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A new model for enabling innovation in appropriate technology for sustainable development

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The task of providing for basic human necessities such as food, water, shelter, and employment is growing as the world's population continues to expand amid climate destabilization. One of the greatest challenges to development and innovation is access to relevant knowledge for quick technological dissemination. However, with the rise and application of advanced information technologies there is a great opportunity for knowledge building, community interaction, innovation, and collaboration using various online platforms. This article examines the potential of a novel model to enable innovation for collaborative enterprise, learning, and appropriate technology development on a global scale.

KEYWORDS: innovations, technology transfer, developing countries, databases, experiential education, Intranet

Introduction

In the "Internet Age" more than one billion people continue to live in impoverished conditions inferior to those of the Minoan Civilization (circa 2200 to 1450 BC) (Gates, 2000; UNDP, 2001). For example, the Minoans had a community-water system (Logiadou-Platonos, 1980), yet today ingestion of unsafe water, inadequate availability of water for hygiene, and lack of access to sanitation contribute to approximately 1.5 million child deaths every year (Ezzati et al. 2002; WHO, 2002). Approximately 2.6 billion people currently have no access to a hygienic toilet or latrine (WHO, 2010), while overall 10.8 million children under the age of five die each year from preventable causes (Black et al. 2003). These deaths are largely related to poverty: as of 2004, just under one billion people live on less than US$1.08 a day and 2.5 billion people live on less than US$2.15 a day (Chen & Ravallion, 2007). The enormous challenge to our generation is increasing as the world's population continues to expand—to an expected nine billion people by 2050 (UNDESA, 2008). How we meet the needs of this growing population in a just and equitable manner within the ecological capacity of the earth is the major challenge of sustainable development.

To address these situations, a variety of government programs, nongovernmental organizations (NGOs) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) have undertaken initiatives to enable technology and information diffusion among communities to support sustainable development. The success of these endeavors requires a systematic approach with coordinated contributions from a wide range of individuals and stakeholders (Limerick et al. 2002; Fiksel, 2006); yet presently, information and communication systems are not sufficiently effective in diffusing technologies among the wide range of audiences. For instance, how can a small business in a developing village in China access the thermodynamics knowledge of a mechanical engineer at an American university? How can the economic sustainability of the community of Gaviotas, Columbia share a simple heat-exchange technology used in Chinese businesses (Weisman, 1998)? How can American communities benefit from the design improvements on solar hot-water heaters made in Gaviotas?

These modes of technology transfer do not presently occur because there is limited and weak communication between developing communities and researchers, resulting in poor technological diffusion and redundant time and resource-consuming research and development for communities of all nations. A new method of technology transfer and communication among communities is clearly needed on a global scale. This article outlines the necessity and the components for creation of a new research endeavor that would allow for much faster and more efficient diffusion of ideas and technology. Such an enabling innovation (EI) system would be designed to inspire the formulation of sustainable social and technological solutions by facilitating knowledge and technology transfer among communities with the support of educational institutions, NGOs, and industry.

This article describes the core of the system's design: an online community that would catalyze and disseminate innovation by providing local innovators with multilingual and visual representation of: 1) innovation use by geographical location and resource availability; 2) innovation evolution or adaptation; 3) social networks among innovators; and 4) networks of complimentary innovations or systems designs. The online community would document the evolution of innovation and provide ready access to local innovators, NGOs, and academic resources to support collaborative development of sustainable solutions. Customized community portals would provide relevant information for specific groups of users (e.g., to match their geographic, economic, or otherwise particular circumstances). Moreover, this communication channel would create an opportunity for faculty and students to directly contribute to sustainable development while enhancing their understanding of key traditional topics in education via experience-based service learning.

Examples of Community-Knowledge Building Using Information and Communication Technologies

To address the challenge of sustainable development, it is imperative that people in the developing world have access to a broad knowledge base that can significantly improve quality of life (King & Hill, 1993; Gurstein, 2000). This kind of collaborative networking via information and communication technologies (ICT) is on the rise. Some examples of knowledge-sharing networks include those that provide access to weather and marine conditions, crop and product valuation, micro-credit loan and financial tracking, government services and records, healthcare information, transportation services, and maps of Geiger counter readings from the 2011 nuclear disaster in Japan (King & Hill, 1993; Arunachalam, 2002; Cecchini, 2003; Tcheeko & Ntah, 2006; Pearce, 2012a). Organizations such as Science for Humanity, Health Unbound, Grameen Bank, One World Trust, and many more are great examples of the collective work being done for sustainable development through a variety of disciplines and domains. The examples highlighted below relate specifically to the historical field of appropriate technology (AT) or modernized open-source appropriate technologies (OSAT). The concept of OSAT refers to technologies that are designed in the same fashion as free and open-source software. These must be AT, which is defined here as technologies that are easily and economically used from readily available resources by local communities in the developing world. Effective AT must meet the boundary conditions set by environmental, cultural, economic, and educational resource constraints of the local community (Pearce, 2007).

Merely supplying ICT equipment is not an optimal solution (Ashraf et al. 2007). A more nuanced approach to the communication of knowledge is required to leverage ICT to support innovation. Arunachalam (2002) points out that the majority of ICT projects flooding the developing world are doing so in an irresponsible manner and for the primary benefit of hardware and software companies. Because these ICT projects often resulted in failure and restrictions, Hicks (2008) demanded new goals of sustainability, scalability, and evaluation. Arunachalam (2002) called for a more "people-centered" approach so that technology could contribute to participatory development, which can avoid these problems. ICT is merely a tool, while user-driven content and use must be the primary foci to help communities become sustainable. To succeed in other endeavors, teachers and organizers apply the same principle to students (Wasson, 2007) or existing online communities like Wikipedia (Baytiyeh & Pfaffmanm, 2010). To achieve this goal, there must be a mechanism for participatory development so that the community is able to play a role in appropriating the technology, and there also must be continuous study of how to improve and evolve the systems to better suit people's needs. Several successful models for accomplishing this aim with large user communities are reviewed here: the M.S. Swaminathan Foundation, Village Earth and Appropedia, Catalytic Communities, and Service Learning.

