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Engineering for Sustainable Energy Education within Suburban, Urban and Developing Secondary Schools

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Abstract

It is crucial that the younger generation be included in the conversation of sustainable development, given the urgent need of a global transition to cleaner energy solutions. Sustainable energy engineering (SEE) taught as early as secondary school can not only increase the number of students that will potentially study engineering to solve global energy issues, but also will spread a social awareness across the students themselves, their families and their communities. This literary review gathers articles that study different methods in teaching SEE across different secondary schooling demographics in an effort to compose a future curriculum that can be used to implement SEE in a range of high-school settings. Some key results found were that most research gaps in SEE were identified in urban schools, whereas college programmes hold many resources that would be beneficial to promoting SEE but are not implemented on a high-school level.

Keywords: Sustainable, SEE element, suburban, urban, developing, demographic, secondary schools, community

INTRODUCTION

On the one hand, developing economies lack access to basic modern energy services while, simultaneously, more urbanized economies are being left behind

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in the transition to cleaner, more sustainable energy solutions. Overall, at least one-fourth of the world's population, 1.6 billion people, currently live without electricity and this statistic has hardly changed in absolute terms since 1970; hence, we now face a two-sided issue—meeting the essential energy demands of billions of people globally while participating in a global shift to clean energy systems that currently accounts for 19.5 per cent of the world's electricity generation (Ahuja & Tatsutani, 2009). With the urban population accounting for 54 per cent of the total global population in 2014, especially concentrated in the lesser-developed areas of the world (World Health Organization, 2014), it is vital that these communities be included in the discussion of clean energy development in their areas, as well as current practices around the world. One area to focus on is their implementation of sustainable energy education (SEE) within their secondary schooling systems.

This review surveys the literature to see what insights can be drawn about the following question: To what degree does incorporating knowledge about engineering sustainability in secondary school, specifically on how students can use engineering to mitigate issues such as energy deficiency and climate change, influence students to pursue engineering as a field of study to make a significant social impact within their communities? We focus particularly on the differences and similarities of findings across different demographic groups, including suburban, urban and developing country schools. We investigate to what degree the literature addresses the question and to what degree there are gaps.

We find that no article answers this specific question in its entirety; we found mainly articles that suggest methods for addressing sustainability education, and a few that address aspects of the question. At the end of this review we suggest some future research that can start to fill in the many gaps.

DEFINING SCHOOL DEMOGRAPHICS

In most sources such as the U.S. Census Bureau (2014), demographics are classified as suburban, urban or rural by the characteristics of a city and its population density. However, for the purposes of this article, we define the urban school demographic as American schools with students primarily of colour and of lower income (Watson, 2011). Developing country schools are classified similarly but in an international, rural setting with even less resources. What we call schools of the suburban demographic draw students primarily from moderate to higher income, and may or may not be ethnically diverse (Debertin & Goetz, 1994).

APPROACH

This literature review gathers readings using a systematic review method to discover which practices work best in teaching various areas that relate to SEE. This study required research from a few disciplines ranging from engineering, environmental education, urban and international education, to sociology. Borrego et al. (2014) suggest analysis conducted in a more algorithmic method to help narrow down the thousands of literature, allowing more objective critique of prior efforts, identifying gaps and proposing new directions for research. Therefore, a variety of databases and web sites were used in our systematic review in an attempt to cover the many practices prevalent in these interdisciplinary fields; some of which include: Engineering Village, ERIC (Education Resources Information Center), ASEE (American Society of Engineering Education), Web of Science, National Society of Black Engineer's SEEK (Summer Engineering Experience for Kids), Engineers Without Borders and the GREEN Program (Global Renewable Energy Education Network).

REVIEW OF LITERATURE ON SUSTAINABILITY AND ENGINEERING EDUCATION

Studies that specifically investigate SEE across several demographic areas are rare. We have included a number of articles that focus on particular sub-categories of SEE in secondary schools. For purposes of this literature review, we define these sub-categories as SEE elements. These SEE elements include:

1. Providing the awareness and motivation that will cause students to take action on global energy issues,
2. Environmental education and research in SEE,
3. Education that integrates realistic energy projects,
4. Problem and project-based learning applied to aspects of SEE and
5. Renewable energy technology education.

AWARENESS AND MOTIVATION TO TACKLE ENERGY ISSUES

When discussing sustainable development among secondary school students, we define this SEE element as the initial steps to assess a student's knowledge about energy issues and encourage an interest in learning ways they can make an impact, whether it is immediate or further down the line, as a field of collegiate study. This section includes research articles that achieve one of the three following goals: (i) measuring students' awareness of energy issues, (ii) providing motivation to monitor their own energy use or take action or (iii) provide the tools to do so. Global climate change can be seen by students as a very massive and daunting matter. As potential future leaders of society that are more likely to witness the transition to global sustainable development, one could argue that it is essential to engage the younger generation in societal deliberations about the current issues. However, Ojala (2012) shows that although many young people show an interest in global problems, feelings of hopelessness, pessimism, denial, as well as inactivity are common. Results from this study report significant positive correlations between having the knowledge and interest in these societal issues and pro-environmental behaviour. Ojala suggests that finding ways to instil hope to encourage the assuaging of the many broad issues within climate change as vital if young people are to take an important role in restructuring the energy system.

