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CHAPTER 2
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Introduction

Demands by industry, and by society as a whole, for the knowledge, skills, and abilities of engineers continue to expand and deepen[1]. Educating engineers who can best address those demands is our challenge. The National Academy of Engineering's report 'The Engineer of 2020' forecasts that engineers of the future must not only be trained to be technically competent, they must also possess a certain business savvy, be culturally aware, able to manage complexity, and possess leadership and communication skills. However, it has become increasingly difficult to meet these needs within traditional curricula given constraints such as: limited time, student credit loads, and course content requirements.

It has been known for some time that for the student, "experience-based education creates a powerful learning environment, which results in new educational outcomes" (pg. 121).[2] As a form of experiential education, service-learning (SL) provides a potential vehicle for achieving a diverse range and greater depth of learning outcomes and presents opportunities to address the goals cited above. Service-learning has been defined by Bringle and Hatcher as: "a course-based, credit-bearing, educational experience in which students (a) participate in an organized service activity that meets identified community needs and (b) reflect on the service activity in such a way as to gain further understanding of course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility."[3] Service-learning has been documented as a pedagogy since the 1960s, with roots dating to the early 1900s[4]. However, the implementation of SL within engineering and with proper emphasis on the various dimensions has only been documented since the 1990s. Significant learning outcomes may result outside of courses in extracurricular activities such as Engineers Without Borders (EWB) and Engineers for a Sustainable World (ESW). Therefore, Learning Through Service (LTS) has been used as an umbrella term to encompass both SL and extracurricular activities that yield educational outcomes[5,6].

This chapter will first more carefully define SL and related activities and outline the scope of such activities. Next, the underlying learning concepts which provide the theoretical foundations for service-learning are summarized. Third, examples of the applications within engineering are provided. Fourth, some of the documented learning outcomes and benefits of such activities within engineering are described. Finally, the chapter concludes with a discussion of the need for sustainable and appropriate technology which provides both an urgent impetus for LTS and a readily available opportunity to integrate SL in any engineering classroom.

Definition and Scope of Service Learning and Learning Through Service

Although Bringle and Hatcher's definition of service-learning is often cited, there is a range of learning environments that encompass elements beyond these defined limits or lack some of the cited aspects. Therefore, Learning Through Service (LTS) has been proposed as an umbrella term to include a broad array of activities. In some cases, the lines between learning environments may not be clear; for example, course-based (SL) versus extracurricular activities. Extracurricular activities can have explicit learning goals as well. For example, EWB was born with two primary goals (1) to help disadvantaged communities and (2) to educate students with the appropriate knowledge and attitudes to lead sustainable engineering projects. Similarly, the Institute of Electrical and Electronics Engineers (IEEE) in their Humanitarian Technology Challenge (HTC) and the American Society of Civil Engineer's (ASCE) Body of Knowledge (BOK2) recognize the important role of extracurricular activities in engineering education[7]. The group effort from the American Society of Mechanical Engineers (ASME), EWB, and IEEE to create Engineering for Change (E4C) also clearly supports such efforts. Thus, extracurricular learning that serves communities in need can be viewed as an appropriate dimension within LTS.

Many criteria within Bringle & Hatcher's SL definition are not always rigorously evident in course-based or extracurricular LTS. For example, if a course does not explicitly evaluate whether students have an enhanced sense of civic responsibility after the activity, is it not actually SL? Some debate can be made between intended outcomes (teaching) versus realized outcomes (learning). This is even more challenging given the authentic and variable nature of student learning in the community. Therefore, rigorous distinction between learning environments is not the goal of this section, but rather to outline the range of learning activities that fall within the sphere of LTS.

First, it is helpful to include all of the commonly used terms that fall within the LTS arena; see Figure 2.1[6,8]. Some of these activities have distinguishing elements, but uninformed usage by practitioners means that there are many examples of perhaps erroneous use of each term which tends to blur the lines between these educational practices. Therefore, a spectrum of structures, student learning outcomes, student attitude outcomes, and community engagement lenses can be found in LTS practice. Mooney and Edwards identified six different community based learning (CBL) options which were defined based on six attributes: in community, service rendered, curricular credit, apply/acquire skills, structured reflection, and social action[9]. However, to fall under the LTS umbrella at least two criteria must be satisfied: a community partner is served and students acquire skills, knowledge, and/or affective outcomes.

