Bringing Environmental Dashboard to Your Community

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This document is intended for communities, organizations and individuals who are interested in employing all or parts of Environmental Dashboard to promote sustainability, resilience and systems thinking. We suggest that you start by reviewing the rest of the environmentaldashboard.org website itself. This website serves two functions. First, it is a template and a working model of how the technology can be applied in a particularly community – Oberlin Ohio. Second it contains resources for other communities that have adopted or are considering adopting all or parts of Environmental Dashboard. "Story of Dashboard", including the video below it, provides a quick introduction to Environmental Dashboard. The section of the website on Teaching and Learning with Dashboard will be of particular interest to educators; it serves as a repository for lesson plans that can be used to support and enhance environmental learning in a variety of educational contexts.

The text below provides a detailed rational, overview and explanation of how organizations and communities can directly adopt technology and build on the lessons learned thus far. This document is divided into sections on various aspects of the technology, approach and implementation. While information is presented in a logical sequence, individual sections can also be read separately. Throughout, we include links to additional research articles and "how to" guides for setting up and managing various components of Dashboard. If your organization or community has additional questions on how you can move forward in implementing Environmental Dashboard the dashboard team can be contacted at dashboard@oberlin.edu.

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1.0 The Big Picture: How the need for ecofeedback leads to "Environmental Dashboard"

The need for easy access to information about resource flows through the natural environment can be traced back through evolutionary history. For the bulk of human existence, our ancestors experienced intimate and continuous feedback from the natural world that informed and constrained all decision-making and helped individuals see themselves as an integrated part of the larger ecological systems they inhabited. Today, members of our industrialized societies spend the vast majority of our lives in cities and in buildings removed from the *ecofeedback* that aligned decision-making with environmental

consequences (figure 1). In the face of unprecedented contemporary environmental challenges, there is a powerful need for fundamental change in thought and action at individual and community levels. Yet the increasing scale of impact and increasing psychological and physical disconnect between humans and nature challenges our native abilities to effectively recognize and respond to these challenges. New solutions are needed that reconnect us with nature and lead to greater integration of ecological, economic and social dimensions of environmental sustainability in decision-making at all scales.

Environmental Dashboard (ED) responds to this need. ED is a novel technology and approach that reintroduces feedback at multiple scales to motivate and empower conservation, promote "systems thinking" (defined below) and build "pro-environmental" identity. Specifically, ED employs monitoring and display technology to provide three levels of ecofeedback: 1) *Building Dashboard* dynamically displays water and electricity consumption in individual buildings; 2) *Citywide Dashboard* animates whole community resource flows; and 3) *Community Voices* combines images and text to celebrate thought and action that advance sustainability in diverse communities. You can click on the links at the top of this website to see "live" examples of each component.

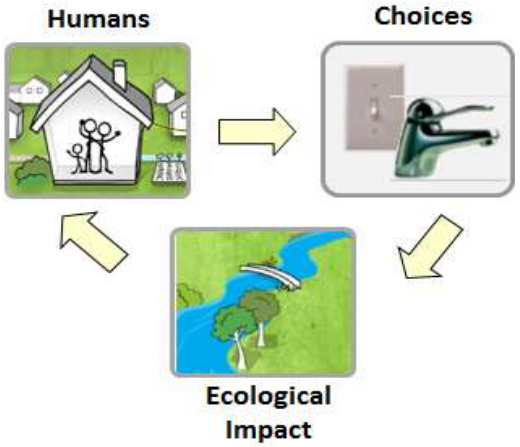

Fig. 1: Modern *ecofeedback* leverages technology to inform better decision-making by presenting information that highlights the social, ecological and/or economic implications.

With generous support from a variety of sponsors including the Great Lakes Protection Fund, U.S. EPA, Ohio EPA, Great Lakes College Association and State Farm Insurance, ED has been developed for communities throughout the Great Lakes and beyond. A pilot implementation initiated in Oberlin Ohio in 2008 has been used to develop and assess all three components of ED. In this pilot (highlighted on this website), resource flows and environmental conditions are monitored in schools, businesses, apartments, college dormitories and through whole-city infrastructure. This information is then displayed in real-time on digital signs in public spaces including schools, storefronts, community service organizations and Oberlin College. Different components of this technology are in various stages of adoption in other communities. For example, hundreds of other schools, businesses and municipalities across the U.S. are already using the Building Dashboard component of the technology and several are in various stages of fully implementing all three components of ED. Research thus far indicates that ED can be used to enhance systems thinking, promote energy and water conservation and

stimulate a better appreciation of resource use and conservation (for overview see Petersen *et al.*, 2014).

2.0 Using ecofeedback to shift thought and behavior: What we know from prior work

Over the last few decades there has been growing interest in the use of introduced feedback as a means of motivating resource conservation in buildings. Several studies have summarize findings on the impact of feedback on residential energy use. For example, a comprehensive meta-analysis that considered 170 published studies concluded that the introduction of feedback generally stimulates households to reduce electricity consumption by between 4 and 12% (Ehrhardt-Martinez *et al.*, 2010). This success in the residential environment suggests that we might look for opportunities to improve and expand the use of feedback to motivate changes in thought and behavior at larger scales.

Sophisticated messaging that carefully considers psychological impact is critical to the delivery of feedback in ways that actually affect behavior. Particularly important factors to consider are: usability, social norms, goals and commitments, emotional resonance and story-telling. With respect to usability, information must be easy to access, actionable and have an impact that the targeted individual can readily observe and/or make meaning out of. Leveraging the power of *social norms* entails communicating the message that others, particularly those who are respected community members, are already exhibiting targeted pro-environmental and pro-community behavior. Messages in which people publicly articulate their personal goals and commitments or in which they encourage others make commitments are likewise highly impactful. Effective information feedback must stimulate emotional as well as more rational modes of decision making (e.g. figure 2). Ultimately humans respond powerfully to narratives that they can personally identify with; data on resource flows and human engagement need to be presented in a way that tells a compelling and motivating story. More detailed information on designing effective feedback messaging can be found in a variety of sources (see Petersen *et al.*, 2014).

For more than a decade a research group at Oberlin College, situated in the small city of Oberlin Ohio (population 8,000), has worked to develop and test a variety of novel approaches and technologies focused on introducing feedback in the built environment to promote positive change in thought and behavior. Work initiated in 2000 focused on how monitoring and display technology might be used to expose and enhance the educational value of "green" buildings – for example with real time display of solar electric, geothermal and other innovative systems integrated into these buildings (e.g. Petersen, 2011). With significant grant funding from the U.S. EPA, research by this group shifted to the application of monitoring and display technology in residential housing on campuses and revealed that feedback combined with competition could result in significant and sustained reductions in electricity and water use (Petersen *et al.*, 2007). Expanding on research conducted in Oberlin dormitories, faculty and student collaborators from Oberlin's Environmental Studies Program and Psychology Department (the Oberlin "dashboard team"), partnered with Lucid, the National Wildlife

Federation, the U.S. Green Building Council and the Alliance to Save Energy to develop "Campus Conservation Nationals". This annual event was designed to use resource reduction competitions in dormitories to promote conservation and environmental leadership development (Petersen and deCoriolis, 2009; Petersen *et al.* 2015). The application of principles of social psychology by the dashboard team has led to a variety of novel technological applications including "environmental orbs" and "empathetic character" gauges (figure 2). Environmental Dashboard incorporates what this team and researchers working around the world have learned, but expands the scale of feedback to include and combine resource use monitoring and display at the scale of whole organizations and whole communities.