M.S. Swaminathan Foundation

The M.S. Swaminathan Foundation (MSSF) is an ongoing nonprofit organization founded in 1988 that focuses on economic growth for poor women in rural areas. Operating in India, with funding from Canada's International Development Research Centre (IDRC) and the Canadian International Development Agency (CIDA), MSSF's Center for Research on Sustainable Agriculture and Rural Development established a network connecting approximately twenty rural Indian villages to the Internet. The key premise has been to promote sustainable rural livelihoods through digital empowerment, technology choices, and dissemination, as well as by encouraging human-resource development. The emphasis has been on locally specific, demand-driven content and capacity building through different communication tools.

The MSSF approach begins by asking villagers what information they are most interested in accessing. To gain access to these services, the villagers must provide a public center to house the computer systems and a salary to pay indigenously trained operators. In return, MSSF provides hardware, software, and support. In addition, the Foundation creates a customized community website or portal using the local language that provides quick access to their requested information. Having demonstrated the benefits of such ICT projects for poor rural communities, MSSF launched another project in 2004 involving a national movement to enable up to 600,000 villages throughout India to build similar rural knowledge centers (Shore, 2005).

Village Earth and Appropedia

Village Earth, a consortium for sustainable village-based development, exemplifies a participatory approach to development. Village Earth is a nonprofit organization (NPO) based in Colorado that works to achieve sustainable development by connecting communities with global resources through training, consulting, and networking to collaborating organizations worldwide (Bradley & Newberry, 2004).

Village Earth has projects with the Oglala Lakota on the Pine Ridge Indian Reservation in South Dakota, the Shipibo-Konibo of the Amazon region of Peru, and in India, Cambodia, and Guatemala. Village Earth begins by leading communities through a series of workshops in which participants create a common vision, identify obstacles and constraints, and formulate an actionable plan. A Village Earth representative provides a link to outside resources and knowledge through a variety of information sources that have been created within the organization, including a digitized AT library comprising scanned books and documents and a more dynamic and newly evolving AT wiki that has recently merged with Appropedia, a website for collaborative development of solutions focused on sustainability, poverty reduction, and international development (Pearce, 2012b).

Appropedia is a wiki-based website (in other words a website where a large number of participants are allowed to create and modify the content directly from their web browsers). Appropedia has enormous potential to assist in fostering sustainable development because it takes on the administration of collaboratively organizing information, project examples, and best practices and thus allowing organizations committed to sustainability, appropriate technology, social entrepreneurship, service learning, and international development to focus on what they do best. Appropedia has already become the AT venue of choice for organizations such as Engineers Without Borders-Australia and Demotech and is set to expand rapidly as other organizations use its information-transfer capability.

The Appropedia website, combined with recent advances in semantic MediaWiki, allows for annotating semantic data within wiki pages. Data that have been encoded can be used in semantic searches and to aggregate web pages; displayed in formats like maps, calendars, and graphs; and exported to the outside world via various formats. The first example of the application of semantic wiki functionality within Appropedia involved the Global Health Medical Device Compendium (an inventory of medical devices designed for use and/or implemented within resource-limited settings). The compendium can be sorted by *health topic* (e.g., malaria or HIV/AIDS), *classification* (e.g., preventative, diagnostic, or clinical), *scope* (e.g., prototype, clinical trial, or commercialized), and *location* (by continent).

The participatory approach supported by Appropedia and used by Village Earth focuses investment toward assisting local residents to research, design, and innovate within their own community. Village Earth teaches people to access information, but the organization's representatives do not make recommendations. The villagers own the projects and the decisions. The Village Earth approach focuses on teaching innovation and development processes that assist communities to better themselves. Once the process is in motion, a resource-access unit is created by training a group of local community members to acquire outside knowledge and resources. Once Village Earth has enabled such a connection, the organization is able to move forward to a new community.

Catalytic Communities

In Rio de Janeiro, Catalytic Communities (Catcomm) provides a third example for assisting communities with ICT through a participatory approach. Catcomm is a NPO with a mission to develop, inspire, and assist a global network of communities generating and sharing solutions (Badamas, 2005). The organization provides physical and virtual spaces for communities to exchange ideas. Their community centers provide ICT access and foster the congregation of community leaders while their community-solutions database enables people to post their success stories, inspiring others to enhance their own communities. The database provides hundreds of examples of successful community solutions throughout the world. It references both social and technical applications, but is primarily built to support social and technological innovations. The community-solutions database was started in 2003, but since 2009 CatComm has been involved in a partnership with WiserEarth, an international civic directory and networking forum that gives community partners access to the knowledge resources of WiserEarth's 1.5 million users from 243 countries around the world.[1] Since the merger, CatComm's database-functionality features have been boosted to include member ratings and collaboration tools.

The Catcomm methodology is useful because it details the steps and potential obstacles to creating these social innovations, allowing others to replicate them within their own communities with a decreased need for in situ research or lengthy processes of trial and error (e.g., lessons learned from applications in the field). Just as Appropedia facilitates the construction and testing of enabling artifacts, such as high-efficiency stoves, Catcomm enables the production and adaptation of quality-of-life enhancing social structures (e.g., how to set up a daycare facility), allowing them to be replicated elsewhere with appropriate modifications accounting for differences in culture, resource availability, regulations, and so forth. The partnership between CatComm and WiserEarth, as well as the one involving Village Earth and Appropedia, recognize that when united under common causes and using the networking capacities of online communities their collective impact and outreach can be much greater than if they operated in isolation.

