Feature

Using Sociotechnical Feedback to Engage, Educate, Motivate, and Empower Environmental Thought and Action

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Aerial view of Oberlin, Ohio.

In Brief

Through the vast majority of human evolution our ancestors experienced intimate and continuous feedback from the natural world that informed and constrained individual and community decision-making. In the last two centuries fossil fuel use coupled with development of technologies for extracting, producing and consuming energy and materials have augmented and partially supplanted our immediate dependence on natural flows of energy and cycles of matter. Combined with urban migration and industrialization this has contributed to a psychological as well as physical separation between humans and the environment. At the same time human influence over the environment has expanded from local to regional to global scales. The technological advances now taking place in energy efficiency, renewable energy, and material science are essential but also insufficient conditions for achieving sustainability. In recent years a fundamentally new class of technologies—made possible by developments in hardware, software and networking and informed by social psychology—are enabling the emergence of novel forms of feedback on resource consumption and environmental quality. In this paper we argue that "sociotechnical" feedback of this sort, delivered at multiple scales and through multiple modes, has the potential to reconnect humans to nature, stimulate systems thinking, and motivate behaviors that are more attuned to ecological constraints and opportunities.

For more than 99.9 percent of the 500,000 years of modern human evolution, the decisions that we have made as individuals and within communities were informed by the direct and intimate feedback we received from the natural world around us. Our success in securing food, fuel, fiber, and shelter to support our families and to build and expand communities has been contingent on our ability to successfully recognize and interpret this environmental feedback and then to collaborate with fellow community members in responding. Indeed, one of the hallmarks of human intelligence may be the sophistication of our capacity to interpret, predict, and act on environmental cues. This is the context in which we evolved and achieved success for most of our history as a species.

Fast forward. Today North Americans spend over 90 percent of our lives inside of buildings.[1] To support this, huge volumes of resources flow through wires and pipes beneath our feet and over our heads. In the U.S., the built environment in which we live and work accounts for 41 percent of all domestic energy consumption, 10 percent of our freshwater consumption, and 40 percent of our greenhouse gas emissions, while the use of resources in buildings continues to increase.[2]

Ironically, the highly connected nature of this infrastructure accounts, in part, for both the physical and the psychological disconnect that has developed between humans and the natural flows of energy and the cycles of matter on which our existence ultimately depends. In contrast to the world of our ancestors, the direct experience of the majority of today's urban population with resource acquisition is that energy and water come from outlets and pipes; food and other material goods come from stores; and waste goes down pipes and into garbage bins. While we experience monetary feedback on consumption in the form of taxes, utility bills, and expenditures on material goods, the reality is that this is an opaque and weak form of feedback. The environmental and human context, costs, and consequences of consuming resources are, for most of us, out of sight and distant and therefore out of mind.

Key Concepts

- **At its simplest level, feedback is a causal loop in which the output of energy, material, or information from one component of a system affects other components of the system in ways that ultimately return to alter the input(s) to the first component.**
- **In *positive feedback*, change leads to further change, while *negative feedback* counteracts change. Positive feedback is critical to a system's capacity to grow, while negative feedback resists change and provides the system with stability.**
- **Whether or not we choose to recognize the ways in which this circular causality influences system dynamics, the reality is that feedback is a ubiquitous control mechanism operating in ecological, technological, economic, and social systems.**
- **Humans construct and modify feedback loops through technologies, laws, and evolving social norms. By explicitly mapping the existing feedback and identifying opportunities for inserting constructive new feedback, humans have the potential to alter thinking and behavior in ways that facilitate the development of more sustainable communities.**
- **New low-cost sensing, processing, and communication technologies and novel applications of social psychology enable the development and delivery of environmentally beneficial feedback through multiple modes and at multiple scales.**

Increasing Scale

In many ways, the origin of the environmental juggernaut that we face today can be traced back to the positive feedback loop initiated when humans first coupled our economies to the extraction and use of fossil fuels. Consumption of this stored stock of ancient sunlight has stimulated advances in extraction technology, agricultural production, manufacturing, and health care, and these, in turn, have led to the exponential growth in human population associated economic activity and the additional consumption of resources. While there are many positives associated with this transformation, two downsides that threaten future sustainability are that we have lost the immediate environmental cues that once informed our decision-making and that the impact of our decisions concerning the planet has transitioned from the local to the regional to a global scale. The 20th century has witnessed both intentional and non-intentional transitions in which humans have assumed a significant degree of control over the flows of energy and the cycles of key materials such as water, carbon, nitrogen, and phosphorus through the biosphere.[3] Feedback is fundamental to all human systems, but with this transition the systems we now engage with are far more complex and operate at broader scales of time and space than those that evolution equipped us to engage in.