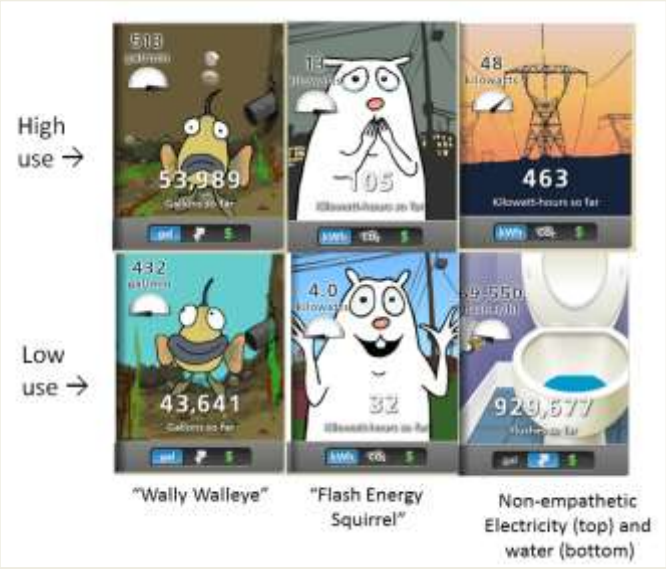

Fig. 2: "Empathetic gauges" stimulate an emotional response to resource consumption. Animated characters exhibit different emotions and behaviors depending on current levels of resource consumption relative to typical patterns of consumption (for example in the simplest case varying from smiling to frowning). Research conducted at Oberlin indicates that empathetic characters are generally more engaging and motivational than non-empathetic displays of real-time resource use.

Over the last decade much has been learned about the impact of introduced ecofeedback. As discussed above, there are now peer-reviewed studies indicating that comparison of electricity and water consumption within and between monitored residential units and competition between units can be a powerful tool for stimulating conservation (Ehrhardt-Martinez *et al.*, 2010; Petersen *et al.*, 2007; Vine and Jones, 2015). However, thus far the majority of research has focused on how targeted feedback on a particular resource, most often electricity, might lead to conservation of that particular resource. Only very recently have studies examined whether changes in thought and behavior related to one resource might produce *spillover effects* in the form of additional conservation behaviors beyond the targeted resource. For

example research indicates that participating in electricity and water use reduction competitions can, indeed, contribute to a variety of other pro-environmental behaviors such as recycling, bicycle riding and even enhanced political engagement (Petersen *et al.* in 2015). The existence of such spillover effects raises important questions about whether and how sophisticated application of ecofeedback might be used to more fundamentally shift people's way of thinking about their relationship to ecological, social and economic community.

3.0 Environmental Dashboard uses multiple scales of feedback to promote systems thinking

3.1 Concept and goals

The questions about spillover effects posed in the paragraph above are important because the transformations necessary to achieve more sustainable societies is likely predicated on psychological, cultural and political changes that extend well beyond altering consumptive behaviors of individuals and conservation of individual resources. It can be argued that this transformation requires that individuals and communities engage in fundamentally new patterns of thought that emphasize *systems thinking*. Systems thinking can be defined as a way of conceptualizing the world that emphasizes relationships, interdependencies, circular causal chains and feedback between parts that form larger wholes; the systems thinker sees herself or himself as an important and engaged agent simultaneously acting at multiple levels within this whole. Necessary transformation also requires multiples scales of behavior change that range from turning off unused appliances to voting for candidates and issues that support sustainability to more deeply engaging in community-building. Is it possible to expand scales and modes of feedback in ways that help facilitate social and ecological transformation? In an attempt to answer this question, the dashboard team at Oberlin has spent several years focused on developing a whole-community approach that employs multiple scales and multiple modes of feedback designed to engage, educate, motivate and empower communities to embrace sustainable thought and action across scales (figure 3).

Fig. 3: Environmental Dashboard: Impacts of resource-use choices (solid arrows) can be made visible through multiple scales of feedback (dashed arrows). Building Dashboard (1) and Citywide Dashboard (2) monitor and display resource flows and environmental conditions through individual buildings and whole communities; Community Voices (3) adds images ideas and stories contributed by community member to strengthen pro-environmental identity, thought and action.

Environmental Dashboard (ED) is a technology and an approach to generating ecofeedback that facilitates pro-environmental and pro-community thought and action. The promotion of systems thinking is a core goal of the technology. Four corollary goals include: 1) fostering a sense of connectedness and belonging between the individual and ecological, social and economic community that the person inhabits; 2) expanding the capacity for individuals to situate personal decisions in a community context; 3) enabling bottom-up as well as top down information flow, for instance by empowering youth and other members of the community who may not currently have a strong public voice to meaningfully engage and share their ideas and actions and to function as agents of change; 4) changing thought in ways that result in multiple scales of behavior change so as to minimize individual and community resource consumption and maximize environmental benefits.

3.2 Modes of information delivery

Environmental Dashboard currently uses three primary modes of information delivery: websites, digital signage and "environmental orbs" and is working towards enhanced accessibility through mobile phone applications. The interactivity possible on a website provides the deepest and richest presentation of content and allows the user to determine the experience and the particular information gleaned (same true of mobile applications). However, a critical barrier for information delivery via a website is that the local audience reached is limited to those who actively seek out content. At present, this is likely to be a very small subset of a population. Mobile applications are similar to website except that the possibility exists to more readily create notices that a user can configure to prompt them when certain environmental conditions are met (e.g. electricity use is above a high point, local river is flooding, etc.). Digital signage and orbs achieve the usability criteria of being visually prominent within the user's environment (figure 4.). The orb is an example of "ambient feedback" -- experiential feedback within occupied spaces that communicates limited and potentially subliminal information that requires low cognitive processing. We have therefore restricted use of the orbs to displaying information related to water and electricity use in individual buildings. In contrast, digital signage provides a context for publicly displaying a much richer set of content over a broad range of scales.

Fig. 4: "Environmental Orbs" glow different colors and with different pulsing patterns to communicate whether current levels of electricity and water consumption within a building are high or low relative to typical levels of use at this time of day. The orb pictured is installed in the lobby of a college student dormitory.

Environmental Dashboard digital signage can be installed in a range of public spaces so as to target the full diversity of a community (figure 5). Both the digital signage and websites combine the three levels of feedback introduced earlier: 1) Building Dashboard" (figure 6) dynamically displays water and electricity consumption in individual buildings within communities; 2) Citywide Dashboard (figure 7) is a conceptual model of a city dynamically animated with real-time data on water and electricity flows and water and weather quality; 3) Community Voices (figure 9) combines images and text drawn from the full diversity of a local community to celebrate pro-environmental thought and action already underway.

