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Teaching Science by Encouraging Innovation in Appropriate Technologies for Sustainable Development

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Abstract

Appropriate technologies, those able to be easily and economically constructed from readily available materials by local craftspeople, have a central role in the alleviation of poverty in the developing world. Research and development of these technologies are, however, generally apportioned relatively modest support by the developed world's institutions in part because the operation of many of these appropriate technologies is dependent on relatively well-understood science accessible even to introductory college science and engineering students. This paper describes a project-based assignment utilized for two years that benefited from this opportunity to motivate students to learn both science and innovative problem-solving by offering them a chance to make concrete contributions to the optimization of appropriate technologies for sustainable development. The outcomes of this new method of service learning will be discussed. Finally, the advantages of applying this teaching methodology will be highlighted.

Introduction

This paper will first define sustainability, establish the global need for sustainable development, and provide an ethical basis for utilizing the educational tool of service learning to assist that development. It will then review the pedagogy of service learning with a view to how it can be focused on non-location-specific research and development. It will then refine the concept of appropriate technology and describe a new type of service learning utilizing the concept. This theoretical basis will then provide support for the two-year educational experiment of introducing appropriate technology projects into basic physics courses. The outcomes for the students and state of technology will be discussed and future methods of improving the projects will be outlined. Finally, the advantages of applying this teaching methodology at primarily teaching-based institutions will be highlighted.

Ethical Requirement for Service Learning for Sustainable Development

The concept of "sustainability" is so powerful and so contrary to the status quo that is often diluted in its meaning by definition in different contexts (Filho 2000). Definitions of sustainability concentrating on the environmental aspects generally encapsulate some version of that found in the World Commission on Environment and Development (WCED 1987, 43), where sustainable development is defined as "development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs." In this paper, this WCED definition will be used. It can be generally agreed that this type of sustainability is good and that we should work on development to reach this state. Unfortunately, we are far from any type of sustainable state and as the singular species on the planet with reason, we fail both as stewards of the earth's resources and at the equitable distribution of our resources so that all humans may live in a developed community. Holmes Rolston III, a well known environmental ethicist, puts the current state of affairs in context (1996):

As a result of human failings, nature is more at peril than at any time in the last two-and-a-half billion years. The sun will rise tomorrow because it rose yesterday and the day before, but nature may no longer be there. Unless in the next millennium, indeed in the next century, we regulate and control the escalating human devastation of our planet, we may face the end of nature as it has hitherto been known. Several billion years worth of creative toil, several million species of teeming life, have now been handed over to the care of the late-coming species in which mind has flowered and morals have emerged. Science has revealed to us this glorious natural history and religion invites us to be stewards of it. That could be a glorious future story. But the sole moral and allegedly wise species has so

far been able to do little more than use this science to convert whatever we can into resources for our own self-interested and escalating consumption, and we have done even that with great inequity between persons.

Some, such as the United Nations, are trying to rectify this situation. The UN believes that education can play a huge role in driving sustainable development and have declared this the “Decade of Education for Sustainable Development” (2005-2014) (UNESCO 2006). There is a lot of development that remains to be accomplished—roughly a sixth of the planet’s population continues to live in conditions below those of the Minoan Civilization (circa 2200 to 1450 BC). The Minoans had a community water system, yet today unhygienic and unsafe water place millions of children at risk of death. Ingestion of unsafe water, inadequate availability of water for hygiene, and lack of access to sanitation contribute to about 1.5 million child deaths and around 88% of deaths from diarrhea every year (World Health Organization 2002; Ezzati *et al* 2002). Overall 10.8 million children under the age of five die each year from preventable causes—equivalent to about 30,000/day (Black, Morris, and Bryce 2003). These deaths are largely due to poverty—approximately 1.2 billion people are living on less than \$1 a day and 2.8 billion people are living on less than \$2 a day (United Nations Development Programme, 2001). This enormous challenge to our generation is growing as the world’s population continues to grow. The United Nations Population Division estimates (2006) the medium variant to be over nine billion people by 2050, about 30% larger than today’s population. This is the challenge of sustainable development.