Designer Feedback

The good news is that, although humans did not evolve to deal with the planetary-scale challenges that we now face, we are developing ever more sophisticated tools that expand our ability to acquire, process, communicate, and respond to environmental information. Is it possible that the psychological and behavioral disconnects we now experience can, in part, be counteracted by selectively reintroducing environmental feedback? That is, can we build more sustainable and resilient communities and cultures by engineering new information flows that realign our thinking and behavior with the realities of the ecosystems that support us? There is reason for optimism—recent work suggests that we can harness what we are learning from social psychology, technology and culture to design novel forms of feedback that reconnect us with resource flows and inform better decision-making.

While we often use different language to describe it, the reality is that humans are continuously engineering and adapting to feedback loops in the form of technologies, laws, and evolving social norms. In her classic paper, "Leverage points: Places to Intervene in a System,"[4] Donella Meadows argues that explicitly recognizing and then altering or inserting new feedback is often the most effective and lowest cost mechanism for nudging a system to reinforce desirable behavior. For example, she pointed out how "right to know" laws that require corporations to report the release of toxins into the environment have dramatically reduced pollution, even in the absence of taxes or fines—that the required release of information alone caused both the public and corporations to interact in ways that have improved environmental conditions.

The term "persuasive technology"[5] is used to classify technology that is explicitly designed to alter cognitive processing, attitudes, and behaviors to achieve desired results. Persuasive feedback technology comes in a variety of forms and distinctions help clarify application and impact. "Sociotechnical" feedback is a special class of information feedback in which technology is employed to acquire, process, and deliver content that is used to alter human thought and action. The term "eco-feedback"[6] is sometimes used when the goal is to elicit pro-environmental behavior. "Ambient feedback" refers to delivery mechanisms in which the recipient is exposed to information that is passively experienced in the environment and requires minimal active cognitive effort to acquire and process (e.g., Fig. 1). All of these terms highlight our capacity to creatively design and harness feedback.

Courtesy of Oberlin College

Figure 1: "Environmental Orbs" installed in the hallways of dormitories glow different colors to communicate current levels of electricity and water consumption within buildings. Our research indicates that the presence of orbs increases awareness and motivation to conserve and significantly reduces electricity consumption.

Feedback in the Built Environment

Over the last few decades there has been a great deal of excitement about the use of sociotechnical feedback as a mechanism for reducing resource consumption in buildings. Although there is some evidence that feedback can be employed to reduce water use,[7,8] the most developed work has focused on the use of consumer-facing feedback on residential electricity use. Residential consumption is an important target because it accounts for 54 percent of total building energy use in the U.S.[2] Occupant activities and choices control up to 50 percent of this consumption, while the balance depends on physical characteristics of buildings and installed equipment over which occupants have no immediate control.[9] It has been estimated that behavior change, including electricity conservation, could reduce household greenhouse gas emissions by 20 percent by 2020.[10] So building-level feedback has the potential to lead to substantial resource use reduction. Several recent publications have summarized findings on the general impact of feedback on residential energy use. For example, the conclusions of a comprehensive meta-analysis considering 170 prior studies are that the introduction of feedback generally stimulates households to reduce electricity consumption by 4 to 12 percent.[11]

What Makes for Effective Feedback?

The design of effective feedback is predicated on accurate models of the cognitive processes driving human behavior. It is important to recognize that many commonly held assumptions that continue to influence resource conservation programs are not supported by research. For example, it is often assumed that knowledge and attitudes are the principle factors driving behavior change. Research suggests otherwise—for example, survey respondents who specified energy conservation as the most important strategy for averting the energy crisis were found to be no more likely to actually engage in energy conservation behavior than those who did not.[12] The assumption that human behavior is principally driven by financial benefit is likewise inaccurate. Research on energy conservation programs has demonstrated that provisions of information and economic incentives both alone and in combination often have negligible effects on human behavior.[13-15] Sophisticated messaging that carefully considers psychological impact is therefore critical to the delivery of feedback in ways that actually affect behavior. Six key features of effective feedback are described below.