Fig. 5 Environmental Dashboard digital signs are installed in very public locations within a community such as in storefronts, libraries and schools. The display pictured is in the window of a popular café in downtown Oberlin.

Thus far deployments have emphasized non-interactive digital signage (figure 6) that rotate through a sequence that includes Building Dashboard, Citywide Dashboard, Community Voices, community calendars and site-specific content particular to each screen location. For example a display in Oberlin's public library consists of a sequence that includes a Building Dashboard depiction of current patterns of water and electricity use within the library facility itself, Citywide Dashboard, Community Voices, a community-wide calendar, promotional content for events taking place at the library, and a feature on environmentally related books available at the library. In the Oberlin pilot, Dashboard signage is currently installed in eleven locations on the College campus and eleven locations within

the city including in all four public schools, four nonprofit organizations and three businesses. In the Oberlin pilot, grant funds were used to support the installation of screens in organizations within the City of Oberlin. However, the benefits and low costs of digital ED signage create a situation in which it is easy to envision local financing; the ED signage allows the host organization to combine information about their own organization (for example information about services and products offered) with ED content in ways that help to brand the organization as a positive and engaged actor within the local community.

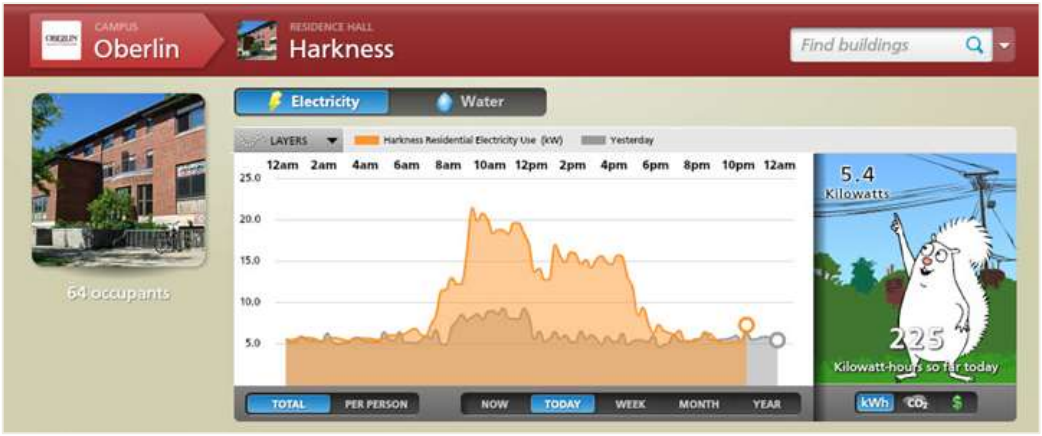

Fig. 6: Building Dashboard displays make information on resource use in buildings accessible and engaging to non-technical occupants: current patterns are compared with past performance of that building and among related buildings; empathetic character gauges animate in response to resource consumption, imbuing quantitative data with emotional resonance (also see figure 2).

3.3 Acquisition of real-time resource use data at multiple scales

Accessing and developing the data for all three components of ED necessarily involves broad-scale community input and collaboration. For example, in Oberlin the development of the pilot implementation provided a context for close collaboration between a college, the surrounding city, public utilities, the public school system, businesses and an array of other community organizations. Based on experiences in Oberlin and elsewhere, the paragraphs below describe critical issues that any community must consider in accessing the information required to develop ED. We highlight challenges, opportunities and lessons learned through the collaborative process.

3.3.1 Citywide Dashboard

The possibilities for a Citywide Dashboard are substantial. Ultimately, it would be ideal for to display variables that capture and communicate economic, social and ecological dimensions of sustainability at a whole-community scale in real time. These might include essential flows of energy (renewable and nonrenewable electricity, gas and other fossil fuels), flows and cycles of water, water quality, air quality, flows of waste and recyclable materials, traffic conditions and other dimensions of transportation and various dimensions of economic, social and political activity and quality. In practice many of these attributes are challenging to quantify and communicate, particularly in real-time. The initial development of Citywide Dashboard has therefore focused on capturing and displaying the subset of information on whole-community flows of energy and water, and

environmental quality that can be readily monitored and communicated in real-time (figure 7). This emphasis takes advantage of the fact that electricity, water and gas utilities are typically already monitor in aggregate as part of routine municipal operations and the potential for access is increasing with further development of "smart grid" technology. Our partners at Lucid have developed protocols for accessing real-time data from a wide range of different types of data collecting systems including most building automation systems and a host of different datalogging devices. Nevertheless, implementing these approaches at the level of a whole city requires careful coordination and collaboration among multiple players. The challenges and opportunities often have as much to do with political relationships as they do with technology.

Fig. 7: Citywide Dashboard. An animated display of real-time electricity and water use and environmental conditions in entire communities or organizations. Gauges and animations of water flowing through pipes and electrons flowing down power lines reveal how decisions made in our homes and workplaces are reflected in citywide patterns and conditions. Messages delivered by "Wally Walleye" and "Flash the Energy Squirrel" narrate the story of current resource use. The goal is to situate individual decision-making in a community and systems context. The landscape has been developed with clustered buildings in order to be able to easily customize the display to feature different cities and organizations (left version features Oberlin college and city, right features Toledo and Lucas County Schools).

In communities across the U.S. electricity, gas, drinking water, wastewater treatment and solid-waste collection services are provided by either public or private companies. Often a single city will rely on a combination of public and private entities. In some cases the particular providers may even differ by region or neighborhood within a city. As an example, in our pilot community of Oberlin Ohio, electricity, drinking water, wastewater treatment and solid waste (but not gas) are provided by public utilities, meaning that that the facilities are controlled and managed by city government. The township around Oberlin, however, uses the same municipal electricity provider, but a different public utility for water and a private contractor for solid waste disposal.

Since the mission of public utilities is public service rather than financial profit, these entities tend to be more receptive to public programming that extends beyond immediate financial return on investment. Thus far our experience has been that public utilities are more interested in collaborating on the implementation of Citywide Dashboard than are private utilities. Even so, different public utilities, even within a community, have different levels of interest and concern regarding making data on resource use accessible. Concerns naturally tend to be greatest when an approach is being tried for the first time. Extensive negotiations were therefore necessary between Oberlin College, the City of Oberlin and Lucid to gain approval for the pilot development of Citywide Dashboard. A number of important lessons have been learned from this experience and from additional discussions with other

communities interested in adopting the technology. One of the more obvious lessons is that inclusion of all of those involved in decision-making, technical implementation and display of the data is important at the outset. Broad inclusion during early discussions helps to generate buy-in and agreement on community-specific protocols for accessing whole-community and individual user data in a way that ensured an acceptable level of security and privacy. Politics differ widely, but it is almost always useful to identify and garner support from individuals and groups within the community who have political power. Schools are often key allies.