The concept of sustainability is gaining attention in the academic community with several new journals being published on the topic including: *Environment, Development and Sustainability*; *Sustainability: Science, Practice, and Policy*; *The International Journal of Environmental, Cultural, Economic and Social Sustainability*; *The International Journal for Sustainability in Higher Education*; *International Journal for Service Learning in Engineering*; and the new *Sustainability Science*. Books on sustainability and sustainable development are flourishing such as: *An Introduction to Sustainable Development* (Elliott 1999), *The Science of Sustainable Development: Local Livelihoods and the Global Environment* (Sayer and Campell 2003), *An Introduction to Sustainable Development* (Rogers *et al* 2006) and *Innovation, Education and Communication for Sustainable Development* (Filho 2006). However, the vast majority of the university community’s resources are not specifically designed to help resolve the developing world’s problems. This is evidenced by the fact that less than 10% of the world’s health research is applied to the health problems in developing countries, where 90% of the avoidable burden of health problems is located (Commission on Health Research for Development 1990). Although research expenditures have increased since 1990, this 10/90 gap remains and is now a symbol of inequity in global expenditures on research (Burke and Francisco 2006).

The vast majority of research expenditures that are related to sustainability are devoted to scientific and technological research focused on quantifying sustainability indicators and the frontiers of science and social theories—pushing the envelope on large and complex problems. Those areas of inquiry are more likely to win large grants (e.g., NSF sponsored research in sustainability) or be published in the highest impact factor journals. Most articles published in the top journals, for example in medicine, focus on issues that are of importance to primarily wealthy Western audiences (Horton 2003), while research from developing countries is under-represented in the main “international” journals (Marusic and Marusic 2001). This is because research into issues of interest to wealthy audiences is likely to be better funded, better described, and hence more likely to be acceptable to “international” journals while research into issues of more local interest, those that are demanded for actual implementation across different cultures, is likely to be less well funded (Ofori-Adjei, *et al* 2006). Research on how to actually implement sustainable practices for small-scale appropriate technologies or applications in developing nations is simply apportioned significantly fewer resources.

For our purposes here, appropriate technologies will be defined as those that must be able to be easily and economically constructed from readily available materials by local craftspeople in the developing world. Appropriate technologies must meet the boundary conditions set by environmental, cultural, economic, and educational resource constraints of the local community. Although some limited research has been done on a number of appropriate technologies, the diffusion of these innovations has greatly lagged behind the demand in the developing world.

This research dearth is largely caused by the fact that the technologies do not represent a new state-of-the-art, “where-the-dragons-lie” type of research—the kind of interest to granting agencies such as the National Science Foundation, most businesses, or leading research faculty. The principles of appropriate technology are well understood by undergraduate science and engineering majors. This glaring lack of research in an area accessible to undergraduates has an obvious solution—service learning. Service learning is defined as “a teaching method, which combines community service with academic instruction as it focuses on critical, reflective thinking and civic responsibility. Service-learning programs involve students in organized community service that addresses local needs, while developing their academic skills, sense of civic responsibility, and commitment to the community (Campus Compact 2000, 17).” This paper relays the experience of Clarion University using appropriate technology development as a form of service learning in physics classes.