Figure 2.1 Range Of Educational Methods That Fall Within The Sphere Of Learning Through Service

Four elements have been proposed that should be present in all SL activities, the four Rs: reciprocity, respect, relevance, and reflection[10]. The presence of each of these elements is also recommended in any LTS activity. Each of these elements is briefly summarized below.

From the reciprocity standpoint, both the students and the community should benefit from the activity. The community should have articulated its needs and goals for itself and then see if it can find an academic partner. A balanced partnership is a key component of a successful SL activity. The perspective of a partnership will help ensure that both sides respect one another. Any outsiders (i.e. students) entering a community should respect its traditions, culture, etc. And they should respect that each community possesses knowledge and skills that are of meaning and value. The lack of a mutually respectful relationship will be detrimental to both the community benefits that are realized and the students' cognitive and affective learning outcomes.

Relevance dictates that the service must be relevant to the learning objectives of the course. The service activity must apply, reinforce, and/or extend the key learning objectives of the course. If students are unable to clearly see this relevance, they may be openly skeptical or even hostile regarding the SL requirement. Engineering courses generally have well defined technical knowledge outcomes that are clear to students, but instructors sometimes are less rigorous in specifying the desired professional skills and attitude outcomes. Articulation of the full range of learning goals for each class improved significantly in many programs due to the outcomes-based engineering accreditation criteria of ABET starting in 2000[11].

Finally, the reflection element is requisite to SL in order to activate students' metacognition regarding the learning that has occurred. This is particularly necessary in service-placement type of activities where the learning objectives are not clearly manifest in the activity. However, within the typical project-based service learning (PBSL) applications in engineering, the learning outcomes are generally obvious in the activities being executed (i.e. design, team work, communication). Therefore, some engineering projects for community partners have not included required reflection activities, but have still generally been termed SL. Clearly, properly structured reflection can and should be executed to enhance student learning in these PBSL contexts.

More recently, a number of stages have been proposed by Root and Jesse[12] and endorsed by Learn and Serve America[13] as the standard process for ensuring the quality of a SL experience. The stages (abbreviated as IPARDC) are: (1) Investigation, (2) Planning and Preparation, (3) Action (engaging in the service experience), (4) Reflection, and (5) Demonstration / Celebration. Sustainability of the beneficial community impacts and the SL program itself should also be considered[114]. Although proposed for a K-12 context, the steps in this cycle also seem consistent with a college-level SL experience.

The typical initiation point of a SL activity is that an instructor has identified a learning goal that can be met via community service, and then seeks out an appropriate community partner. However, the Bringle & Hatcher SL definition implies that secondary benefits are derived from SL beyond the specific learning outcome desired, such that students will be endowed with an enhanced sense of civic responsibility and a broader perspective on their discipline. The extent to which all SL courses expect and evaluate students' civic responsibility and disciplinary perspectives to be enhanced is unclear, and frequently does not appear to be rigorously evaluated. This is perhaps driven by engineering educators' focus on assessment of accreditation-required outcomes and specific content-based technical elements. More information on the documented student outcomes from LTS will be discussed later in this chapter.

It is also important to note the range of potential "community" partners in the SL effort. Community partners in engineering are typically non-governmental organizations (NGOs), non-political governmental institutions, municipalities or towns, schools, hospitals or health clinics (typically within developing countries), individuals with disabilities, and for-profit micro-enterprises in developing countries. Student work for corporations and industrial partners is excluded from the definition of SL[4]. Although it should be noted that work with industry partners on projects that are defined by the needs of the community (e.g. energy efficiency and emission reductions in non-energy industries) have been used as SL projects successfully[13].

Theoretical Foundations for LTS

A number of learning theories have elements that seem to explain why LTS will be a powerful and particularly effective pedagogy. This section will highlight a few of the learning theories that are most relevant to the LTS experience. Understanding of these theories helps highlights attributes of an LTS experience that should optimize student learning. Readers are referred to a number of good articles that have discussed relevant educational theories that support the basis of SL in more depth[14,15,16].