Another lesson is that managers responsible for different municipal facilities will be comfortable with different approaches to accessing data and different levels of collaboration. Several distinct approaches to collecting data on electricity and water flows and environmental quality tested and successfully implemented in Oberlin are serving as models for other communities working to implement Environmental Dashboards. For example, in Oberlin the Director of the drinking water treatment plant had a high level of concern regarding the potential risk of malicious computer hackers sabotaging plant operations via any connection that directly accessed real-time data from the plant over the internet. In response, the Oberlin dashboard team worked with the plant to develop a highly secure protocol that exports data in analog form from their plant control system, through an external datalogger and to the internet for storage, processing and display. A similar approach was taken to obtain data from the wastewater treatment plant, however, the dashboard team collaborated with plant operators to add additional sensor technology at this facility which measures water quality upstream from the plant as well as in water flowing out of the plant. In contrast, the municipal electrical utility collaborated on installation of software to their plant control system that exports data directly to the internet for storage and processing without the use of an on-sight datalogger.

Weather data used on Oberlin's Citywide Dashboard (temperature, precipitation, humidity, wind speed and direction) are a combination of data taken from a weather station managed by Oberlin College and open-source data accessed from a weather station at the nearest local airport.

Citywide Dashboard is intended to communicate important and motivating information about resource use and environmental conditions to a non-technical audience. Certain variables can be easily identified as important to achieving this goal. For drinking water it is useful to characterize total drinking water consumption by dominant organizations and by the whole community. In communities that extract water from a reservoir, the amount of water stored (or percentage full) can be particularly useful in communicating the importance of water conservation during times of draught. Wastewater treatment plants typically drain directly into either a river or lake (they are rarely pumped into ground water or directly reused). Basic information useful for conveying impacts of wastewater treatment includes the total delivery of water to the plant and, if it drains into a river system, the flow of water in the river upstream of the plant. For both drinking water plants and waste water plants, the difference in water quality between the associated natural body of water and the treated water provides a powerful mechanism for communicating the impact of human activity at the scale of whole watersheds. Treatment of both drinking water and wastewater is energy intensive and is often second only to management of buildings in terms of municipal greenhouse gas emissions. Displaying electricity use and/or greenhouse gas emissions associated with water treatment is therefore a powerful means of conveying environmental impacts of water treatment.

Water flows are important for communicating information about conservation. The particular opportunities for monitoring water *quality* differ, but many treatment plants already monitor various

water quality parameters before and after plant water is treated. Certain variables are widely used as measures of water quality. Oberlin's dashboard team collaborated with the Director of the local wastewater plant to add water quality sensors that continuously monitor levels of dissolved oxygen, turbidity, dissolved solids, temperature and pH in the river system upstream of the plant and also in the plant effluent. These five water quality parameters are standard and provide an excellent basis for communicating the ecological health of streams, rivers and lakes. They can be used to help the public understand the impact of activities in the watershed (farming, yard care, road salting, etc.) and wastewater treatment system on the health of aquatic ecosystems. It is obviously important that a dashboard display contain additional information that explains the importance of these water quality variables. On the website, each gauge is linked to an explanation of the importance of the parameter displayed (click here for an example).

The *electrical grid is* the network of wires and transformers used to transfer power from the point of generation to the point of use. Local electrical grids differ in their organization; different communication opportunities are present in different communities. As with water systems, the total geographic areas served by a given electric utility as well as the smaller areas that can be separately monitored may or may not correspond neatly with the political, social and economic boundaries that would be most useful for communication purposes. In large cities individual neighborhoods are often broken out with separate infrastructure and metering. For example, Oberlin Municipal Light and Power provides electricity for the city of Oberlin, but also for some of the consumers in the surrounding township. While control of the local grid does not enable separate monitor of electricity used by different neighborhood, it does break out certain end-uses including the amount of electricity used for treating freshwater and wastewater. Researchers at Oberlin College have analyzed greenhouse gas emissions associated with electricity and water consumption in Oberlin and these are also displayed on our Citywide Dashboard.

3.3.2 Building Dashboard

Building Dashboard was the first component of Environmental Dashboard developed. In the early 2000s, prototype technology was developed at Oberlin College to monitor and display resources use in the Adam Joseph Lewis Center of Environmental Studies and then expanded into dormitories. Students and faculty involved in this early effort founded Lucid in 2004. This approach to monitoring resource use in individual buildings and groups of buildings is now off-the-shelf technology; by the end of 2015 Lucid's BuildingOS software was being used to acquire, process and display environmental performance data on over 10,000 buildings in the US, Canada and Australia.

The Oberlin pilot provides example of the growing range of opportunities for accessing real-time data on building performance. Currently the majority of buildings on the Oberlin College campus are incorporated in the Lucid monitoring and display system including all 36 residential houses (dorms and smaller units). Total electricity consumption is included in all monitored buildings. Total water use is included for most of these as well. In many buildings sub-metered electricity data are also collected – for example electricity use is often separately monitored on individual floors and wings or in some cases by end use (mechanical, lighting, plug loads). In an increasing number of buildings Oberlin College now meters the delivery of heating energy (steam) and cooling (chilled water) and gas used for cooking. In a few buildings room temperatures, CO_2 concentrations and other conditions are also monitored in real time. Within the City of Oberlin, monitoring technology has been installed to monitor and display electricity water use in all four of the public schools and in the public library. In addition, a mixed-use development constructed in downtown Oberlin includes monitoring for 33

apartments and 12 commercial rentals. At Oberlin and in other Lucid installations, three approaches to acquiring data on the environmental performance of buildings can be distinguished: dataloggers, building control systems and smart grid technology. These approaches are explained below.

Dataloggers: In older buildings (e.g. most buildings), the easiest (and often only) way to access data is through the installation of sensors and dataloggers. The datalogger reads data from the sensors and then transmits these data to a remote server for processing over the internet. In some cases data can be accessed from existing utility meters. For example in Oberlin we have negotiated an arrangement with our public utility whereby the utility installs water meters with two separate registers – one delivers the data to the utility for billing and the other feeds the same data into a college-owned datalogger. A single datalogger can receive data from multiple different meters. For example, Oberlin's Environmental Studies Center represents an extreme situation in which a single datalogger receives and processing data from multiple different electrical circuits (including solar production), multiple water meters within the building, multiple temperature sensors, a weather station, and chemical sensors installed in and on-site wastewater treatment plant.

Building control systems: Recently constructed buildings typically contain sophisticated building automation systems (BAS) that combine sensors with programmable logic computers and programming sequences to control building function. In principle, data used by these control systems can be transmitted for use in Dashboards. A challenge to accessing these data is that different control system vendors (e.g. Siemens, Johnson Controls, Honeywell, etc.) use distinct and proprietary code for processing data. Fortunately, Lucid has developed a host of different integration protocols that enable data to be directly accessed from the majority of these systems as well as from other devices in buildings that collect and process data such as lighting control systems and solar inverters. In some cases it is more cost effective to extract data from these systems and in other cases it is simpler and more cost effective to install separate dataloggers and monitoring technology.