Academically Rigorous Service Learning

Although service learning has a poor reputation in some circles as academically vapid, “how do you feel” scholarship, true service learning can be differentiated from other approaches to experiential education by the explicit intent to benefit both the provider and the recipient of service as well as by its emphasis on both the service provided and the learning that is occurring in tandem (Furco, 1996). The list of studies providing evidence and conclusions that service learning outcomes have been positive for students, faculty, educational institutions, and involved community partners has grown formidable (Bingle and Hatcher 1996, Cohen and Kinsey 1994; Driscoll, Holland, Gelmon, and Kerrigan 1996; Giles and Eyler 1994; Panici and Lasky 2002). Service learning has proved successful to such a degree that the Kellogg Commission on the Future of State and Land-Grant Universities (1999) concluded that service learning “should be viewed as among the most powerful of teaching procedures, if the teaching goal is lasting learning that can be used to shape student’s lives around the world.” (29) The Kellogg Commission’s conclusion focuses on the outcomes for students, a clear strong point of service learning. Students are more motivated, work harder, learn more, and experience lasting benefits from their experience (Cohen and Kinsey 1994, Giles and Eyler 1994, Pearce and Russill, 2005). Unfortunately, experiential-based service learning that unites learning with the real needs of communities is far from ubiquitous. In the majority of disciplines, students are required to replicate memorized information at the expense of higher-order cognitive skills that are associated with critical thinking (Twombly 1992, Cross 1993). Higher education also tends to divorce a knowledge set from its context in society. Disciplinary fragmentation of human inquiry into academic departments and disciplines has magnified the ambiguity inherent in reality (Kochelmans 1979). Students are well-trained to perform specific tasks in their major and gain the credentials that will help them obtain their first job, but they fail to graduate with the skills necessary to solve the complex discipline-spanning problems that face contemporary society (Boyer Commission 1998). In order to be academically rigorous, service learning needs to be concentrated on tasks that bring the discipline specific skills to the students while teaching them how to be real world problem solvers. Appropriate technology research for sustainable development provides such a tool.

Appropriate Technology Research and Development as a New Paradigm of Service Learning

Appropriate technology is technology that is most suitable to the specific location where it is employed. Appropriate technologies must meet the environmental, cultural, economic, and educational resource constraints of the localized community. It is not a precise definition because of the vast assortment of contexts that are available around the globe. E. F. Schumacher argued in the book *Small is Beautiful: Economics as if People Mattered*, that use of appropriate technology tends to promote values such as health and permanence (an early call for sustainability) (1973). Shortly after the publication of Schumacher’s book, Peter Logan argued that physics could play a major role in sustainable development by contributing to the interdisciplinary field of appropriate technology (Logan 1980). Since this time, more work has been done on appropriate technologies for sustainable development, but it is still rarely observed in the standard curriculum or in the research trajectories of today’s schools of higher education. The proven ability of undergraduate students to solve such real-world problems is generally neglected (Pearce and Russill 2003). Yet college students are both capable and enthusiastic real-world problem solvers if they are freed to undertake structured self-directed assignments (Pearce 2001). The operation and fabrication of appropriate technologies for sustainable development are governed by physical

laws taught in introductory physics classes and are well within the scope of college level engineering design courses. Students also have an advantage over the field engineers that currently do the majority of work in appropriate technology. The field engineers may or may not have a solid foundation in the scientific method and physics principles learned in university introductory physics courses. They also do not normally have access to the scientific literature in the university libraries and sophisticated scientific equipment, which can be used for controlled studies of appropriate technologies. By studying appropriate technologies, students can perform the basic research necessary to optimize such devices more effectively than the *status quo* trial and error in the field, while gaining a better understanding of applied science and engineering.

This could change dramatically as there is now a conduit for connecting university student research in appropriate technologies directly to the developing world. The new sponsorship of the *International Journal for Service Learning in Engineering (IJSLE)* by the National Collegiate Inventors and Innovators Alliance (NCIIA) provides an outlet for student research on appropriate technologies and thus offers an opportunity for college students to directly contribute to sustainable development. *IJSLE* is a semi-annual, peer-reviewed, free electronic journal. The *IJSLE* targets manuscripts based on original work of students and researchers with a specific focus or implication for service learning in engineering, engineering entrepreneurship in service, or related service learning pedagogy. For example, in a recent issue of the journal, Weiss, George, and Walker described the process of redesign for a manual shredding machine used to harvest breadfruit in the Republic of Haiti (2006). Their methodology examined each function of the shredder assembly to determine if parts could be eliminated or combined and if there were simpler ways to meet the performance criteria without sacrificing quality. The applied science and engineering skills the students gained from working on the project were only eclipsed by the positive benefits of the research itself. This work resulted in a machine that was easier to build in a developing country, used materials that were more commonly available, had a reduced number of parts, was more robust, was easier to clean and keep sanitary, and cost less to fabricate. A consortium called Enabling Innovations, made up of universities and non-profit organizations, is forming to develop a free-access database to warehouse such basic plans for appropriate technologies that contribute to sustainable development—to make the designs themselves easily accessible. This database will include work of those at the Engineering Projects In Community Service (EPICS) programs, Engineers for a Sustainable World, Engineers Without Borders, and the growing list of excellent engineering and science programs worldwide that are using appropriate technology as a means of service learning for student education and sustainable development.