A New Research Thrust

The above examples constitute a new model to facilitate community involvement to reach successful sustainable development that reduces poverty while allowing communities to thrive indefinitely on renewable resources. However, all of these methods, although successful in terms of solving locally focused sustainability problems, are still somewhat limited in scale and only reach a small fraction of the world's developing communities. The keystone for harnessing this enormous potential is in a reliable method of networking the knowledge of numerous organizations—including institutions of higher education, NPOs/NGOs, and governments—with developing communities. These organizations provide a direct conduit of necessary information between communities in developing countries and research groups that are working on generalizable solutions to technical and social problems. More than a decade ago, Bruce Alberts (1999), a former president of the National Academy of Sciences in the United States, called for

> [A] global electronic network that connects scientists to people at all levels—farmers' organizations and village women, for example. The network will allow them to easily access the scientific and technical knowledge that they need to solve local problems and enhance the quality of their lives, as well as to communicate their own insights and needs back to scientists.

Since this appeal, the need for an OSAT network has not diminished (Zelenika & Pearce, 2011). The EI system, proposed here as a major new research project, is designed to build such a network to allow AT research to reach a much wider range of communities.

Research Design Model—Enabling Innovation

The EI research design model consists of two primary functions: create a system for the exchange of indigenous knowledge and innovation among developing communities and then establish a communication channel to allow communities to solicit support from educational institutions and service organizations. The EI database would provide a hub for knowledge and technology transfer among developing communities, educational institutions, and service organizations. First, the database would offer a space to document the evolution of innovation of OSATs. This would allow people across the globe to learn from and inspire each others' sustainable solutions. Second, community portals would provide access to the database in a context relevant to specific groups of users. Finally, this communication channel would create an opportunity for faculty and students to directly contribute to sustainable development while enhancing their understanding of key traditional topics.

Community portals would provide a customized interface with access to local resources in addition to the EI database. The layout of the database information and default search parameters would be optimized for particular communities, institutions, or professional associations. For instance, an urban community portal would highlight and favor solutions from similar communities until the user requested to search beyond the default settings. Some communities might want the project story and historical context to be displayed first while other cultures (such as a professional association) might grav-

[1] For more details refer to http://www.catcomm.org.

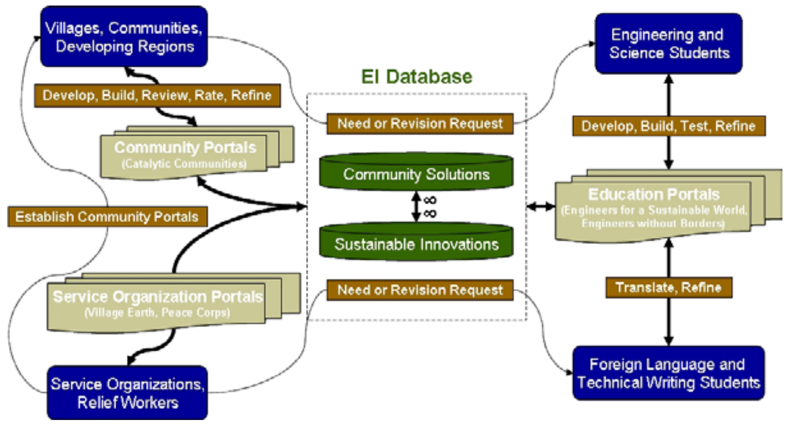

Figure 1 Conceptual Layout of Enabling Innovation.

itate toward technical diagrams and cost information. Catcomm is an example of a community portal that has been optimized for the city of Rio de Janeiro with local community and leadership networks, fundraising resources, and project highlights.

Figure 1 shows the conceptual layout of EI. The upper-left-hand section illustrates that communities in developing regions would submit a need or a revision request to EI through their customized portal, which houses both community (systems) solutions and individual sustainable innovations (technical- and policy-based solutions to specific problems). When the need was established, the request would be sent to university students, who would then develop, test, and refine proposed solutions. The students and faculty would access the EI database through their own portal. Similarly, foreign language students and volunteers would obtain information and completed solutions that need translation in EI through the educational portals;[2] they would then translate the information and upload it back into the EI database. Service organizations and trade associations would also have their own portals, where they could not only upload useful information to assist businesses in their disciplines, but also request solutions from universities or other EI groups to solve identified challenges. Finally, individual communities and villages would have the same ability to provide their real-world tested solutions to the database for translation and technology transfer.

[2] Nabuur, the Global Neighbor Network, is an Internet-based volunteering platform that links online volunteers with local communities in Africa, Asia, and Latin America. See http://www.nabuur.com.

Core EI Database Capabilities

The core building block of EI is a database designed to document, inform, and inspire sustainable solutions to developing community challenges. Relevance and searchability within such a vast network of information is the key constraint of the database design. Thus, the database must support a suite of tools intended to target useful, pertinent information for each desired user. These core capabilities, critical to the success of the EI system, include multilingual support, innovation evolution or revision tracking, innovation review and rating, innovator rating, certification capability, geographical use and resource tracking, and system-design capacity.

Multilingual Support

To make information accessible around the globe, the EI database would need to support numerous languages. Most large collaborative websites and wiki-sites handle multilingualism by spawning a separate and largely independent site for each language (Désilets et al. 2006). Unfortunately, this approach results in redundancy and squanders resources to replicate existing research and development in each language because the content must be researched, tracked, and written for each language. To overcome this challenge, EI would utilize a system similar to that of Catcomm that relies on a network of volunteers (as does Appropedia as well) where foreign language students would translate material developed in one language into multiple languages (ter Horst & Pearce, 2010). As each native language entry was input into the database through a portal, the entry would be delegated out to a network of translators. This method would not only reduce redundant effort, but would also offer potential as a service-learning teaching tool for language classes. An enormous and steady amount of valuable work would need to be performed to maintain the EI database considering the fast and ever-changing nature of the development of appropriate technology all over the world. At the same time, translation software is also improving, potentially eradicating language barriers to information. Such automated translation services could serve an important stop-gap role to provide rudimentary details when entries were first input, but computer translations of such material are still notably flawed, necessitating the intervention of human translators.

