioning and that designers of technology know what is best in terms of sustainability. This approach could be successful for simple scenarios that have been pre-conceived by the designers (e.g. don't boil more water than you need to). However, as discussed above, sustainability is a complex construct that varies substantially according to the particulars of a household's geographical, political, and cultural situations [18],[28]. Therefore, rather than creating artifacts to reinforce pre-determined behavioral outcomes, we suggest that designers should instead focus on empowering families to define sustainability on their own terms in the context of their own unique situations. For this purpose, supporting inquiry learning is a valuable strategy because it emphasizes the idea that learning involves integrating knowledge with authentic practices in meaningful contexts. This means more than mimicking behavior on cue and memorizing and regurgitating facts. Research suggests that supplying people with content knowledge in the form of facts and figures, while often helpful, is not necessarily sufficient to provoke sustained behavior change in homes (e.g. knowing about global warming will not necessarily change behavior) [5]. Rather, research suggests that mastery of the inquiry process and content knowledge develop hand-in-hand, each supporting the other [22]. While we think that designing to support inquiry in homes is important, much work remains to be done in terms of understanding how inquiry will manifest itself and how it can be supported over time.

4. CONCLUSION

In this paper, we discuss the role of learning in the design of eco-feedback and management technology (eco-FMT) for use in homes. We propose two interrelated design questions to help guide the development and evaluation of eco-feedback and management technology: First, how can eco-FMT be designed to encourage *entire families*, children as well as adults, to become meaningful and active participants in the management of household resource consumption? And second, how can eco-FMT be designed to engage families in *inquiry-based learning* around concepts of consumption and sustainability? Our hope is that these questions will help both inspire new designs and add to the set of criteria by which existing designs can be evaluated. An open question is how aspects of learning sustainability will manifest themselves in the homes. Furthermore, there is much work to be done to illuminate the design space involving these aspects of eco-FMT. The research we have discussed offer some insight, but there is still much work to be done to ground the concept of learning sustainability in empirical research.

5. FUTURE WORK

We are currently conducting research and design work in this area, including interviewing families and developing new interactive technology. Our goal is to create designs that are accessible to children and encourage them to become active and engaged in household resource conservation efforts. We also hope to understand learning that happens in homes with existing eco-feedback technology and to explore new ways to facilitate inquiry learning in homes.

6. REFERENCES

[1] Arroyo, E., Bonanni, L., & Selker, T. (2005). Waterbot: Exploring feedback and persuasive techniques at the sink. In Proc. CHI 2005, ACM Press (2005), 631-639.

[2] Ballantyne, R., Connell, S., & Fien, J. Students as catalysts of environmental change: a framework for researching intergenerational influence through environmental education. Environmental Education Research 12, 3-4 (2006), 413-427.

[3] Chetty, M., Tran, D., and Grinter, R.E. Getting to green: Understanding resource consumption in the home. In Proc. UbiComp'08, ACM Press (2008), 242-251.

[4] Darby, S. The effectiveness of feedback on energy consumption: A review for DEFRA of the literature on metering, billing, and direct displays. Environmental Change Institute, University of Oxford, 2006.

[5] Darby, S. Social learning and public policy: Lessons from an energy-conscious village. Energy Policy 34 (2006), 2929-2940.

[6] Dillahunt, T., Mankoff, J., Paulos, E., and Fussell, S. It's not all about "green": Energy use in low-income communities. In Proc. UbiComp 2009, ACM Press (2009), 255-264.

[7] DiSalvo, C., Sengers, P., and Brynjarsdóttir, H. Mapping the landscape of sustainable HCI. In Proc. CHI 2010, ACM Press (2010), 1975-1984.

[8] Ecobee programmable thermostat (www.ecobee.com)

[9] The Energy Detective (www.theenergydetective.com).

[10] Fender, J.G. & Crowley, K. How parent explanation changes what children learn from everyday scientific thinking. Journal of Applied Developmental Psychology 28 (2007), 189-210.