Schelly et al. (2012) argue that public awareness of the economic costs and environmental impacts of energy consumption at a local scale has caused individuals and organizations to consider altering their habits. She reports that public schools are an ideal location for energy conservation measures; that schools can reduce their energy use by 20 to 30 per cent with a variety of behavioural and operational strategies. Results from her findings indicate that educational initiatives that engage students in monitoring their energy consumption may lead students to act as role models in their communities. In her study, she found that once the students started monitoring their energy consumption, the faculty, administration and school organization made a shift towards becoming more environmentally responsible. In a similar study, Gottlieb et al. (2012) had students track their energy use (defined as an ecological footprint); this led to the students gaining a deeper understanding of the impacts of their lifestyles beyond the narrow limits of their schools, homes and communities. Including methods similar to the ecological footprint analysis used in Gottlieb et al. (2012) in SEE has the potential to provide schools with the knowledge to plan and manage changes towards sustainability within the school community. In addition, results in Fujihira and Osuka (2009) also show that when students have knowledge of their own energy consumption they have the control to deal with it themselves, in turn enabling students to take action within their own communities and globally.

Riel (2007) would call this ecological footprint method as the start of a cycle defined as collaborative action research, a path of learning from and through one's practice by working through a series of reflective stages that may not only lead to personal and social change, but also affect the community in which it is implemented. Similarly, MacDonald (2012) describes self-monitoring energy use as participatory action research where the empowerment of oppressed individuals to partner in social or economic change encourages a larger capacity of change for all in the community who participate. The same reading recommended utilizing focus groups, participant observations and interviewing methods for data analysis when conducting action research.

In this section, we see some evidence that when students are aware of SEE issues, they are motivated to take action. This is related to our central question in the following way: as awareness leads to action, and engineering is a key way to take action, we hypothesize that awareness of SEE issues, especially when presented in an engineering context, will provide motivation for students to pursue engineering to solve SEE problems.

ENVIRONMENTAL EDUCATION AND RESEARCH IN SEE

This section includes articles that argue the importance of environmental education when promoting SEE, even if in some cases engineering principles may not be included. Articles in this area also suggest alternative methods of teaching environmental education. Weber (2014) states that engineering can be misconceived by students as an area of study that is mainly technical, and only appropriate for those with strong mathematical and scientific backgrounds. Prior research reports that high-school students perceive engineering as a field where they cannot make a difference in the world or help solve major societal problems. The same study showed that by following lessons in environmental sustainability, students became more positive towards the possibility that their engineering studies could affect sustainable development. While sustainability is an increasingly common term and course topic at US colleges and universities, it does not seem to be a common topic in secondary curricula (Kumler, 2011). Still, even on an undergraduate level, programmes have been slow to incorporate environmental sustainability within their curricula; when offered at all it is often treated as an elective. The perception of many engineering academics is that environmental sustainability is non-essential to the engineering discipline, as its multidisciplinary components (i.e., ethics, policy, sociology) are too complex to fuse with a science-based programme (Weber, 2014).

Even if environmental sustainability is incorporated into an engineering programme, Barrett (2006) finds about two-thirds of environmental educational systems fail to relate the issues back to the students on a more local level. These educational systems can be vague, failing to take into account the dynamics of inequality of a student's demographic (Siegel, 2006). The curricula described in these two papers are consistent with what Metz, McMillan, Maxwell and Tetrault (2010) describe as teaching *about* the environment—a general curriculum which displays statistics and images foreshadowing what the world will become if the population continues to consume in the manner it currently does in an attempt to shock individuals into better consumption habits.

In contrast to this, Metz et al. (2010) define teaching *in* the environment as: education where the surrounding environment replicates what is taught in the classroom. An excellent example of this is the GREEN Program, which engages university students in hands-on education at functioning renewable energy facilities, including site visits and study abroad opportunities in Costa Rica, Iceland and Peru (The GREEN Program, 2014). Researchers have found that participatory action research processes, such as GREEN, is potentially empowering, liberating and consciousness-raising for individuals, as it provides critical understanding and reflection of local and social issues (MacDonald, 2012).

The study by Metz et al. (2010) compares environmental educational practices within a secondary school in a Canadian province and one within the Costa Rican public school district. With Costa Rica where over 90 per cent of energy use is from sustainable energy, the curriculum in the school significantly surpassed that of the Canadian school when the study compared hours per week teaching about, in and for the environment. In both contexts, committed, motivated teachers who were aware of and used a wide variety of teaching and assessment strategies to implement environmental education were found, although the Costa Rican teachers were more specifically prepared for their subject area. It would be more difficult to employ environmental education in a school where the community is not invested in better environmental habits. Most existing teaching materials for environmental education are outdated and lacking specifics; they are vague and cannot be easily absorbed if the school does not provide the proper tools or environment to teach the students in (Yan, 2004).