It should be pointed out here that in addition to spreading information, capturing indigenous knowledge is not limited to language translation. It would, of course, be difficult to build the ontology, structured data tagging, protocols, and systems to ensure quality control for a large variety of topics across a great number of cultures. While the power of collective works should not be undermined, there are limitations to the expertise, continuity, and organization provided by university students and volunteers. For this reason, structure, supervision, and support would also be necessary for the systems to work. Such supervision would ensure that the primary thrust of the project would remain intact, similar to how a core team of experts guides the Linux coding community when changes to the kernel are proposed.

Innovation Evolution or Revision Tracking

Unlike a "best practices" approach that disseminates selected case studies for replication, EI aims to document and inspire creative, local innovation. This does not mean that best practices would be ignored and the figurative wheel would be reinvented in every community, but that communicating the evolution of an innovation is just as essential as disseminating the innovation itself. For instance, a researcher would be able to learn about how a particular community designed a small dam to help resolve desertification problems and to improve local agricultural output. The primary entry would be linked to similar entries portraying how different users in various communities have adapted the dam to work within the environmental, economic, and materials constraints of their particular location. These different adaptations are synonymous to forks in computer coding. Expanding a specific entry would unveil even more adaptations and case studies. This unfolding process would assist the user to innovate—to determine how best to adapt the technology or innovative system for the needs of a particular community. The primary idea or solution would evolve and be optimized for a given context. Communities could use a version applied in a locale most similar to their own. The comparison of these methodologies would provide another useful research opportunity.

Innovation Review and Rating

Often the investment required to recreate or build an innovation is high. To overcome these developmental costs, first, there must be adequate information and schematics for a user to trust that there is due diligence in a given design and that the designed device can perform to specifications. Second, particularly for small communities with limited access to funding, there must be a successful history of implementation before an investment in time and resources can be justified. Similar to an online store (e.g., Amazon.com), product information, accompanied by successful customer reviews or testimonials, can be useful before purchasing a specific item. EI would need to support a review and rating system for documented innovations. Through user reviews and scoring, successful innovations could be quickly referenced while unproven or unwanted content could be easily avoided by screened sources and display ranking. Similar to Google's capacity to place the most relevant search string at the top of a list, the most highly ranked innovation to solve a specific problem of a particular device design would be provided to users before less proven designs.

Innovator Rating

To reduce barriers to the diffusion of innovations, new applications from reputable sources could also be prioritized. If an innovation was novel and unproven, but the designer had a long history of successful concepts, a user would be more apt to build off of or invest in the provided information. Furthermore, an innovator-rating system would provide a currency or incentive to encourage participation and quality submissions. Like eBay's feedback points, experienced innovators could develop a reputation for high-quality technologies. While eBay's system rates transactions between users, the EI innovator rating would be more product-focused. Buyers would rate the product and the seller's rating would then be derived from an average of the ratings of the products that they sold. The innovator rating would be based on an average of their innovation ratings adjusted to favor relatively more experienced designers, such that someone with ten five-star innovations would score higher than someone with three five-star innovations. This social capital system is also similar to the impact-factor rating in peer-reviewed literature, where journal articles from publications with high impact factors are presumed to be of better quality. This is an admittedly conservative approach to the diffusion of ideas. It has the benefit of quickly giving credit to innovations from established groups, but has the disadvantage in lowering the value of work from less established entities. Further work is needed to overcome this limitation.

Certification System

An organizational certification system is yet another way to convey trust and overcome barriers to innovation diffusion and information adoption. For example, the forestry sector uses organizational certification to promote sustainable practices by providing trust through a third party that certifies forest products (Rametsteiner & Simula, 2003; Lewandowski & Faaij, 2006). Similar to a *Consumer Reports* stamp of approval, organizations specializing in particular appropriate technologies would be given certification power. This procedure both delegates a certification process and provides organizations with a similar incentive to build, highlight, and market their own set of successful innovations. For example, certain innovations could be certified by the Peace Corps or Engineers Without Borders-Canada. This arrangement would create a currency for organizational participation and allow users who are familiar with or trusting of a specific organization to search through their proven, successful, certified technologies.

Geographical Use Tracking

The location of an innovation is often critical to its appropriateness or success. Many renewable energy technologies, such as solar photovoltaic cells, are sustainable solutions in some situations, but have decreased usefulness in areas that are prone to dense cloud cover. In addition, the ability to find innovations that are used locally will allow for a site visit, increase trust, and ease communication with the innovator. All of these factors would reduce barriers to entry or technological adoption. Cross-referencing innovations with sophisticated open-source GIS systems would allow adaptive searching for culturally, ecologically, and economically relevant technologies.[3]

Resource Tracking

When documenting an innovation for EI, it is imperative to include the necessary resources, tools, and skills. The database would ideally work like a recipe program, allowing users to input their available resources and responding with solutions that fit their needs. This basic functionality is already seen in Thingiverse, which is a database of physical 3-D objects primarily for applications of 3-D printers. As communities recreate, review, and revise innovations, EI "learns" about their accessibility to resources and helps to autopopulate some of the entries for a given community. The larger the number of communities that utilize the system, the more the database "knows" about the availability of resources, tools, and skills throughout the world and the more adaptive and appropriate the search results can become. Thus, this application increases its value not only with each additional user, but also with each additional use.