Smart grid: The emerging "smart grid" consists of metering and communications hardware and software that provide direct and in some cases instantaneous access to data from individual utility meters. Utility companies are using this technology to automate billing, identify service problem and increase the resolution at which they can monitor and control customer services. The development of the smart grid has the potential to enable broad-scale adoption of consumer-facing feedback (Ehrhardt-Martinez *et al.*, 2010). While utilities (particularly private utilities) may wish to control access to these data, there are broad scale political initiatives underway to require that these data be made directly available to consumers. For example, "Green Button" legislation recently enacted in the entire state of California requires private as well as public electric utilities to make hourly consumption data available through the internet in a standard format to all customers. Although logistical and privacy challenges remain to be worked out, data from the smart grid can potentially also be aggregated to provide for the development of Citywide Dashboard displays that are customized to aggregate data for particular neighborhoods, organizations or even for communities that share a social identity but not physical location (for examples members of a particular church or civic organization).

Like many communities, Oberlin is moving forward incrementally with smart grid technology. In this case, Oberlin's public utility has implemented automated meter reading ("AMR"), which is an early stage in the development of full smart grid deployment. In AMR, each individual meter (electricity, water and/or gas) is equipped with a radio transmitter and data from each meter are transmitted to a radio receiver mounted on a vehicle that drives through the community at monthly intervals.

Permanent receiving stations can be installed to gather data from these same meters in real-time. The Oberlin dashboard team has negotiated an agreement with the local utility that will allow this team to install central receiving technology and then to interact directly with individual consumers using existing utility meters to provide households with Building Dashboards that allow password protected access to electricity consumption data for their homes. The team is still working through technological challenges necessary to access and process these data.

Security and privacy issues are inherent in metering of individual homes and organizations. These do not generally pose significant barriers for schools or dormitories because consumption data are aggregated over multiple individuals and malicious use of data is limited in potential. Residents and business owners have more legitimate concerns about the implications of publically available data. In Oberlin, occupants of some of the commercial spaces have agreed to make their electricity and water use data public. For others and for the residential occupants, password protected access can be provided to a unique Building Dashboard display for each unit.

3.4 Generating content for Community Voices

As discussed above, the goal of the Community Voices component of ED is to discover, communicate and strengthen pro-environmental and pro-community thought, action and identity. Community Voices is premised on an understanding that most people are already engaged in a variety of pro-environmental and pro-community thought and action in their daily lives that can serve as the basis for further transformation towards the goal of social, economic and ecological sustainability. Community Voices also embraces diversity to highlight and leverage the unique history and character of a particular community so as to foster pride in accomplishments and encourage further aspiration.

The text and photographs that are used to generate content for CV are gathered through a process that is quite distinct from the collection of the real-time data employed in the other two components of ED. Text content is developed through short interviews, historic archives and public documents. Images are contributed by community members and taken from historic archives. There are multiple target audiences in the CV data gathering process. First, the process of interviewing a person and then featuring content from that interview helps the interviewee to develop a stronger sense of pride and identity as a community leader. Those viewing the material see "people like them" and ideally people they might recognize exhibiting pro-environmental and pro-community behavior, thus establishing and reinforcing positive social norms around these behaviors. The dashboard team has developed six categories of content to highlight distinct contributions to sustainability:

1. "Neighbors" features quotes from members of a community who are, through personal example, promoting sustainable actions in their homes, backyard, gardens, neighborhoods, etc.
2. "Heritage" includes images and words reflective of a community's legacy of stewardship and engagement on important issues of the day. A key goal of this category is to help viewers to understand how the environmental challenges and leadership opportunities that a community faces today build on the historic challenges and opportunities that the community has addressed and overcome in the past.
3. "Our Downtown" includes commitments and environmental thoughts of those who own and work in local businesses. This category helps to encourage local economic purchasing and development and to connect economic, social and ecological dimensions of sustainability.

4. "Natural [name of your community]" (e.g. "Natural Oberlin") includes images and words that relate to the natural and cultivated beauty of a community. In this category, photographs and artwork emphasize people interacting with and appreciating the natural and cultivated world in order to reinforce connection to nature and people's sense of pride and belonging to ecological place.
5. "Serving our Community" features the sustainability related work of non-profit community organizations, public schools and city workers. This recognition helps to build a stronger sense of civic engagement and dedication of public workers already in place within a community.
6. "Next Generation" features words and often artwork by and/or about children. This category recognizes children as important agents of change within a community who are not often provided with a public voice.

Photographs and text are combined with a category title and an associated icon for display (figure 8). Content is managed within an open-source software that allows for different types of content to be emphasized on different screen locations.

Fig. 8: Sample content from four of the categories within Community Voices. The database for the Oberlin community has many hundreds of images with text clips that are randomly selected for display on public screens at any time based on a designated probability of occurrence. A strong emphasis is placed on neighbors, children, nature, community service and local economic development.

3.4.1 How to develop content that promotes pro-environmental and pro-community thought and behavior

The approaches employed in Community Voices embody a set of principles developed through extensive research in social psychology, marketing and communication (excellent summaries of these

approaches can be found in Ardoin *et al.*, 2013; Cialdini, 2009; Markowitz *et al.*, 2014; McKenzie-Mohr and Smith, 1999; Hirsch *et al.* 2016). A detailed Community Voices User's Guide (click link to view) describes how content can be generated and managed. The following eight principles are used to inform the development of interview questions and the selection of text and image content:

1. Focus on stories that are personal, local and connected. This includes emphasizing specific actions people can take and are taking within the community, featuring local environmental burdens and benefits, emphasizing relationships between local economy ecology and community and connecting local with global.
2. Celebrate positive thought and action. This includes emphasizing solutions rather than problems, appealing to people's desire to be "good people", featuring images that convey pleasure and pride and that capture pro-environmental and pro-community action.
3. Feature diversity. This entails including content that represents and resonates with different groups in a community that may have distinct values and worldviews. It includes featuring individuals who are not commonly heard from and non-traditional as well as traditional leaders. Every potential viewer should feel that they see "someone like me" represented in the display.
4. Leverage social norms and satisfy people's desire to belong. This means highlighting the work of diverse groups that community members associate themselves with, demonstrating that a broad range of individuals are exhibiting target thought and behavior and helping people to understand that their efforts are part of a larger effort.
5. Feature commitments and goals. These should highlight positive commitments individuals are making to improve themselves, their families, their community, the environment and the local economy. This includes featuring public commitments, goals and rationales made by NGOs, businesses, schools and government as well as by individuals.
6. Emphasize positive consistency in thought and action. This includes prompting people to engage in actions that are consistent with whatever pro-environmental and pro-community values and worldviews they already subscribe to. It means demonstrating how solutions are aligned with common values and priorities of community members.
7. Appeal to self-interest, convenience and personal health as well as to community interest. This includes featuring personal benefits to individuals, families and community in terms of economy, ecology and social motivations. It means featuring circumstances in which sustainable choices are also, easy, convenient, economically beneficial and healthy choices.
8. Select engaging and eye-catching images and messages. This includes content that catches the attention of audience, elicits emotional and empathetic responses, provokes thought, empowers positive action, is humorous or heart-warming and avoids preachiness, condescension, political partisanship, and exclusionary connotations.