Courtesy Lucid

Figure 2: The Building Dashboard makes information on resource use accessible and engaging to non-technical building occupants: current patterns are compared with past performance and amongst buildings, and character gauges animate in response to resource consumption.

1. Usability

There are several attributes that are essential to making feedback information usable. First, the information must be easily *accessible* with a minimum of barriers to encountering and absorbing the information signal. Second, the information must be *actionable* in the sense that the person experiencing it actually has the capacity to change decision-making in ways that would affect system performance. *Ease* is important as well—it is perhaps no surprise that the most frequently performed pro-environmental behaviors are those that are perceived as being easiest.[16] Usability is also enhanced by a *tight feedback cycle* in which the implications of decision making are immediately observable so that cause and effect can be related.[14]

A dashboard in a car provides a good example of a high level of usability—gauges that provide critical information about safety, available fuel, engine condition, and (increasingly) fuel efficiency are located immediately in front of the driver and require a simple glance downward. In more crass terms, key data that inform immediate driving decisions are "in your face and in your space." The design of sociotechnical feedback has, for good reason, been influenced by the dashboard concept (Fig. 2).

2. Social norms and comparison

Although we routinely underestimate the extent to which our decisions are influenced by other people,[17] the reality is that comparison, sometimes in the form of competition with others, is highly motivational. Indeed, this *normative* social influence has been found to be significantly more motivational in stimulating energy conservation behavior than environmental, financial, or societal benefits.[17] Even in the case of monthly utility bills, the simple addition of information that compares a given month's electricity use with past performance and with the performance of neighbors stimulates significant reductions in electricity use.[18] What's more, the rate at which pro-environmental behaviors are adopted is enhanced as the norm becomes more contextually specific to the individual[19] and is likewise enhanced if the information provided relates to people within the target individual's peer network.[20] To maximize impact, feedback needs to answer two normative questions for those experiencing it. First, how are we doing relative to members of groups with whom we identify (and leading figures that we strive to emulate)? Second, how are we doing now relative to how we have done some time in the past?

3. Goal setting, rewards, and commitment

Many studies have found that commitment (and in particular, public commitment) to goals enhances conservation.[21] Although people favor simple tasks, research indicates that, when combined with feedback, challenging goals are more effective in motivating conservation than easy ones.[22] While rewards as well as goals can significantly increase energy conservation, a review of the literature suggests that reward-driven action alone is sometimes short-lived once the rewards are removed.[14]

4. Consideration of scale and group dynamics

Feedback is most effective when delivered frequently and at a fine enough scale that the effect of individual choices can be easily interpreted.[14] Most feedback interventions treat individuals as the ultimate decision-makers. However, the reality is that consumption and conservation occur within the context of social systems in which culture and group dynamics influence consumptive behaviors. For example, feedback that includes comparisons among whole offices and whole dormitories has been shown to promote electricity conservation.[8,23] Similarly, commitments made by whole groups of households as well as those made by individual households have been found to motivate conservation.[24] An important caveat here is that the effectiveness of individual and group feedback differs among cultures. For example, group feedback has been demonstrated to be more effective as a motivator in collectivistic cultures such as Japan than in more individualistic cultures such as the Netherlands.[25]

5. Tapping into less rational motivational mechanisms

We often implicitly assume that behavior is the end result of a rational process when, in fact, it is strongly determined by habitual, emotional, and non-rational cognition.[26] It makes sense to deliver clear quantitative information to inform a logical decision-making process, but it also makes sense to encourage "empathetic linking"—that is, the packaging of information in a form that emotionally or experientially connects consumption decisions to feelings and concern for social and ecological communities. Although research on the topic is limited, one study on the retention of energy conservation information found that social approval or disapproval delivered orally by a mechanical cat had a stronger persuasive impact than factual feedback alone.[27] Understanding and designing feedback that harnesses what has been termed "core social motives"[28] is a critical line of research.