Integrating Appropriate Technology Development into Science Classes

For the last two years appropriate technology designs have been assigned as an end-of-the-semester project. Students were required to design a physics lab including some form of basic testing around an appropriate technology that they constructed. The inexpensive nature of appropriate technologies allowed students to largely fund the construction of their own devices. The students then studied their devices utilizing the scientific testing equipment in the physics, chemistry, and biology departments (e.g., solar simulators, computer controlled thermocouples, autoclaves, cell cultures, pH meters etc.)

Students, working alone or in groups of two, identified and researched the technical specifications of an appropriate technology that interested them through library research, examples from former students, my own collection of books and articles, and the Internet.

They were then asked to write a project proposal based on the specifications necessary to be later input into an appropriate technology database organized by fields that include: 1) the title of the device or system; 2) an abstract describing the function of the device or system; 3) a list of keywords to describe the device or system (the key words will be used in a search engine in order to locate the device or system); 4) sustainable developmental needs addressed (e.g., food, heat, electricity, clean water, health care etc.); 5) materials needed for fabrication of device and alternative materials if they are not available (e.g., an ideal reflector for a solar cooker might be silvered glass, but a less robust yet functional alternative might be the inner side of potato chip bags); 6) tools needed for fabrication of the device and alternative tools if they are not available (e.g., a Dremel Moto-tool may be the ideal tool for fashioning a more efficient metal stove, but the same stove can be fabricated with a little more effort using a hacksaw blade); 7) skills and knowledge necessary to make the device (e.g., basic woodworking), 8) technical specifications including a

drawing or picture of the device (This is the most important section because the technical description must be detailed enough to ensure that someone could construct the device from the description alone. This is also an excellent method for encouraging students to practice precise technical writing.); 9) estimated costs; and 10) the sources of all information including developmental needs, designs (if they did not design something new), and cost estimates.

These projects were centered in a physics class so students constructed functional prototypes of their devices and designed a laboratory around their devices to test at least one physical principle. The laboratory write-ups were modeled from the conventional laboratories that the students completed all year in class: 1) Introduction-Purposes, 2) Setup, 3) The Physics Theory/Principle(s) to test, 4) Procedure (the procedures include step-by-step laboratory instructions for the experiment, which ideally were detailed enough that a physics student could do the lab without assistance), 5) Data and Formula Sheet for the laboratory, 6) Questions, and finally most importantly 7) Proposed future research to optimize the device. The last section on proposed future research sets the stage for future student independent study projects on the best designs, which can then be integrated into developing world collaborations.

The appropriate technology projects were completed during the final two weeks of classes. Students stored their devices in the laboratory and brought in their lab instructions/questions. They exchanged labs and completed their peers' labs in the same way that laboratories are integrated into the traditional physics curriculum. Two such rotations were included to give students some experience with different devices and different physical theories. In addition to completing the labs, the students provided feedback to their peers to improve their labs for the final turn in date at the end of the semester.

The majority of students based their projects on well-known designs of appropriate technology devices (e.g. solar cookers) from the literature and began the long task of optimizing the devices, while others challenged themselves and tried to develop something new. Overall, students chose a wide range of appropriate technologies and physics principles to study based on their own interests, competencies, and perceived advantages for preparing for the final (i.e., choosing projects testing a principle that they had particular difficulty understanding). Appropriate technologies that students explored included water storage, pumps, and purification systems such as solar water purifiers; stills, pasteurizers and filters; evaporative cooling/refrigeration; cooking and food preparation devices such as stoves/ovens, solar cookers, and food dehydrators; and other passive solar devices and reflectors. Other students looked at transition technologies, those that might not be constructable by local craftspeople but that could help with development or environmental sustainability such as solar photovoltaic systems (Pearce 2002). These projects included electronic balance of systems, batteries, and basic electronics for micro-hydro, solar photovoltaic, and micro-wind power.