[11] Forehlich, J., Findlater, L., & Landay J. The design of eco-feedback technology. In Proc. CHI 2010, ACM Press (2010), 1999-2008.

[12] Froehlich, J., Larson, E., Campbell, T., Haggerty, C., Fogarty, J., & Patel, S.N. HydroSense: Infrastructure-mediated single-point sensing of whole-home water activity. In Proc. UbiComp 2009. ACM Press (2009).

[13] Gleason, M.E. & Schauble, L. Parents' assistance of their children's scientific reasoning. Cognition and Instruction 17, 4 (1999), 343-378.

[14] Goodman, E. Three environmental discourses in human-computer interaction. In Proc. CHI 2009 (extended abstracts), ACM Press (2009), 2535-2544.

[15] Google PowerMeter (www.google.com/powermeter/).

[16] Gyllensward, M., & Gustafsson, A. The power-aware cord: Energy awareness through ambient information display. In Proc. CHI'05, ACM Press (2005), 1423-26.

[17] He, H.A., Greenberg, S., & Huang, E.M. One size does not fit all: Applying the transtheoretical model to energy feedback technology design. In Proc. CHI 2010, ACM Press (2010), 927-936.

[18] Hirsch, T. & Anderson, K. Cross currents: Water scarcity and sustainable CHI. In Proc. CHI 2010 (extended abstracts), ACM Press, 2843-2852.

[19] Kempton, W. & Montgomery, L. Folk quantification of energy. Energy 7, 10 (1982), 817-827.

[20] Kiesler, S., Zdaniuk, B., Lundmark, V. & Kraut, R. Troubles with the Internet: the dynamics of help at home. Human Computer Interaction 15(2000), 323-51.

[21] Kirman, B., Linehan, C., Lawson, S., Foster, D., & Doughty, M. There's a monster in my kitchen: Using aversive feedback to motivate behaviour change. In Proc. CHI 2010 (extended abstracts). ACM Press (2010), 2685-2694.

[22] Koslowski, B. Theory and evidence: The development of scientific reasoning. MIT Press, 1996.

[23] Kuznetsov, S. & Paulos, E. UpStream: Motivating water conservation with low-cost water flow sensing and persuasive displays. In Proc. CHI 2010, ACM Press (2010), 1851-1860.

[24] Midden, C.J.H., Meter, J.F., Weenig, M.H., & Zieverink, H.J.A. Using feedback, reinforcement and information to reduce energy consumption in households: a field-experiment. Journal of Economic Psychology 3 (1983), 65-86.

[25] Patel, S.N., Gupta, S., & Reynolds, M.S. The design and evaluation of an end-user-deployable, whole house, contactless power consumption sensor. In Proc. CHI 2010. ACM Press (2010), 2471-2480.

[26] Payne, P. Families, homes, and environmental education. Australian Journal of Environmental Education 21 (2005), 81-95.

[27] Pierce, J., Odom, W., & Blevis, E. Energy aware dwelling: A critical survey of interaction design for eco-visualizations. In Proc. OZCHI 2008.

[28] Pierce, J., Schiano, D.J., Paulos, E. Home, habits, and energy: Examining domestic interactions and energy consumption. In Proc. CHI 2010, ACM Press (2010), 1985-1994.

[29] Riche, Y., Dodge, J., & Metoyer, R.A. Studying always-on electricity feedback in the home. In Proc. CHI 2010, ACM Press (2010), 1995-1998.

[30] Rode, J.A., Toye, E.F., & Blackwell, A.F. The domestic economy: A broader unit of analysis for end user programming. In Proc. CHI 2005, ACM Press (2005).

[31] Strengers, Y. Smart metering demand management programs: Challenging the comfort and cleanliness habitus of households. In Proc. OZCHI 2008, 9-16.

[32] Woodruff, A., Hasbrouch, J., & Augustin, S. A bright green perspective on sustainable choices. In Proc. CHI 2008, ACM Press (2008), 313-322.

[33] World Commission on Environmental Development. *Our common future.* Oxford University Press (1987).