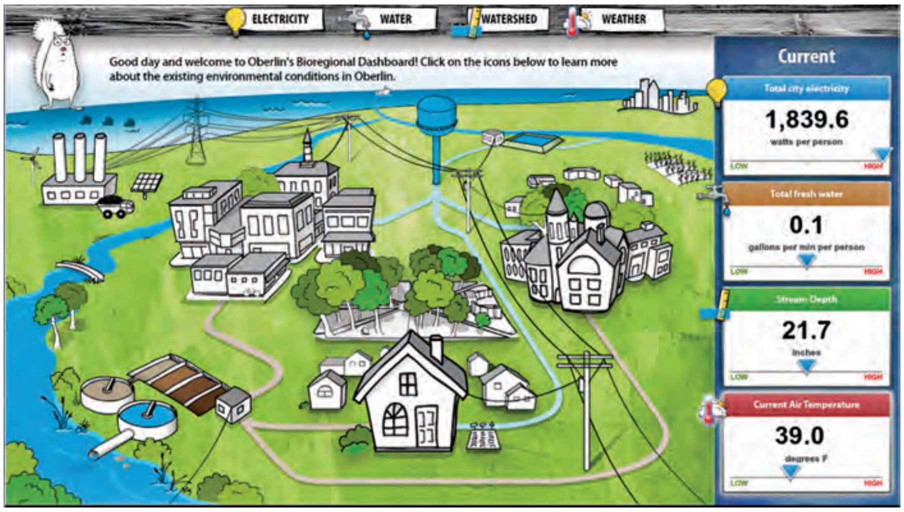
In the past two decades, the City of Oberlin and Oberlin College have defined themselves as leaders in sustainability.

6. Combining approaches and addressing differences in motivation

Different people are motivated by different things. Women tend to have a stronger degree of concern for the environment than men.[29] Some people may be motivated when electricity use or savings are expressed in terms of kilowatt hour, some when it is expressed in dollars, and some when it is expressed in greenhouse gas emissions (e.g., see unit selector in Fig. 3). Ideally, feedback is tailored so that the information delivered is specific to the interests and decision-making opportunities of the recipient. Alternatively, a recipient may be provided with the capacity to easily select the information that they find most interesting and relevant. Even when information is tailored, research demonstrates that feedback is most effective when it combines a range of approaches such as goal setting, normative information, historical comparison, and incentives.[24,30,31]

Feedback in Green and Brown Buildings

Over the last ten years our research group at Oberlin College has worked to develop a variety of novel approaches and technologies focused on the introduction of feedback in the built environment to promote changes in thought and behavior. This work started in 2000 with an initiative to develop a real-time monitoring and display system for the newly completed Adam Joseph Lewis Center for Environmental Studies. The brainchild of David Orr, an eminent environmentalist and distinguished professor of environmental studies at Oberlin, this building rapidly achieved iconographic status in the green building movement which was then in its formative stages of development.[32] During the first two years of occupancy, more than 150 sensors were installed throughout the center's building and landscape to provide detailed monitoring of different flows of energy, cycles of matter, and other environmental conditions. A key goal was to create a real-time display system for the lobby and for a website that would translate technical performance data into a form that was easily accessible and engaging to a non-technical audience of building occupants and visitors (www.oberlin.edu/ajlc).[33] The enthusiastic response of design professionals and the public to this technology motivated the formation of Lucid Design Group which subsequently developed a commercially available monitoring and display platform for buildings that it called "Building Dashboard."



Oberlin College

Figure 3: The Citywide Dashboard: "Flash" Energy Squirrel narrates the dynamic story of current flows of water and electricity and environmental conditions in whole communities. The goal is to situate individual decision-making within a community context.