John Dewey's theories (circa 1933, 1938) are often listed as a foundation for understanding the attributes of SL that make it a powerful teaching method[17,18]. Dewey's theories point to the power of experiential learning, of which SL is one form. LTS forms the situation where the student interacts with the community environment in a meaningful way from which the student learns and grows. LTS situates the learner in the community in a unique way which helps catalyze the learning process. Dewey postulates five phases of reflective thought[17], which can describe why critical reflection by the students is an important and indispensable part of the learning cycle. Project based learning through the engineering design process maps well to these learning phases, which can be summarized as:

1. A disturbance where an individual determines that routine approaches are insufficient to solve a problem.
2. Problem definition which requires exploration.
3. Analyzing potential methods and resources needed to solve the problem, developing hypotheses.
4. Reasoning which involves thinking through courses of action and hypotheses, to estimate likelihood of success
5. Action to solve the problem.

The added benefit of SL may be seen through Dewey's four criteria for "projects to be truly educative"[17]:

1. a service learning project often generates genuine interest among the students because it addresses a real problem;
2. SL projects are worthwhile because they have intent to create a real positive benefit for specific individuals;

3. SL projects often present problems that demand students' creativity and self-directed learning; and
4. most PBSL experiences generally span enough time (typically at least an entire semester) to allow genuine learning to occur.

SL projects in engineering meet the continuity requirement if students realize that they can build on their previous knowledge to solve the SL problems and also feel that they may reasonably be able to build on these learning experiences in the future[14,15].

Jean Piaget's educational theories are relevant to LTS through the assertion that learning and cognitive development occur when conflict or an uncomfortable situation triggers the active processes of assimilation, accommodation, and equilibrium[19]. Therefore, LTS may provide an unfamiliar experience, leading to discomfort or even personal mental conflict. This part of the learning process points to the importance of placing students in situations outside of their normal experience, whether it is working at a homeless shelter or serving an impoverished rural community in a foreign country via EWB. However, Piaget's theory postulates that learning and growth will not occur from the experience unless the student processes and works through these feelings and conflicts. This reinforces the importance of reflection that was also evident in Dewey's learning theories[16,20].

David Kolb's learning cycle (circa 1984) extends Dewey's concept of the importance of experiential learning[21]. Concrete experiences (stage 1) are followed by reflective observation (stage 2), which leads to assimilation into abstract conceptualization (stage 3), and then active testing and experimentation (stage 4). This testing and experimentation phase provides new experiences, which feeds into additional learning cycles. The cyclic engineering design process is somewhat reflective of this experiential learning cycle. This is particularly true in an authentic LTS project. Experiences with the partner community to understand their challenges are the spark, while the data gathering and structured reflection are also key ingredients in the learning cycle. Stage 3 requires the students to apply basic science and engineering fundamentals to address the problem. The active testing is the application of the design and the determination if changes are needed[15,16].

Paolo Freire has also been cited as posing theories about education that are particularly relevant to service learning[15,22,23]. His writings seem at first most relevant in describing the symbiotic partnership between our students and the community, where both entities can benefit and learn in a respectful environment. This transforms the framework of the learning from a "service" paradigm that seems to imply a power structure of the "server" (student, teacher) and the "served" (the community), to a more balanced relationship. In a similar fashion, the students and instructors involved in LTS tend to rebalance the traditional learning perspective of one-way transmission of knowledge to a student-driven learning cycle. Instructors often find LTS particularly appealing and rewarding as they find themselves learning and growing through the process of facilitating these experiences and partnerships with communities. However, many engineering educators are likely to find Freire's focus on the ideological purpose of education less relevant to their concept of the role of engineering education, and may therefore discount his theories on learning.

Additional educational theories have been described as relevant to SL[24,25]. In all cases, these theories highlight different aspects of LTS that create a powerful environment for student learning. Viewing LTS through these different lenses of educational theory can highlight elements of the learning structure which faculty should build into the LTS experience in order to produce optimal learning. Explicit discussion of SL pedagogy with engineering students may be help alleviate some negative pushback from students as they initially enter this generally unfamiliar mode of learning and are perhaps uncomfortable with some aspects, in particular the requirement for critical reflection.