System-Design Capacity

Many innovations are complimentary or symbiotic while others require a more complex system to succeed. The watershed example mentioned earlier required small dams, terracing, specific agricultural techniques, and an innovative community water-credit system. Any single technology, taken out of context, should not be expected to resolve a problem. Nor could all of the technologies, if transplanted together, necessarily address a similar dilemma in a different context. It is thus important that the user be able to view the innovations as a system. Only then can the appropriate understanding be transferred, assisting other users in meeting their own needs. Similar to Amazon's suggestive sales techniques, innovations may be highlighted because of their use in conjunction with others. Small businesses that sell a specific water pump, for example, also use a matching wind turbine to drive the pump. In addition, relationships between required supportive technologies can be defined and conveyed to users.

System design applied to businesses or industry is often referred to as industrial ecology or industrial symbiosis. In industrial symbiosis, traditionally separate industries are considered collectively as a system to institute mutually beneficial physical exchanges of materials, energy, water, and/or by-products. The key benefits to using industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity (Chertow, 2000). Successful industrial symbiotic systems have historically evolved as networks of innovations and innovators that collectively optimize material and energy flows at efficiencies beyond those achievable by any individual firm. The leading example is Kalundborg, an industrial city in Denmark, that evolved over a long period of time through incremental partnerships rather than systematically planned or coordinated development (Ehrenfeld & Gertler, 1997). It has been observed that this spontaneous community of industrial symbi-

[3] See, for example, Geographic Resources Analysis Support System (GRASS) at http://grass.osgeo.org and the proposed work of Nodius at http://dev.zevinpolzin.com/nodilus. These tools would allow communities to quickly determine if an innovation were locally appropriate. One such application might be integrating a solar irradiance and irradiation model like r.sun into GRASS to determine local yearly solar flux to gauge the viability of a solar energy-system design in a particular community (Nguyen & Pearce, 2010).

Table 1 EI functionality compared to existing services**.**

	MSSF	CatComm	AT Wiki	EI
Customized Community Portal	X	X	X	X
Innovation Browsing by Need Addressed		X	X	X
User-Communication Tools		X	X	X
Multilingual Support		X	X	X
Revision Tracking			X	X
Innovation Reviews		X	X	X
Innovation Ratings				X
Innovator Reviews			X	X
Innovator Ratings				X
Certification				X
Geographical Use Tracking				X
Resource Tracking				X
Suggestive Searching				X
System-Design Tools			X	X
Multiple Developer Collaboration		X	X	X
Higher Education Institutional Support and Collaboration			X	X

osis emerged because communication and transaction costs were distinctively low since agents were communicating socially. This is difficult and time-consuming to replicate. EI would reduce these informational exchange costs as resource (waste) availability would be part of the database and allow for the design of systems based on industrial symbiosis.

Comparison to Existing Services

Table 1 summarizes the functionality of the EI system compared to the existing information services of MSSF, CatComm, and Appropedia. As is clear from Table 1, EI would provide functionality that is not currently available in any competing/ complimentary services for addressing the needs of communities for sustainable development. Overall, the EI system would offer six additional functionalities that currently do not exist in any of the comparable systems 1) innovator rating, 2) innovation rating, 3) formal certification, 4) geographical use tracking, 5) resource tracking, and 6) suggestive searching. Innovator and innovation rating and formal certification could be integrated into Appropedia using existing technology, but have not yet been implemented. Appropedia has enabled Google maps to begin to provide some mapping possibilities, but is far from a fully functional GIS package. Resource tracking and suggestive searching would need substantial developmental work before being implemented in a wiki environment.

Educational Curriculum Enrichment

The third design component of EI is a set of curriculum-enhancement methodologies to leverage service learning to support sustainable development while educating the next generation in sustainability. Sustainable design and development principles are key foci of higher education at many institutions and service learning is increasingly used to enhance traditional curricula while teaching sustainable design principles (Bryden et al. 2002; Green et al. 2004). However, the field is still in its infancy (Bielefeldt et al. 2005; Sandekian et al. 2005) with much room for development and discussion of pedagogy and methodology to maximize the value of service learning in teaching sustainability. Unfortunately, relatively little work has been done in direct collaboration with developing communities with notable exceptions such as Engineers for a Sustainable World (ESW), Engineers Without Borders (EWB), and the United States Environmental Protection Agency's P3 (People, Prosperity, and the Planet) programs. On one hand, there are limitations to the impact students can have given their limited knowledge, experience, and commitment to development projects. On the other hand, students' passion, creativity, and desire to make a difference can be substantial (Komives, et al. 1998; Westheimer & Kahne, 2004). While the type and scale of projects would depend on a given group of students, creating a direct communication link among students, educators, businesses, and community members presents an opportunity for service learning to have a potentially enormous impact.

Service Learning

EI provides an opportunity for students to directly contribute to sustainable development in a streamlined fashion. Generally, the most successful university service-learning projects involve students directly with businesses or community groups to address specific problems. These projects usually entail large investments in both time and financial resources for the students to travel and collaborate with local residents involved in the service opportunity, such as the work of Engineers Without Borders (Wing et al. 2007). This type of program can be excellent but prohibitive because of resource constraints for most educational institutions and most universities that do not have on-site service-learning programs.

Creation of the EI database would allow students to work on, research, and solve real-world problems while at their home institutions with no additional financial outlay. This model would also allow developing communities to take advantage of service learning and university research and development, while at the same time harnessing the service-learning motivational advantages for enhancing student learning (Pearce, 2007; 2009). The EI database would enable nearly all of the disciplines to integrate service learning into their curricula. For example, all the science and engineering fields could work on developing and testing OSATs for basic science or engineering labs; mechanical engineers could develop computer-aided design (CAD) files for OSAT projects; the language programs could use EI to provide content for students to proofread, copyedit, and translate; geography students could help identify areas with a competitive advantage for specific innovations; business, accounting, finance, advertising, and marketing majors could assist businesses in formulating successful business and marketing plans; and education majors could develop curricula about individual innovations for accelerating technological diffusion to developing communities.