Monitoring and displaying performance in "green" commercial buildings has proved useful because it provides a mechanism for exposing the real-time function of environmentally beneficial technologies such as photovoltaic and geothermal performance and consumption of water and electricity. In this sense, the technology fosters the goal of reconnecting occupants to the resource consumption necessary to support their activities within the built environment. However, perhaps ironically, one of the insights that emerged from our experience in developing monitoring and display technology for green buildings is the recognition that the capacity for true feedback is constrained in so-called "smart buildings." These buildings are characterized by sophisticated technological feedback algorithms that are incorporated into the mechanical control systems, such as motion-activated lighting, CO_2 sensors that control ventilation, and weather-predictive heating and cooling. Although smart building technology has the potential to dramatically enhance environmental performance, it also removes many decisions from the building occupant, such as when to turn the lights on or off or when to open and close the windows. An undesirable feature of emphasizing purely technological feedback over sociotechnical feedback is the potential to reduce self-efficacy, thereby disempowering occupants and implicitly communicating the message that responsibility for intelligent decision-making resides principally with the authority embodied in technological design rather than in the individual or community.[8] In this sense, "smart" building technology has the potential to contribute to a behavioral dumbing down of occupants.

Based on this realization, our subsequent work has shifted emphasis towards the development and application of a variety of feedback mechanisms for residential environments in which the buildings themselves are often entirely devoid of environmental features (i.e. "brown" buildings), but the occupants exert significant personal control over their consumption of electricity and water. In particular, our work in developing feedback for college dormitories has been premised on the idea that introduced feedback can be used to change both thinking and behaviors. In marked contrast to smart building technology, the goal here is to create environmentally smart people in what are essentially dumb buildings. The emphasis on achieving behavioral change in colleges and universities recognizes the undergraduate experience as a seminal and transformative period during which future decision-makers develop knowledge and ways of thinking and acting that will inform their personal, political, and professional choices throughout the rest of their lives.[34]

Starting on the Oberlin College campus in 2006, competitions were used to provide an incentive for students to use feedback to reduce consumption. In a comparative study, we found that the two dormitories that were provided with real-time feedback on electricity use reduced their consumption by 55 percent during a three-week competition, versus the average 31 percent reduction for dormitories provided with weekly updates on their performance.[8] Expanding on the Oberlin experience, Lucid partnered with the National Wildlife Federation, the U.S. Green Building Council, and the Alliance to Save Energy to develop "Campus Conservation Nationals."[35] Feedback was combined with competition among dorms on individual campuses and collaboration among schools at the national level to achieve a common goal of resource reduction. The result has been significant and sustained reductions in electricity and water on hundreds of participating campuses.

Multiple Modes of Information Acquisition and Delivery

Like others, our group has placed significant emphasis on the use of websites, digital signage, and kiosks as mechanisms for delivering feedback to building occupants. The web provides a rich environment for graphical displays and for interactivity in which users can explore patterns of resource use over time, make public commitments, share conservation ideas, etc. However, recent work suggests the value of employing multiple modes of information delivery that tap into multiple senses and allow individual users to access information according to their preferences. These include ambient technologies such as "Environmental Orbs" (Fig. 1), as well as tactile and auditory modes of experiential feedback. Although application has been limited, early research suggests that ambient and even subliminal delivery can result in a significant response.[36] Empathetic gauges likewise emphasize qualitative rather than quantitative modes of communicating information (e.g., Figs. 2 and 3). Clearly incorporating the full spectrum of communication technologies that are both present and emerging (email, text messages, Facebook, Twitter, apps, etc.) is important in ensuring that the information signals are effectively delivered to the widest possible audience in a form that resonates with the individual.

Two recent developments have the potential to rapidly expand opportunities for low cost and widely adoptable feedback. The first is "smart grid" infrastructure in which real-time data from electricity and water monitoring technology installed on all metered buildings is networked and potentially accessible. The second is the emergence of inexpensive, open source, and networked computing and sensing hardware and software that expands opportunities for developing low-cost environmental monitoring and display.

Kansas Sebastian / Flickr

Over the last few decades there has been a great deal of excitement about the use of sociotechnical feedback as a mechanism for reducing resource consumption in buildings.