Applications of LTS within Engineering

There are a number of examples of the application of LTS within engineering. Because LTS often begins at a grass-roots level with a single professor adding SL into a single course, an exhaustive list of LTS efforts in engineering is not possible. However, there are three common types of engineering classes where SL has been implemented: design (any level from first year to capstone design), experimental lab courses, and analysis-based engineering science (i.e. thermodynamics, fluid mechanics). Integration into design courses appears the most common. There are also organizations that facilitate LTS which are very popular with students (i.e. Engineers for a Sustainable World (ESW)).

There are many examples of SL in first year introduction and/or projects courses, such as at the University of South Alabama[26], University of San Diego[26], Virginia Commonwealth University[27], and the University of Colorado[28]. In many of these courses, SL projects are among many choices available to students or selected as the topic for a particular section of the course. Often these courses are very large, which poses coordination challenges. The first-year course at the University of Toronto has over 1000 students in the fall semester, and includes required SL projects[29].

There are also many examples of SL projects in capstone design courses[30]. Civil and environmental engineering programs seem particularly well-suited to community based SL projects due to the traditional nature of projects in these disciplines, with well-documented examples at the University of Colorado Boulder, South Dakota State University, the University of Vermont, and Michigan Technological University[30,31]. Mechanical and biomedical engineering programs often include assistive technology devices in capstone design courses. Examples include Duke University[30] and the University of Massachusetts Amherst[32].

Laboratory courses can provide an opportunity to provide data to communities that they find useful for a variety of purposes. Examples of laboratory courses that include SL are: a transportation course in civil engineering at University of Hartford[33], a surveying course at Union College[34], a materials lab at University of Dayton[35], and an environmental engineering lab at the University of Massachusetts Lowell[36].

Examples of service integration into core engineering courses have been less commonly published. There are a number of examples from the Service Learning Integrated throughout the College of Engineering (SLICE) program at the University of Massachusetts Lowell, including statics, dynamics, thermodynamics, fluid mechanics, heat transfer, and materials courses across five different engineering majors[36,37]. The SLICE program is an example of how a coordinated effort can ease the burden on faculty and lead to widespread incorporation of SL. Their success indicates that SL may be appropriate for any course. Another example is a heat transfer course at Grand Valley State University[38]. However, studies have found that many engineering faculty do not believe that SL is appropriate to core engineering science courses. A survey at MIT found that while 94% of the mechanical engineering faculty mentioned The Product Engineering Process as a course suitable for SL; for Thermal-Fluid Engineering and Mechanics and Materials only 25% and 15% of faculty noted these courses, respectively, as suitable for SL[39].

Beyond specific, individual courses, there are broader curricular efforts (many originally sponsored by the National Science Foundation (NSF)), programs, certificates, and extracurricular organizations that embrace LTS. A few of these programs are listed below. The list is not intended to be exhaustive, but merely to provide some concrete examples. Also note that some programs offer a mixture of courses and extracurricular activities, so the specific examples are only loosely arrayed under each specific category.

Example Curricular Efforts and Initiatives:

1. Engineers in Technical, Humanitarian Opportunities of Service-Learning (ETHOS) at the University of Dayton (http://www.udayton.edu/engineering/ethos/)
2. Service-Learning Integrated throughout the College of Engineering (SLICE) at the University of Massachusetts - Lowell (http://www.slice.uml.edu/)
3. Massachusetts Institute of Technology (MIT) Edgerton Center, Public Service Center and D-Lab: Introduction to Development (http://web.mit.edu/Edgerton/www/ServiceLearning.html (http://web.mit.edu/servicelearning/index.shtml) and (http://web.mit.edu/d-lab/)
4. Entrepreneurial Design for Extreme Affordability at Stanford University (http://soe.stanford.edu/publicservice/courses0607.php)
5. Humanitarian Engineering and Social Entrepreneurship (HESE) at Penn State University (www.hese.psu.edu)
6. Global Resolve at Arizona State University (http://globalresolve.asu.edu/)

7. University of Vermont, Civil and Environmental Engineering, http://www.uvm.edu/~sysedcee/?Page=service/default.php&SM=service/_servicemenu.html

Example Certificates and Programs:

1. Engineering Projects in Community Service (EPICS) started in 1995; members at 20 universities in the U.S. and abroad, and even high school efforts (http://epics.ecn.purdue.edu/)
2. Community Service Engineering Certificate Program (Michigan Technological) (http://www.d80.mtu.edu/Certificate.html)
3. (Humanitarian) Engineering and Community Engagement Certificate Program (Penn State) (www.hese.psu.edu)
4. Master's Degree in Engineering for Developing Communities and Peace Corps (Michigan Technological) (http://www.cee.mtu.edu/peacecorps/index.html)
5. Engineering for Developing Communities (University of Colorado) (http://www.edc-cu.org/index.htm); graduate certificate
6. Ohio State University, Engineers in Community Service (ECOS) (http://ecos.osu.edu/)

Example Extracurricular Student Organizations:

1. Engineers Without Borders (EWB) (http://www.ewb-international.org/)
2. Engineers for a Sustainable World (ESW) (http://www.esustainableworld.org/)
3. Engineering World Health (EWH) at Duke University (http://www.ewh.org/about/index.php); becoming an NGO

It is important to note that the student activities associated with extracurricular student organizations have often crossed into course-based settings. At Rice University, the Civil and Environmental Engineering Department created three courses to complement their EWB activities: project management, sustainable technologies, and a senior-level special problems design course[40]. At the University of Wisconsin – Madison the EWB activities reportedly led to the creation of a course on sustainability[41]. At some universities, EWB projects have formed the basis for senior design projects within the capstone design course (i.e. University of Colorado Boulder, Lafayette College, University of Arizona)[30].

Student Learning Outcomes from LTS

Although there should be a balance between community and students in the learning partnership, the outcomes for students have been much more widely documented than outcomes for the partner communities. Therefore, this section focuses on the documented cognitive and affective (interest, attitudes, and values) outcomes from student LTS participants. In addition, the potential diversity impacts, particularly in regards to recruiting and retention, will be explored.

There is a substantial and yet rapidly expanding body of literature showing that service learning outcomes have been positive for students, faculty, educational institutions, and community partners[13,42,43,44,45,46,47,48,49]. Service learning has proved so overwhelmingly successful that the Kellogg Commission 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."[50]. Research into service learning pedagogy has been maturing quickly. It is now well established that service learning has a positive impact on students' academic learning, moral development, improves students' ability to apply what they have learned in the "real world", and improves academic outcomes as demonstrated complexity of understanding, problem analysis, critical thinking, and cognitive development[51,52,53,54,55]. The largest benefactors of an experiential education or service learning approach are thus students, who are more motivated, work harder (and longer), learn more, and experience lasting benefits from their experience[56,57,58,59,60,61].

Bielefeldt et al.[30, 62] summarized a wide range of student learning outcomes that have been achieved in engineering using LTS methods. This included all of the ABET a-k outcomes[63], many of the additional ASCE Body of Knowledge 2nd edition outcomes[7], and additional attributes. Jaeger and LaRochelle mapped EWB activities with all of the ABET a-k outcomes[64]. Faculty who have incorporated SL into courses have direct evidence of student learning via students' performance on traditional graded assessments, such as homework, lab reports, and exams. There also is interest in evaluating whether SL provides additional learning benefits over other teaching methods. This information is less widely available because it would require a controlled study where some students do not participate in SL activities. The data on the benefits of LTS toward student learning includes primarily indirect evidence that is self-reported by students. There are also anecdotal reports from many engineering professors. There has been less data presented from direct methods used to assess student performance such as graded exams, projects scored using detailed rubrics, standardized tests, or concept inventories. For example, some researchers are exploring whether PBSL provides differential learning outcomes compared to PBL[65]. The sections below highlight some examples of outcomes assessment information; readers are referred to Bielefeldt et al.[66] for additional examples.

Knowledge and Skills Learning Outcomes

First, SL can provide an effective method to teach academic subject matter in core engineering areas such as thermodynamics, fluid mechanics, heat transfer, circuits, and dynamics. For the SLICE program at University of Massachusetts–Lowell, Duffy reported positive results of indirect measures of subject matter comprehension measured by increased grades[37]. Students self-reported being more motivated to learn course subject matter, which is a key ingredient in learning. Students also stated that they voluntarily spent more time on SL tasks. Faculty agreed with the statement that students learn course subject matter better with SL. Holtzclaw reported that EWB students had self-reported increases in confidence levels in basic civil/environmental engineering concepts and principles; however, statistical evaluation of the data was not presented[67].