The vast majority of academic programs could thus implement such “service learning lite” assignments into the curriculum to have students working to solve real-world problems of sustainable development and upload their projects for wider benefit. The motivational aspect of such efforts should not be underestimated. For many students who have never had the opportunity to travel abroad (or even those who have done so), to have their work translated into multiple languages, used by communities all over the world, and receive feedback and international ratings could be extremely gratifying and motivating. The EI project could provide this incentive by encouraging enhanced education through service learning.

Educational institutions have the potential to provide an immense set of resources for fostering AT in developing communities, but there are significant barriers to its adoption (Zelenika & Pearce, 2011). The Massachusetts Institute of Technology, the California Institute of Technology, and the University of Michigan, for example, all feature courses dedicated to developing sustainable AT within a context of engineering or science curricula.[4] Sustainable development AT research, however, is far from ubiquitous. Although some limited work has been done on a number of ATs, the diffusion of these innovations has greatly lagged behind the demand by communities in the developing world, as witnessed by the slow rate of technological diffusion. Service learning is a method to integrate AT research, development, and diffusion into the university curriculum.

Service-learning projects generally provide sophisticated design challenges within a specific set of constraints and they have proved useful as educational tools because when engaged in service learning, students are more motivated, work harder, learn more, and are left with lasting benefits (Cohen & Kinsey, 1994; Giles & Eyler, 1994; Astin & Sax, 1999; Pearce, 2001; Gallini & Moely, 2003; Pearce & Russill, 2003; 2005; Keen & Hall, 2008). Most importantly, the AT projects are so highly engaging and motivational that some universities use them strictly to enhance the educational experience, with little or no method to disseminate the acquired innovations (Pearce, 2007; 2009). The service-learning approach represents a vast (and largely untapped) resource for accelerating sustainable development while enhancing course-based learning.

Challenges

The development of EI represents an amalgamation of many challenges, not all of which are technical (Pearce & Mushtaq, 2009; Zelenika & Pearce, 2011). As Wasson (2007) explains, while there may be no recipe for successful database formation and learning enrichment, given the potentials of collaborative networked scenarios, even the challenges are exciting. It is assumed that the technological challenges of coding the database itself are solvable with an adequate supply of funding and time. Perhaps the greatest inclusive challenge to the EI system is the wide spectrum of target audiences; creating a tool that is concurrently used by faculty at MIT, a business in Switzerland, and remote villagers in the Yu-

[4] See, for example, D-Lab at MIT (http://web.mit.edu/d-lab), Product Design for the Developing World (E105) at CalTech (http://www.its.caltech.edu/~e105/index.htm), and the AT degree concentration at the University of Michigan (http://www.engin.umich.edu/students/bulletin/interdisc/concentrations.html).

catan Peninsula will require a great deal of creativity and expertise by communication specialists.

The system must be compatible to support local and community ownership and participation. Existing models include 1) OpenMRS, a community-developed, open-source enterprise for electronically managing medical records; 2) Coded in Country, an initiative to locally train and support programmers and entrepreneurs in developing regions working on projects that directly affect their own countries; and 3) the social innovations developed and shared by communities at Catcomm.

In addition, this approach can also build communication networks that are in line with or on top of communication systems already in use by various departments and organizations (e.g., existing structures that librarians use, or between field offices and ministry departments). This would make the enterprise easier to sustain over time because of existing support and has the additional benefit of providing a mechanism for secondary communication to grow out of already high-priority communication channels. Having international organizations, which already require multinational or multiorganizational forms of communication, the platform could provide another important mechanism to both scale quickly and maintain sustainability in the long term. Such compatibility and continuity would ensure higher efficiency, influence, and impact. Separate evaluation schemes would need to be designed to evaluate the usability and utility from each user's perspective. However, the three main challenges to be discussed here are usability and searchability, economic sustainability and intellectual property, and safety.

Usability and Searchability

The EI database is a system for exchanging knowledge and its success is dependent on its ability to support streamlined collaborative exchanges among users. Project-work flows can be observed and studied. The results can then be used to optimize the communication system. Searchability is another primary challenge and will heavily influence content utility to users. The content must be in a format that is the most conducive to learning and users must also be able to identify economically, environmentally, and culturally viable innovations for use in their specific contexts. As such, there is plenty of research demand on how to provide efficient learning services to best support people's needs and ways to incorporate them within the technological capacity (Huang et al. 2010). As database content grows, search algorithms should be refined to produce the highest quality and most pertinent results.

Economic Sustainability and Intellectual Property

The long-term viability of EI would also depend on its ability to generate direct revenue streams. The project could initially launch through contributions, but could evolve to be self-supportive. In the quest to make the EI venture profitable, extreme care would need to be taken to ensure that the open system is not compromised, nor the integrity of the innovations. This challenge can be partially addressed by the open-source models used by Appropedia and advocated by the Open Sustainability Network (i.e., the text is licensed to the public under the GNU Free Documentation License) (Pearce et al. 2008; Buitenhuis et al. 2010; Pearce, 2012b).[5] Companies could upload their product designs, enabling anyone to construct them, yet they could also offer links to their own sites for selling the professionally finished product. Intellectual property law would thus quickly become a primary concern for EI. New licensing systems would likely need to be established and open-source software-licensing models might have to be adapted for free and open-source hardware.

Safety

Just as any other technology or information system can be corrupted, the EI system is vulnerable to unethical acts. Mechanisms would need to be created to prevent EI from facilitating harmful innovations such as weaponry, foreseen hazards, poisonous systems, or other forms of violence and terrorism. Reporting systems would have to be implemented to deter, discover, and disable harmful innovations. These are not as serious as they may seem: Wikipedia and Appropedia are vandalized on a daily basis, but given the ease of notifications and the ability to "revert changes" instantaneously, such attacks are largely inconsequential.