Utilizing physics as service has proven successful in the past (Hollinsworth and Day 2000) and therefore it was not particularly surprising that the appropriate technology project was a guarded success. It unquestionably increased the students' motivation to learn physics because they felt as if their work meant something (or at least had the potential to do so). Students invested a lot of time outside of class on the projects—more so than with standard assignments. From discussions with the students it appeared that they understood the base principles that applied to their projects better than before. This was corroborated by a modest increase in exam grades after the project as compared to those before (with an average of approximately a half letter grade) for four fifths of the classes, with one fifth remaining the same. Most importantly the largest improvement was observed in the academically weakest class, whose class average increased by 12% (a statistically significant increase based on a standard paired t test), while the highest achieving class showed no improvement. These results indicate that students who do not learn as well traditionally can benefit more from an appropriate technology laboratory based course, while those students who do well in a traditional classroom are not hurt academically. This could, in part, be from the fact that each student acted as a teacher for his or her lab and thus was highly motivated to learn and understand the material so as not to be ridiculed by peers. The results are guarded because not all of the student work was of high enough quality to consider for publication in either *IJSLE* or an appropriate technology

database such as *Enabling Innovations*. As the program grows, starting students at the step where former students ended may assist in extracting higher quality projects.

Future work that is necessary to improve the program includes the enhancement of lecture materials to cover knowledge about the context in which the developing country finds itself including the culture, language, and sociology. These factors are all of paramount importance in determining how a technology will be adopted by a particular community. Particularly because the assignment gave students the freedom to choose a developmental problem in any geographic area, these social areas of inquiry are beyond the scope of traditional physics classes. This indicates that the teaching methods described in this article could be better optimized in either 1) a multi-class curriculum addressing sustainable development or 2) a more interdisciplinary large credit course (possibly running over multiple semesters) such as science, technology and society (STS) classes, but grounded in hard science. Either of these types of instruction would allow a much more in-depth exploration of the implementation of the technologies to be addressed such as the entrepreneurship, marketability, and commercialization components. Finally, future work is needed to further quantify the improvements observed in student examination grades after completing the appropriate technology assignment.

Additional Benefits for Teaching Universities

At many primarily teaching institutions, research is undervalued (Elliott 1996). This is most striking in the guidelines for tenure and promotion which in some schools, for example, rank attending meetings equally to presenting research findings in the tenure/promotion point system. In addition, at non-R1 schools, the facilities to do state-of-the-art research are significantly lacking and institutional funds are often spent on instructional equipment rather than research-grade equipment.

By undervaluing faculty research at these primarily teaching institutions, a chilling effect is created where fewer faculty members have an incentive to encourage undergraduates to do research, and thus fewer students partake in research projects. A cycle is created where few undergraduates have older student role models that are working on research and therefore research is not a consideration. The end result of this feedback loop is the loss of all the positive benefits of real scientific research and low science enrollments/retention. Benefits of undergraduate research include increased retention (particularly of minorities) (Nagda *et al* 1998), greater gains in research skills, greater research productivity (as measured by papers and presentations), stronger interest in research as a career choice than students who do not participate in research (Kremer & Bringle 1990), greater enhancement of several important cognitive and personal skills, higher satisfaction with their undergraduate education, and higher rates of going to graduate school (Zydney *et al* 2002). Utilizing appropriate technology projects has provided a model to overcome the challenge of doing research at institutions with little research infrastructure. This methodology could be extremely valuable in assisting other teaching-focused institutions to begin to obtain the benefits of applied research at their schools.

Conclusions

This paper established the global need for sustainable development and provided an ethical basis for utilizing the educational tool of service learning to assist that development. It then presented appropriate technology research and development as a new paradigm of service learning and described how appropriate technology laboratories were integrated into the curriculum of five physics classes. The projects were extremely motivating to the students in part because they had an opportunity to contribute to a social service. The students had an overwhelmingly positive attitude toward the assignment, tended to gain in-depth understanding of science issues, and had an overall increase in final exam grades. Finally, the advantages of applying this teaching methodology beyond research universities to primarily teaching-based institutions were discussed and therefore should be strongly considered for mainstream use.

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