The widespread implementation of service learning in design courses, has shown documented success in teaching students engineering design[30]. Ariely[68] described the outcomes from a capstone design course in mechanical engineering where there were a combination of service and non-service projects. Student self-evaluations were indicative that the real clients for the SL projects helped students better understand the design process although the statistical difference was only p=0.09. Students who worked on the SL projects did have a significantly higher self-reported appreciation for the ability to help communities as engineers ($p < 0.02$). In addition, it was found that under-represented minorities (URM) students expressed significantly more interest in community service and in using engineering to solve social problems[68]. The SL experience also differentially impacted URM students' belief in engineers' social responsibility[68].

Other common outcomes reported from SL seem to largely result from the team environment and project communication requirements. Blomstrom and Tam[69] looked for significant differences in self-reported gains in content, organization, delivery, team skills, and personal skills in a first-year speech communication course taken by engineering majors. For the 5-factors combined, differences between SL and non-SL were not statistically significant. The service learning group, however, might have a stronger treatment effect based on the changes of the means. The changes in the means were higher in the service-learning subset for each of the five factors. Likewise, the partial eta-squared calculations for each of the five factors were also higher in the service-learning group, indicating that the course had stronger effect on the overall outcome than the non-service learning students. SLICE also found self-reported student gains in teamwork and communication skills as a result of SL[37]. Students in the Purdue EPICS program reported that the most valuable things that they learned from the SL experience were teamwork and communication[70]. Similarly, a survey of EWB members also found self-reported gains in the appreciation of the importance of teamwork[64].

Leadership was posited as a learning outcome from LTS by Ejiwale and Posey[71] but they present no concrete data to support this claim. A specific course "Leadership and Teamwork from Within" for Honors Students at the University of Cincinnati included SL as one of many components (seminars, PBL, a leadership camp). The leadership-related learning objectives were reportedly achieved[72]. Meanwhile, "increased student understanding of and commitment to leadership" was reported as one among many outcomes from an integrated first-year experience that included SL[73]. Leadership was also taught in a first-year engineering projects course via a SL project at the University of California Berkeley[74].

Students self-reported improvement in their engineering skills at the end of the course, including leadership and management skills. In these various examples it was difficult to attribute the leadership gains uniquely to the SL experience as distinct from PBL or other teaching methods.

In a large study of approximately 800 students participating in multidisciplinary projects, Huyck et al.[75] found that service learning projects compared to non-SL projects did not appear to differentially increase the students' self-perceptions of their own competence in communication, teamwork, ethical awareness, or project management. In addition, the researchers found no difference between the students who completed the three structured reflective writing exercises and those students who did not. This provides further support for the difficulty in identifying potential differential benefits of PBSL over other PBL experiences. Although, obviously the PBSL projects had the potential to–and often did–benefit the community partners, the PBL projects had no such capacity.

Thus, the true power of LTS may be its ability to achieve a wide array of learning outcomes in an efficient manner that is equally as effective as other methods that are more targeted. For example, a PBSL experience in a heat transfer course may teach heat transfer principles equally as well as traditional textbook problems. But in addition, the PBSL experience benefits students' understanding of the impacts of engineering on society, contemporary issues, modern engineering tools, communication, and teamwork skills. Beyond these skills, the service learning experience may impact students' attitudes about community service, the professional responsibilities of engineers, and their motivation to remain in engineering. Finally, SL courses have been shown to make a positive material difference in the real world. These ideas of motivation to persist in engineering and the impact of SL to benefit global society are elaborated on in the next section.

Diversity Recruiting and Retention

There has been speculation in the literature that engineering which focuses on benefits to communities and individuals might be more attractive to groups traditionally under-represented in engineering, specifically female and URM students. Support for this notion has been provided by statistics which indicate that women are over-represented by a significant percentage in optional LTS activities such as EPICS and EWB[70,76,77].