Multiple Scales and Dimensions of Feedback: Environmental Dashboard

Current research on feedback has generally emphasized the direct impact of information on resource use choices. However, the transformation to a sustainable society is predicated on deep cultural and psychological transformation that requires individuals and communities to engage in fundamentally new ways of understanding and acting. How can feedback be employed to help facilitate this transformation? In an attempt to answer this question, recent efforts of our research group have focused on developing a whole-community approach that employs multiple scales and modes of feedback designed to engage, educate, motivate, and empower community members to embrace sustainable thought and action. Five closely related goals have guided the development of a technology and approach that we refer to as "Environmental Dashboard":

1. Promote "systems thinking," which can be defined as an understanding that the collective behavior of a community is determined by relationships, interdependencies, and feedback between individuals and related subsystems.
2. Foster a sense of connectedness and belonging to ecological and social place.
3. Develop the capacity for individuals to situate personal decisions in a community context such that individual and small group choices are also viewed as acts of citizenship.
4. Develop a suite of technologies and approaches that embody bottom-up as well as top-down mechanisms for information flow: for instance by empowering youth and other members of the community who may not currently have a strong voice to contribute ideas and actions and to function as environmental communicators.
5. Change behaviors in ways that minimize individual and community resource consumption and maximize environmental benefits.

Environmental Dashboard employs digital public signage and websites to combine three levels of feedback:

- Building Dashboard dynamically displays water and electricity consumption in individual buildings and residences (Fig. 2).
- Citywide Dashboard is a conceptual model of a city dynamically animated with real-time data on water and electricity flows and water quality (Fig. 3).
- Community Voices combines images and text contributed by the full diversity of a community to celebrate thoughts and actions promoting environmental sustainability.

In 2008 we initiated a pilot of Environmental Dashboard in the City of Oberlin, Ohio. Real-time data is accessed from drinking water, wastewater, and municipal electricity systems and more than 60 buildings and residences. Currently, residential and commercial building monitoring is accomplished through a variety of data monitoring and hardware technologies specifically installed for the project. We collaborated with the local utilities to develop an approach in which we extract data on whole-city water and electricity flows from their control systems. Additional technology is then incorporated to monitor the water flow and quality within the local river system. Digital display technology has been installed throughout the public schools, in the public library, in storefronts, and at Oberlin College. The digital displays rotate through a sequence that juxtaposes the Building Dashboard content most relevant to the immediate audience (e.g. consumption of water and electricity in the elementary school for their display), Citywide Dashboard, Community Voices, and community calendars and special features specific to the locations (for example a section highlighting books on different environmental topics that are available in the library).

The impact of Environmental Dashboard is being assessed through a combination of direct user testing of components and surveys conducted before and after exposure in the different locations. In a controlled assessment we compared college students regularly exposed to Citywide Dashboard (Fig. 3) against a group exposed to a display that contained identical information but without the conceptual model of resource flow through the community. We found that several dimensions of systems thinking are enhanced by Citywide Dashboard, including the degree of connectedness with nature (assessed using the scale of Mayer and Frantz),[37] the perception of the community as an ecological system, and the perceptions of causal linkages and responsibility (assessed using the approach of Maddux).[38] We have been working closely with teachers to develop materials that integrate Environmental Dashboard into public school curricula in ways that enhance systems thinking. The ultimate goal is to develop a technology that has the flexibility to be easily reconfigured for use in communities and on academic, corporate, and military campuses to promote and celebrate a pro-environmental culture that advances sustainability goals.

Future Technological Narratives

Throughout our evolutionary history two properties unique to the human species—technology and storytelling—have shaped the way that we perceive and interact with each other and with our natural environment. Two of the dominant narratives told by environmentalists have focused alternatively on technology as savior or as culprit. The technological optimists among us point out how radical improvements in energy efficiency and in a biomimetic material science might be coupled with renewable energy to allow humans to live within ecological limits without fundamentally altering our lifestyles. Technological pessimists relate a story of technological advances that are tightly coupled with the ever-increasing depletion of environmental resources and a world in which technology often separates and alienates us from the ecological systems upon which we depend. Largely missing from either narrative has been a mature discussion of the full complexity of the interactions between human thought, action, technology, and nature. The examples of sociotechnical feedback that we have shared suggest the potential emergence of fundamentally new types of technology that engage rather than separate humans from each other and from nature. At its core, affective sociotechnical feedback is compelling storytelling that incorporates real-time data as a key narrative element. We believe that powerful storytelling using this new approach has deeply transformative potential for the individual and for society. A great deal of additional exploration is necessary to determine the extent to which this promise might be realized.

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http://www.spgsolar.com/

PG Solar designed and installed a solar tracking system at Oberlin College that covers roughly 10 acres.

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