Conclusions

This article has outlined a new research endeavor to create an electronic database to inspire sustainable technological solutions by facilitating knowledge and technology transfer among communities with the support of educational institutions and NGOs. EI would enable communities to assist each other to create sustainable solutions that could significantly improve their quality of life. To this end, such a tool could play a significant role in alleviating poverty,

[5]The GNU Free Documentation License (GFDL) is a so-called "copyleft" license for free documentation. It gives readers the rights to copy, redistribute, and modify a work and requires all copies and derivatives to be available under the same license. The GFDL was designed for manuals, textbooks, and other reference and instructional materials.

reducing disease, improving public health, growing local economies, generating ecologically sustainable enterprise, and establishing social and political justice and stability.

Although the variety of government programs and NGOs is growing to enable innovation and information diffusion among developing communities, clearly the EI concept represents a new trajectory for research and development policy. This article describes a means of systematic global communication among communities and provides an opportunity to rapidly accelerate technological diffusion, reduce redundant research and development, and speed economic growth for communities of all nations but particularly for developing countries. Work is currently underway to develop the needed technology for the EI database, while in parallel, Appropedia is being upgraded with functionalities discussed here and continues to collect and distribute OSAT in wiki form.

References

Alberts, B. 1999. *Science and the World's Future.* National Academy of Sciences 136th Annual Meeting. April 26, Washington, DC.

Arunachalam, S. 2002. Reaching the unreached: how can we use information and communication technologies to empower the rural poor in the developing world through enhanced access to relevant information? *Journal of Information Science* 28 (6):513–522.

Ashraf, M., Swatman, P., & Hanisch, J. 2007. Some perspectives on understanding the adoption and implementation of ICT interventions in developing countries. *The Journal of Community Informatics* 3(4).

Astin, A. & Sax, L. 1999. Long term effects of volunteerism during the undergraduate years. *The Review of Higher Education* 22(2):187–202.

Badamas, M. 2005. Information technology for sustainable development and global competitiveness: comparing curriculum in Africa and America. *World Review of Science, Technology and Sustainable Development* 2(3–4):261–276.

Baytiyeh, H. & Pfaffman, J. 2010. Volunteers in Wikipedia: why the community matters. *Educational Technology & Society* 13(2):128–140.

Bielefeldt, A., Summers, R., Amadei, B., Sandekian, R., Shah, J., Pinnell, M., & Moeller W. 2005. *Creating an Engineering for Developing Communities Emphasis in Environmental Engineering*. Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition. June 12–15. Portland, OR.

Black, R., Morris, S., & Bryce, J. 2003. Where and why are 10 million children dying every year? *The Lancet* 361(9376): 2226–2234.

Bradley, W. & Newberry, B. 2004. *Science and Appropriate Technology for Underdeveloped Countries: One Emphasis in the Master of Engineering Program at Baylor University*. International Symposium on Technology and Society. June 17–19. Worcester, MA.

Bryden, K., Hallinan, K., & Pinnell, M. 2002. *A Different Path to Internationalization of Engineering Education*. 32nd Annual Conference on Frontiers in Education. November 6–9. Boston, MA.

Buitenhuis, A., Zelenika, I., & Pearce, J. 2010. *Open Design-Based Strategies to Enhance Appropriate Technology Development*. Proceedings of the 14th Annual National Collegiate Inventors and Innovators Alliance Conference. March 25–27. San Francisco, CA.

CatComm.org. 2009. CatComm Today. http://www.catcomm.org/en/?page_id=57. September 24, 2010.

Cecchini, S. 2003. Tapping ICT to reduce poverty in rural India. *IEEE Technology and Society Magazine* 22(2):20–27.

Chen, S. & Ravallion. M. 2007. Absolute poverty measures for the developing world, 1981–2004. *Proceedings of the National Academy of Sciences* 104(43):16757–16762.

Chertow, M. 2000. Industrial symbiosis: literature and taxonomy. *Annual Review of Energy and the Environment* 25:313–337.

Cohen, J. & Kinsey, D. 1994. Doing good and scholarship: a service learning study. *Journalism Educator* 48(4):4–14.

Désilets, A., Gonzalez, L., Paquet, S., & Stojanovic, M. 2006. *Translation the Wiki Way*. WikiSym'06, August 21–23, 2006, Odense, Denmark.

Ehrenfeld, J. & Gertler, N. 1997. Industrial ecology in practice: the evolution of interdependence at Kalundborg. *Journal of Industrial Ecology* 1(1):67–80.

Ezzati, M., Lopez, A., Rodgers, A., Vander Hoorn, S., Murray, C., & the Comparative Risk Assessment Collaborating Group. 2002. Selected major risk factors and global and regional burden of disease. *The Lancet* 360(9343):1347–1360.

Fiksel, J. 2006. Sustainability and resilience: toward a systems approach. *Sustainability: Science, Practice, & Policy* 2(2):14–21. http://sspp.proquest.com/archives/vol2iss2/0608-028.fiksel.html.

Gallini, S. & Moely, B. 2003. Service-learning and engagement, academic challenge, and retention. *Michigan Journal of Community Service Learning* 10(1):5–14.

Gates, W. 2000. Shaping the Internet Age. http://www.microsoft.com/presspass/exec/billg/writing/shapingtheinternet.mspx. July 3, 2012.

Giles, D. & Eyler, J. 1994. The theoretical roots of service learning in John Dewey: toward a theory of service learning. *Michigan Journal of Community Service* 1(1):77–85.

Green, M., Wood, K., Duda, F., Van Gaalen, N., VanderLeest, S., & Erikson, C. 2004. *Service-Learning Approaches to International Humanitarian Design Projects: A Model Based on Experiences of Faith-Based Institutions*. American Society for Engineering Education Annual Conference. June 22–23. Salt Lake City, UT.