In a study of recruiting and retention associated with the SLICE program at the University of Massachusetts Lowell (UML), it was reported that the number of entering students increased 50% in the four years SLICE was in existence[37]. Twenty-three percent of the incoming students reported that SL was one of their reasons for their choosing UML. Although female student enrollment in engineering did not increase, the number of Hispanic students enrolled increased 50%. UML students also indicated that SL increased the likelihood they would remain in engineering. Females and URM students at UML indicated a significantly more positive impact of SL on retention in engineering. Monroe and Lima[78] found that female retention increased significantly at Louisiana State University after a first year course focused on service learning was added into the curriculum; an increase to 86% retention into the second year compared to 50% prior to SL.

The Benefits of Service Learning to Communities

The Need For Just Sustainable Development

Although the sections above have shown the clear benefits from an educational perspective for SL, this does not mean that the assistance engineering students can provide to both local communites and the global community should be ignored. Service learning provides an ideal vehicle for students to apply their academic skills toward this end through engagement and collaboration with marginalized communities.

The need for development is as great as it has ever been, but future development in such marginalized communities cannot simply follow past models of economic activity, which tended to waste resources and produce prodigious pollution[79,80,81,82,83]. For the future, the entire world population needs ways to achieve economic, social, and environmental objectives simultaneously. There is thus a need for just sustainability, which is “the egalitarian conception of sustainable development”(pg. 32)[84]. It generates an improved definition for sustainable development so that it is “the need to ensure a better quality of life for all, now and into the future, in a just and equitable manner, whilst living within the limits of supporting ecosystems" (pg.5)[85]. This new form of sustainable development prioritizes justice and equity, while maintaining the importance of the environment and the global life support system. In order to meet this goal, international co-operation to overcome technical problems is necessary to eliminate poverty and help all the world's people develop as we move towards a just global society.

The present global picture is sobering and demonstrates how far we are from a just, sustainable world: Around 1.2 billion people live on less than $1 a day and 2.8 billion people live on less than $2 a day[86].

- 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[87,88].
- Overall 10.8 million children under the age of five die each year from preventable causes – equivalent to about 30,000/day[89].

The well known environmental ethicist, Holmes Rolston III, puts the current state of affairs in context[90]:

> *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.*

This enormous challenge to our generation is growing – the world's population will probably increase to over 9 billion people by 2050[91]. How do we engineer our future development so that all people, both in developed and developing communities, have basic human needs met and a clean, healthy, and safe world in which to grow and prosper? This is the challenge of creating a just sustainable world for all.

The global community has recognized that we must face the challenge of sustainable development immediately and do so with education. The United Nations has labeled this the "Decade of Education for Sustainable Development" (2005-2014). **Teaching sustainability has become the most important goal in education in this century.** Yet science and engineering education has not even begun to meet the global needs. For example, Al-Khafaji and Morse in their recent international survey of engineering students, found widespread and startling knowledge gaps about many core aspects of sustainable development[92].

Despite this lack of universal sustainable engineering knowledge, there is also a growing list of examples of engineering service learning to teach sustainable design principles, most notably discussed at the American Society for Engineering Education Conferences and the Annual Conferences on Frontiers in Education. Also, although global conditions continue to reflect a marked underinvestment in sustainable development, a growing body of university student work has been shown to solve environmental and developmental problems on a small scale using service learning projects[93,94,95,96,97,98,99,100].

Similarly, although a body of academic work devoted to sustainable development has begun to amass, much of the research conducted at universities is not specifically designed to help resolve the developing world's problems. The vast majority of resources, both mental and economic, are concentrated on 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. However, the less grand questions of how to actually implement sustainable practices across a range of contexts, particularly for small-scale appropriate technologies, or applications, in developing nations is often apportioned significantly less resources for inquiry[101].

Service Learning and Appropriate Technology

Appropriate technology is technology that is most suitable to the specific location where it is employed. It can be defined as any object, process, idea, or practice that enhances human fulfillment through satisfaction of human needs[102]. In the context of the developing world, appropriate technologies must be able to be economically constructed using locally available materials, energy resources, and tools or processes maintained and operationally controlled by the local population. Appropriate technologies must meet environmental, cultural, economic, and educational resource constraints of the localized community.

For example, Weiss, George, and Walker describe the process of redesign for a manual shredding machine used to harvest breadfruit in the Republic of Haiti[103]. 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. 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 make!