Interview and follow up questions should be explicitly designed to elicit content that meets the eight criteria described above. Of course no single interview quote or image will accomplish all of these goals at once; it is the combination of many images that accomplishes the goal of creating social norms. As discussed further below, in the Oberlin pilot, college students have played a principal role in conducting interviews and have done this in the context of a variety of classes and independent projects focused on developing communication and research skills. A standard set of questions has been developed (see here for examples), but interviewers are provided with latitude to add and substitute questions appropriate to the particular people interviewed and the context in which the interviews take place (e.g. children or adults, workers, volunteers, clergy, neighbors, etc.). It can be helpful to use images that you would like to pair with quotes as prompts during the interview process; the interviewee is primed with questions about the environment and community and then asked to

respond to the images. Interviews are typically recorded using either a digital recording device or cell phone apps and the interview is then transcribed. The person interviewed is provided with the text transcription and an opportunity to make minor corrections and to approve the interview before the content is used to develop messages. While the primary goal of the process is to extract quotes that can be paired with images, the full text of interviews is generally also posted and linked to quotes on the ED website. Extracted messages paired with photographs are kept to the shortest possible length to convey the desired message (>35 words or 180 characters). The pairing of images and words and the assignment of these pairs to a given category is conducted by students and staff.

Given the strong emphasis on being inclusive, the task of identifying and prioritizing a diverse group of individuals for interviews is a particularly important component of the process. Well-networked individuals in the community function as valuable advisors in the process of identifying interviewees and interviewees themselves can be asked to identify other community members. In addition to relying on well-connected individuals, groups associated with the different content categories can be targeted. For example, working in collaboration with the "Oberlin Business Partnership" (equivalent to a local chamber of commerce), the dashboard team sent emails to all local business owners inviting them to participate in interviews. This approach has had the benefit of ensuring that no business owner has felt excluded from participating in the process. Like many other communities in the Midwestern and southern U.S., Oberlin has no less than eighteen churches and other houses of worship and the ministers of these function as important civic leaders. Ministers have therefore also been targeted for interviews to develop content for Community Voices. The extensive integration of Dashboard within schools (discussed below) has provided easy access to children. Oberlin schools' standing policy of seeking annual parental permission for the photographing every child has greatly facilitated development of photographic content. Residents from virtually all sectors of the Oberlin community have now contributed content.

The dashboard team has developed the technology for managing Community Voices as open-source software that is made available on request (as a plugin for WordPress content management software which is also open source). The software consists of a photo database and display tools that can generate content for digital signage and for the website. In addition to associating photographs with quotes, the database contains information on the photographer as well as keywords associated with each photograph and a probability that controls how likely each particular photograph and message is to be displayed. This allows certain content to be more heavily featured than other content. Each time Community Voices is posted on digital signage or on the website the particular image and text combination is randomly selected from the database. Each digital sign installed in the community can be separately configured to emphasize content from different display categories. For example, displays installed in the Oberlin public schools emphasizes more content from the Next Generation category (content by and about youth) and less content from the Our Downtown category. The CV software also allows communities to add, remove or modify the display categories as well as to upload alternative icons representing these or different categories. In order to retain community interest new content is added regularly. As discussed below, the development of fresh content for Community Voices provides an excellent opportunity for collaboration between college, local schools and members of the larger community.

3.5 Integration with teaching and learning at the college and university level

Universities possess powerful intellectual and financial resources for developing and advancing solutions to pressing environmental, social and economic challenges. Given their credibility and role as repositories of expertise on a wide range of issues, they are also well-positioned in society to facilitate interaction and coordination among different entities. At the same time, the historical legacy of higher education as both "ivory towers" and as tools of government and industrial policy create certain barriers to fulfilling this role. Over the last several decades, the increased emphasis on community-based and civically engaged learning has done much to overcome these barriers at the institutions that have pursued these approaches. The emerging focus of both cities and universities on researching and promoting economic, social and environmental dimensions of sustainability is creating new opportunities for further engagement. ED is a potentially powerful context for collaboration between campuses and the communities in which they are located.

A fundamental goal of the ED project has been to combine research, development and education with community transformation. At the college level, educational goals include developing college students' communication and research skills such as interviewing, archival research, public presentation, community organizing and grant writing. These skills have been cultivated by actively engaging students in developing and managing all components of ED and this experience has often placed them in collaborative relations with residents of the larger Oberlin Community. An expanding range of classes have begun to further integrate ED into their pedagogy. These have ranged from introductory through advanced courses and now encompass courses in academic departments that include environmental studies, sociology, anthropology, religion, theatre, biology, computer science, education and women and gender studies.

Through these courses as well as independent study and summer research fellowships, college students have developed new applications for Environmental Dashboard. For example, groups of college students played a central role in the integration of ED into the Oberlin public schools. In the context of an advanced seminar, a group of students coordinated a series of meetings with teachers, principals, the superintendent and high school students to determine whether and how Dashboard technology might contribute positively to the K-12 curriculum in Oberlin public schools. Subsequent project groups then contributed significantly to the development of successful grant proposals to the Ohio EPA and State Farm Insurance that secured funding for installation of monitoring equipment and digital signs in the schools. Other groups of students have since collaborated with teachers to develop and research the impact of curricular materials focused on quantifying the impact of Dashboard technology on learning. Other student groups have significantly contributed to the design of the Environmental Dashboard website, have developed promotional materials and have worked with teachers to develop lesson plans for K-12 students. Yet other groups have played a key role in calibrating and managing water quality monitoring equipment. Over the last six years, dozens of students and former students have now co-presented research on the Dashboard at national conferences such as Greening the Campus, Association for the Advancement of Sustainability in Higher Education, Behavior Energy and Climate Change, American Psychological Association, and the National Center for Science Education. These real-world experiences of collaborating with faculty and community members on the development of ED and then presenting research at professional meetings have provided college students with the opportunity to develop a range of valuable skills and insights. As mentioned, students involved in the earliest years of the dashboard team went on to found Lucid, which now employs a staff of over 70 and provides the most comprehensive and widely adopted products available for monitoring, displaying and analyzing resource flows through buildings. Quite a few other students have also build careers in

academics, education, business and non-profit that build directly on their work as part of the dashboard team.

The ongoing process of developing new content for the Community Voices component provides particularly rich and interesting opportunities related to both pedagogy and town-gown collaboration. Student participation in interviews of community members provide an unusual and valuable context for challenging typical models of community-based learning. College and university students who choose to engage in service learning are generally eager to *disseminate* their knowledge – that is to share and apply skills, information and insights that they develop through their studies. The process of conducting interviews for Community Voices inverts this model of information transfer in an important way by placing students in a position of *receiving* rather than delivering knowledge. Students who have experienced this inversion report that they gain significant and valuable insights; they are often quite humbled by what they learn from community members, many of whom are rich in life and career experience while sometimes shorter in experience with higher education. For the community members as well, the experience of having their ideas and insights listened to and valued by college students and by the faculty involved in the project does much to improve their view of higher education and "town-gown" relationships. While most of our experience with this inversion still comes from the Oberlin pilot of ED, we are beginning to learn important lessons from the other communities that are now developing their own Community
Voices content and look forward to sharing what is learned.