Gurstein, M. 2000. *Community Informatics: Enabling Communities with Communications Technologies*. Hershey, PA: Idea Group Publishing.

Heeks, R. 2008. ICT4D 2.0: the next phase of applying ICT for international development. *Computer* 41(6):26–33.

Huang, J., Yang, S., Huang, Y.-M., & Hsiao, I. 2010. Social learning networks: build mobile learning networks based on collaborative services. *Educational Technology & Society* 13 (3):78–92.

Keen, C. & Hall, K. 2008. Post-graduation service and civic outcomes for high financial need students of a multi-campus, co-curricular service-learning college program. *Journal of College and Character* 10(2).

King, E. & Hill, M. 1993. *Women's Education in Developing Countries: Barriers, Benefits, and Policies.* Baltimore: Johns Hopkins University Press.

Komives, S., Lucas, N., & McMahon, T. 1998. *Exploring Leadership: For College Students Who Want to Make a Difference.* San Francisco: Jossey-Bass.

Lewandowski, I. & Faaij, A. 2006. Steps towards the development of a certification system for sustainable bio-energy trade. *Biomass Bioenergy* 30(2):83–104.

Limerick, D., Crowther, F., & Cunnington, B. 2002. *Managing the New Organization: A Blueprint for Networks and Strategic Alliances*, 2nd ed. New York: Wiley.

Logiadou-Platonos, S. 1980. *Knossos: The Minoan Civilization.* Athens: D.I. Mathioulakis.

Nguyen, H. & Pearce, J.2010. Estimating potential photovoltaic yield with r.sun and the open source geographical resources analysis support system. *Solar Energy* 84(5):831–843.

Pearce, J. 2001. The use of self-directed learning to promote active citizenship in science, technology, and society classes. *Bulletin of Science, Technology, & Society* 21(4):312–321.

Pearce, J. 2007. Teaching physics using appropriate technology projects. *The Physics Teacher* 45(3):164–167.

Pearce, J. 2009. Appropedia as a tool for service learning in sustainable development. *Journal of Education for Sustainable Development* 3(1):45–53.

Pearce, J. 2012a. Limitations of nuclear power as a sustainable energy source. *Sustainability* 4(6):1173–1187.

Pearce, J. 2012b. The case for open source appropriate technology. *Environment, Development and Sustainability* 14(3):425–431.

Pearce, J., Grafman, L., Colledge, T., & Legg, R. 2008. *Leveraging Information Technology, Social Entrepreneurship and Global Collaboration for Just Sustainable Development*. Proceedings of the 12th Annual National Collegiate Inventors and Innovators Alliance Conference. March 20–22. Dallas, TX.

Pearce, J. & Mushtaq, U. 2009. *Overcoming Technical Constraints for Obtaining Sustainable Development with Open Source Appropriate Technology.* Institute of Electrical and Electronic Engineers International Conference on Science and Technology for Humanity. September 26–27. Toronto.

Pearce, J. & Russill, C. 2003. Student inquiries into neglected research for a sustainable society: communication and application. *Bulletin of Science, Technology, & Society* 23(4):311–320.

Pearce, J. & Russill, C. 2005. Interdisciplinary environmental education: communicating and applying energy efficiency for sustainability. *Applied Environmental Education and Communication* 4(1):65–72.

Rametsteiner, E. & Simula, M. 2003. Forest certification: an instrument to promote sustainable forest management? *Journal of Environmental Management* 67(1):87–98.

Sandekian, R., Bernard Amadei, B., & Pinnell, M. 2005. *A Summary of the Workshop on Integrating Appropriate-Sustainable Technology and Service-Learning in Engineering Education*. American Society for Engineering Education Annual Conference. June 12–15. Portland, OR.

Shore, J. 2005. Work in Progress—Rural Pondicherry's Wireless Internet. http://www.idrc.ca/en/ev-47023-201-1-DO_TOPIC.html. September 24, 2010.

Tcheeko, L. & Ntah, M. 2006. Information and communication technologies and poverty reduction in developing countries: the case of Sub Saharan Africa countries. *Systemics, Cybernetics and Informatics* 4(6):112–115.

ter Horst, E. & Pearce, J. 2010. Foreign languages and sustainability: addressing the connections, communities and comparisons standards in higher education. *Foreign Language Annals* 43(3):365–383.

United Nations Department of Economic and Social Affairs (UNDESA). 2008. *World Population Prospects: The 2008 Revision.* New York: United Nations.

United Nations Development Program (UNDP). 2001. *Human Development Report 2001: Making New Technologies Work for Human Development*. New York: Oxford University Press.

Wasson, B. 2007. Design and use of collaborative network learning scenarios: the DoCTA experience. *Educational Technology & Society* 10(4):3–16.

Weisman, A. 1998. *Gaviotas: A Village to Reinvent the World.* White River Junction, VT: Chelsea Green.

Westheimer, J. & Kahne, J. 2004. What kind of citizen? The politics of educating for democracy. *American Educational Research Journal* 41(2):237–269.

Wing, M., Edwardsen, K., McNair, M., Miles, E., Wilson, K., & Sessions, J. 2007. Developing a sustainable water-delivery system in rural El Salvador. *Sustainability: Science, Practice, & Policy* 3(1):72–78. http://sspp.proquest.com/archives/vol3iss1/communityessay.wing.html.

World Health Organization (WHO). 2002. *The World Health Report 2002: Reducing Risks, Promoting Healthy Life.* Geneva: WHO.

World Health Organization (WHO). 2010. *Millennium Development Goals: Progress Towards The Health-Related Millennium Development Goals.* Geneva: WHO.

Zelenika, I. & Pearce, J. 2011. Barriers to appropriate technology growth in sustainable development. *Journal of Sustainable Development* 4(6):12–22.