It should be noted here that in some cases the most appropriate solution to a community's challenges may involve some components outside of the scope of local production[104]. For example, Ros, et al. describe the establishment of a computer laboratory to provide an education resource to encourage learning and creativity for a children's center in Guatemala[105]. They utilized the appropriate technology of the open source Linux operating system, a free and technically superior alternative to commercial software. Design and implementation of the project covered not only technical areas but also social aspects of computer technology. Although some research has been done on a number of appropriate technologies, the diffusion of these innovations has greatly lagged the demand in the developing world.

Unfortunately for many institutions, the expense of sending large cohorts of students on international service learning trips is prohibitive. Yet, students remain enthusiastic and well equipped to assist in sustainable development. One opportunity to conduct engineering service learning that attempts to overcome this challenge has been developed enabling students to provide solutions to sustainable development problems. This is accomplished using on online tool titled Appropedia.org. Appropedia is the site for collaborative solutions in sustainability, poverty reduction, and international development through the use of sound principles and appropriate technology and the sharing of wisdom and project information. It is a wiki, a type of website which allows anyone to add, remove, or edit content. This method of virtual service learning has been demonstrated in the past to benefit from some of the positive outcomes of service learning, while avoiding the challenges of finding appropriate community partners for every specific learning goal[106].

IJSLE and Opportunities for Students

The creation of the *International Journal for Service Learning in Engineering: Humanitarian Engineering and Social Entrepreneurship (IJSLE)* in 2006 provided opportunities for students to contribute directly to sustainable development and have their work published in a peer-reviewed journal and disseminated internationally. A quarter of a century has now passed since Logan suggested science could play a major role in sustainable development by contributing to the interdisciplinary field of appropriate technology[107]. Yet, the majority of appropriate technology research has been accomplished by time-consuming trial and error methods in the field by individuals without technical backgrounds. The ability of undergraduate students to solve such real-world problems is generally neglected[108]. Yet university students are both capable and enthusiastic real-world problem solvers if they are freed to undertake structured self-directed assignments[109]. Recent examples include: appropriate wheelchairs[110], wind powered LED lighting[111], and corrugated fiberboard cartons for produce[112]. The operations of many of these appropriate technologies are governed by physical laws taught in introductory physics and engineering classes. In addition to a solid foundation in the scientific method and engineering principles, students have access to the scientific literature in the university libraries, which is often not available to developmental agents in the field. The students also have access to some relatively sophisticated scientific equipment (e.g. computer-integrated thermocouples), fully equipped machine shops, which can be used for both prototype and controlled studies of appropriate technologies. Finally, most engineering students have access to very sophisticated design and simulation software tools (e.g. ANSYS for FEA; FLUENT for CFD; Solid Works and Solid Edge for 3D CAD; TRNSYS for transient systems simulation, Cambridge Engineering Selector (CES) technology for engineering materials selection, etc.). However, it should be noted that in order for local populations to have the best access to the designs, open source engineering software should be used and further developed[113]. By studying appropriate technologies students can perform the basic research necessary to optimize such devices, while gaining a better understanding of physical principles and engineering practice.

IJSLE assists in the growth of this burgeoning field by providing a platform for members of the academic community to help harness the knowledge and skills of university students, faculty, researchers, and practitioners to enhance global sustainable development. IJSLE includes examples of work undertaken by service learning organizations, curriculum, and programs.

A Way Forward

Appropriate technologies have a central role in the alleviation of poverty in the developing world. However, research and development of these technologies are generally apportioned relatively modest support by the world's institutions in part because the operation of many of these appropriate technologies is dependent on relatively well-understood science and engineering concepts accessible even to undergraduate university students.

The International Journal for Service Learning in Engineering: Humanitarian Enginnering and Social Entrepreneurship provides an outlet for university students that undertake project-based service learning assignments, and their mentors, to publish their work. Professors at all the world's institutions can capitalize on this opportunity to assist students to learn engineering more effectively by offering them a chance to make concrete contributions to the optimization of appropriate technologies for just sustainable development.

The next few chapters focus on specific types of service learning approaches which address both the educational goals for students, the scholarship activities of faculty, the implementation of design solutions by practitioners, and the enhancement of the lives of those living in marginalized communities. These approaches include: humanitarian engineering, social entrepreneurship, and frugal innovation.

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