3.6 Integration with teaching and learning in K-12

A variety of K-12 schools have integrated various components of dashboard into teaching. The experience that the dashboard team has had in Oberlin Public Schools serves to illustrate some of the opportunities. Here, collaborations between college faculty, college students and teachers and administrators in the Oberlin public schools have focused on curriculum development, on creation of content in the "Next Generation" category for Community Voices and on resource use reduction competitions among the four public schools. With respect to curriculum development, a variety of lessons have been generated that use ED to teach content associated with the existing topics and standards and to enhance the development of systems thinking skills. These are featured in the "Teaching & Learning with Dashboard" section of this website. For example, Building Dashboard and Citywide Dashboard have been used to teach lessons focused on stream water quality in the 5th grade, electrical circuits in the 4th and 5th grade and algebra, environmental science and consumer science in the high school (figure 9). Text and artwork drawn from students in all four Oberlin public schools has been extensively incorporated into the Community Voices display. With the goal of better integrating systems thinking skills into school curricula, faculty at Oberlin College led a workshop for 10 local teachers in the summer of 2014 to support learning in subjects ranging from social studies to math and pre-engineering. Collaboration is ongoing between college faculty, college students and faculty and administrators in the public schools. We are currently planning similar curricular development workshops for several other school districts in North East Ohio that have adopted all or part of ED.

Fig. 9: Students in Langston Middle School using Environmental Dashboard to study water quality in the local watershed

K-12 Schools across the country have used the Building Dashboard component of ED to host electricity and water reduction competitions. By collaborating with the Oberlin Public schools on running several competitions within the schools, the Oberlin dashboard team has learned a variety of important lessons about what is possible and what students learn from the experience. In the spring of 2014 and 2015 Building Dashboard was used to hold two successful inter-school resource-use reduction competitions concurrent with a longstanding resource reduction competition held among Oberlin College dormitories. The 2014 competition among schools focused on electricity and lasted for two weeks. The 2015 competition included water as well as electricity and lasted for three weeks. Percent reduction during the competition was calculated as the average rate of consumption during the competition compared to the average rate of consumption during the three week period immediately before the competition. Town-gown collaboration was fostered as college students worked to organize the competitions by: teaching mini-lessons relating to using and understanding ED and sustainability in the public schools, organizing city-college events, and working with children to create promotional materials. As an example of the type of town-gown collaboration that occurred, students in all four public schools created posters encouraging conservation that Oberlin College students working on the project then posted in college dormitories during the competition. In both years Prospect Elementary (grades 3-5) achieved over 30% reductions in electricity use which is indicative of the extraordinarily high level of engagement that is possible on the part of students, faculty and staff (figure 10). The same school achieved a 10% reduction in water use in the 2015 competition. In Eastwood Elementary (pre-K through second grades) students noticed unusual patterns of water use displayed on the Dashboard during the competition. This led to the discovery of a substantial water leak in the building which was subsequently fixed. As this example demonstrates, the competitions have proved to be a powerful tool for engaging K-12 students in authentic real-world learning. Competitions have likewise proved to be an exceptional opportunity for collaboration between college faculty and students and the students, faculty and administrators in the public schools.

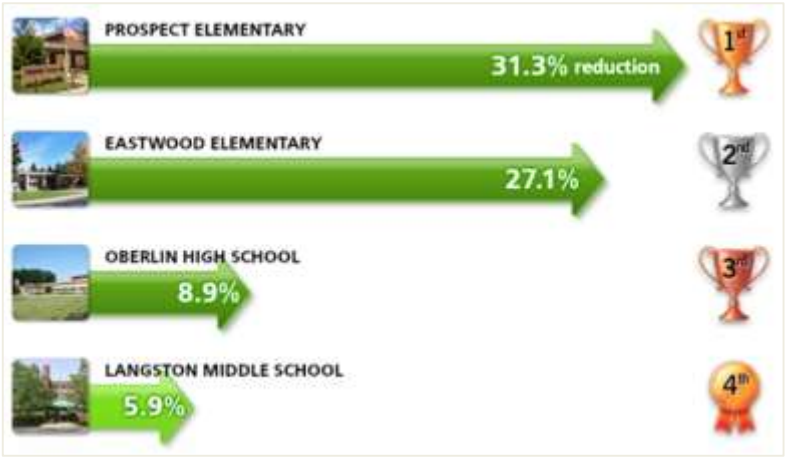

Fig. 10: Screenshot of results of 2015 resource reduction competition among Oberlin City Schools, as displayed on the ED website and digital signs in the schools.

3.7 Research on the Impact of Environmental Dashboard

Faculty and student researchers at Oberlin College are engaged in extensive ongoing research on each of the components of ED. Impact is being assessed through a combination of direct user testing and surveys conducted before and after exposure. Extensive research by the Oberlin dashboard team has found that feedback from Building Dashboard in combination with competition leads to significant reductions in resource use in college dorms (Petersen *et al.*, 2007; Petersen *et al.* 2015). A very active research program is now focused on both Citywide Dashboard and Community Voices, with particular emphasis on better understanding impacts on systems thinking skills and differences in the impact of messages attributed to adults and children.

3.7.1 Effect of Citywide Dashboard on systems thinking

Three separate studies have been conducted to test the extent to which systems thinking is affected by exposure to Citywide Dashboard. In these studies, a sample of college students and a sample of adults from across the U.S. were regularly exposed to Citywide Dashboard (figure 7). Viewers of Citywide Dashboard were compared with a group exposed to a display that contained identical information and similarly engaging animations but without the conceptual model of resource flow through the community. Results indicated that several dimensions of systems thinking were enhanced by exposure to Citywide Dashboard including degree of connectedness with nature (assessed using the scale of Mayer and Frantz, 2004), perception of community as an ecological system and perceptions of causal linkages and responsibility (assessed using the approach of Maddux and Yuki, 2006). These findings suggest that systems thinking can, in fact, be enhanced by exposure to this animated conceptual model.

3.7.2 Effects of Dashboard-focused teaching on content retention and systems thinking

Prior research suggests that systems thinking can be explicitly taught in a classroom setting (Fazey, 2010; Hipkins *et al.*, 2008; Hung, 2008). However, to date research has generally focused on older children and adults, and been primarily observational. Experts have recommended that systems thinking be explicitly taught and integrated into curricula as early as elementary school (Assaraf and Orion, 2005; Rutherford and Ahlgren, 1990). This reveals a need for the development of age-appropriate educational materials and assessment tools for systems thinking. To assess the potential use of ED to support learning in K-12 schools and to improve systems thinking, the dashboard team

conducted a study that used Building Dashboard and Citywide Dashboard components to support 4th and 5th grade units on electricity in an Oberlin elementary school. Children in classrooms that received instruction using ED showed enhanced systems thinking skills, enhanced content retention and improved self-efficacy compared to a control group that received normal instruction that did not incorporate the technology (Clark *et al.* in review).

3.7.3 Effects of Community Voices on perception and action

Research is currently underway to assess the effectiveness of Community Voices. In preliminary studies, the dashboard team has found that exposure to Community Voices significantly enhances people's level of concern for the environment and commitment to taking action on environmental issues. Targeted research has also been conducted to assess whether the same message attributed to and associated with images of adults versus children has different impacts. Preliminary findings indicate that differences in the effect of messages attributed to adults versus children are relatively small and depend on the measure being assessed.

A study has also been initiated to assess the impact of being interviewed and featured on Community Voices. We hypothesize that this experience may enhance the interviewees sense of connection to community, connectedness to nature, self-efficacy and self-reported conservation behavior. Surveys were conducted to assess baseline metrics prior to the interview for Community Voices. The dashboard team plans to conduct follow-up research within the next year to determine whether changes are evident in these psychological metrics.

3.7.4 Effects of exposure to digital signage on perception and action

Prior to installation, extensive survey work was conducted at each of the sites within the community in which ED digital signage has been installed. The goal was to quantify baseline data related to a range of psychological metrics associated with systems thinking and views towards the environment and community. The dashboard research team plans to conduct a follow-up surveys to assess the impact of exposure to the digital signage in 2016.

3.8 Expanding Environmental Dashboard to other organizations and communities

The dashboard team has been in dialogue with numerous communities throughout the U.S. and in Canada who have expressed interest in developing full implementations of ED. Because the Building Dashboard component is commercially available and actively marketed by Lucid, as of 2015 it is already installed in over 150 colleges (over 2,500 campus buildings) and over 800 K-12 school buildings. In the fall of 2014, Oberlin College, in partnership with Albion College, Antioch College, DePauw University, and Hope College, was awarded a grant from the Great Lakes College Association (GLCA) as part of their "Expanding Collaboration Initiative," funded by the Andrew W. Mellon Foundation. The project's purpose is to use ED to foster programs of teaching, research, and outreach across college campuses to heighten awareness of how human behaviors affect the well-being of the natural environment, as well as the sustained vitality of human society in local settings and the broader global context. As of this writing Building Dashboard has been installed in at least three buildings on each of these campuses, Community Voices content is being developed by each institution that is specific to each community and two of the institutions are actively engaged with their local communities in scoping the feasibility of developing the Citywide Dashboard component. The Oberlin research team is enthused about the larger collaborative group now focused on researching and

further developing Environmental Dashboard as a technology that connects colleges and universities with the communities in which they are embedded.

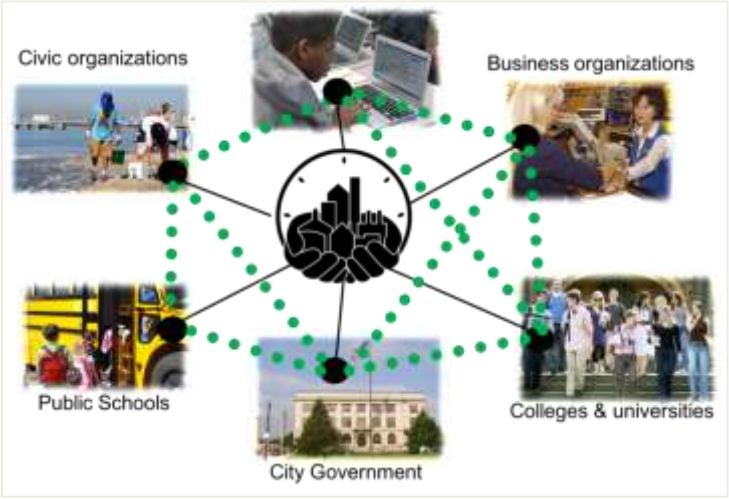

Fig. 11: Ultimately the goal is systems thinking in action– fostering a sense of belonging and connectedness. Each community being unique and key players differing in different communities. There's a need to develop approaches that are scalable transferable but also adaptable to represent the site-specific conditions and aspirations of each community. This technology is successful if it successfully connects people with each other and with nature and promotes behavior change that moves us towards sustainability and resilience

3.9 Costs, software and sequence for implementing in your community

"How much does it cost?" Unfortunately, the unsatisfying answer to this question is, "it depends". A range of factors influence cost including: how extensively an organization or community is monitored (how many individual points), how many different kinds data sources are integrated (for example building automation systems and dataloggers), how many digital signs are installed, how extensive the programming is around ED (for instance whether it is deeply integrated into the school curriculum), how Community Voices content is managed. It is important to understand that an ED implementation combines several distinct software components, some of which are being developed in an open-source or freeware model and some of which are commercial. For example, Lucid is a private company with a *software as a service* revenue model meaning that customers of Lucid pay an annual fee for the service of data collection, processing and storage, analytical tools and delivery for display. On the presentation side, Lucid offers a wide variety of data visualizations that can be combined within ED. In contrast, Citywide Dashboard is being developed open-source shareware display technology that is animated by a real-time data source. The data source for Oberlin's Citywide is provided by Lucid, but it could, in principle, be provided by other sources. As explained previously, Community Voices is designed as shareware that uses and further develops various building blocks within the open-source WordPress framework. The Environmental Orbs currently in use at Oberlin were developed using the open-source Arduino hardware and software framework. The dashboard team is currently working to develop a version of the Orb that will utilize commercially available Wi-Fi enabled colored lighting. This shift to an off-the-shelf display product will make it far easier for other organizations and communities to adopt the orb as a display technology. Like Citywide Dashboard the Orb is currently configured to run off of data that is provided by Lucid, but as with Citywide, the orb could, in

principle, run on other data sources. Oberlin and several other College communities and public school systems are using the Rise Vision digital signage product for displaying ED on public signs. Rise Vision builds directly off of the Google Chrome browser and provides a low-cost (potentially free) and easy-to-use platform for combining the three components of ED together with community calendars and site-specific content that the host organizations can be trained to easily modify on their own.

Although we believe there is particular psychological value and impact in combining the three components of ED as a unit, it is possible to sequentially build from each of the individual components. Indeed, this appears to be the common trajectory that most other communities are taking. As mentioned, the Building Dashboard component is currently the most widely adopted. Those interested in this component can directly contact Lucid for a cost estimate. There are a number of communities, such as Toledo Ohio, in which there is strong support for building out the complete ED, but that have decided to start by installing Building Dashboard within different community organizations. In the case of Toledo, they have started with an installation that includes all 44 school buildings as well as several municipal buildings. The group of four collaborating Great Lakes College Association schools discussed previously are starting with both Building Dashboard and Community Voices on campus, but have various plans for expanding ED within the cities in which they are located.

4.0 Conclusion

This section of the website has described the roles that the technological tools and approaches embodied in Environmental Dashboard can play in advancing community transformation. While it is early to draw broad conclusions, the Oberlin pilot and more recent work in other communities suggests that approaches like this can, indeed, harness social psychology, technology and programming to generate novel forms of feedback that reconnect people with resource flows and inform better decision-making. Environmental Dashboard offers rich opportunities for engaging a variety of stakeholders to support sustainability measures. By inviting an entire city to collaborate using a common digital platform, Environmental Dashboard enables collaboration (figure 11) and helps generate a shared vision and plan for a more sustainable future.

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