We find that a majority of our research suggests that environmental education plays a vital role in promoting sustainable development; it can increase awareness of the issues and equip students with the technical, ecologic and economic knowledge to implement sustainable development in their individual lifestyles, homes and schools (Jennings & Lund, 2000). Related to our main question, the work reviewed in this section indicates that there are major gaps in tying engineering to the environment and in making environmental education relevant and up to date; it appears that hands-on community relevant education is the most promising approach to this. It suggests that immersing students in projects that have both engineering content and wider sustainability content may be a positive way to motivate students into engineering and into jobs that make a difference.

ENGINEERING EDUCATION INTEGRATED WITH REALISTIC ENERGY PROJECTS

Barret (2006) argues that it is not enough for students to learn *about* or even *in* the environment and become *armchair critics*; they need to get their hands dirty and learn how to take action. This section focuses on studies in which students are engaged in energy projects that improve a school or community. Metz et al. (2010) would describe this action-oriented learning as education *for* the environment. It fits into the engineering design process as a part of developing and designing a prototype or solution (Billiar, 2014). A statewide survey conducted by the Illinois Clean Energy Foundation, found that the vast majority of Illinois residents, from both urban and rural areas, want to see widespread use and development of renewable energy sources such as wind and solar power (Youakim, 2005). This study analyzed a project where engineering students of Northern Illinois University assembled a 1 kW photovoltaic solar system acquired through a grant. 'Not only did this energy system reduce energy consumption and cost, but it allowed for the students to improve their learning and teaching environment themselves and increase energy awareness among the students' (Youakim, 2005). The World Energy Project (2013), a non-profit group that delivers sustainable energy projects to developing country schools, states that once a school begins to generate its own electricity, it is no longer dependent on power from an unreliable grid. Money that used to pay utility bills can now be reinvested in the school to upgrade facilities, buy supplies, hire new teachers or lower school fees for families. Engineers without Borders also excels in this area, as another non-profit organization that partners university student chapters with communities around the developing world in fundamental need of energy and other various basic necessities (Wittig, 2013).

Collectively, the above references discuss opportunities that provide students with the experience of real-life sustainable energy projects. This is intriguing, but, besides the one study, they lack evidence that action-oriented learning increases learning outcomes, awareness or interest in using engineering to promote sustainable development. In addition, all examples are executed at the collegiate level. Thus, whether these hands-on community-based projects lead to higher interest in engineering among secondary students is an open question.

PROBLEM AND PROJECT-BASED LEARNING

In this section, we review papers that study the use of hands-on, team-based projects as well as projects based on current issues in the world as an effective way to engage students in learning sustainable development and engineering. Papers of this section also include methods to employ these projects in classrooms. Billiar (2014) provided a method that infuses the engineering design process into project development in efforts to increase understanding and interest among secondary school students over three consecutive summers. After this 3-year study, a pre- and post-comparison of 15 teachers' ratings increases from 13 to 60 per cent of teachers' seeing their students' competence in the engineering design process. Similarly, the same sample of teachers' ratings increases from 20 to 87 per cent in noting their students convey excitement about engineering. The systematic and descriptive process for curriculum development provides tools for teachers to approach the difficult task of incorporating engineering design process principles into a secondary school environment.

Oppliger (2010) finds that three things are most effective in terms of improving learning outcomes on engineering at the pre-college level. These include project-based learning, blending engineering into an existing science or math curriculum and exposure to an engineering work environment. In addition, the article reports that a continuous issue that high school educators face when developing STEM lessons is addressing problems in the world and providing developmentally appropriate content within curriculum constraints.

Under a High School Enterprise (HSE) programme, Oppliger conducted a 5-year study with 12 demographically diverse schools that applied STEM learning. These schools include rural, suburban and inner city schools from all income levels, first generation college students and high numbers of students from ethnic groups that are traditionally under-represented in engineering. Although there was no data to support their claims, this study reports that there is much evidence that HSE student participants had an appreciation of the engineering projects and the ebbs and flows that accompany the design process. It was apparent that the HSE student body is one anticipated to enter STEM fields of study. Their project-based learning methods, as well as teachers being educated to reinforce the engineering design process, provide a foundation for introduction of design concepts.

In regard to sustainable energy, hands-on sustainable projects play a role in inspiring students to use engineering concepts to take on energy projects in their schools and communities. Adoption of experiments on energy saving and utilizing solar energy helps participants realize the value of using environment-friendly technology (Fujihira & Osuka, 2009). In a study by Toolin and Watson (2010), students of Montpelier High School in Vermont participated in various sustainable projects. Community experts from local businesses also played a role in contributing to the success of the projects by assisting with data collection when gathering information from the Internet was ineffective. After 6 years of this teaching method, results showed that the key project-based learning experiences should include: a driving question that is relevant to a student's life in their local community, collaboration, use of technology, interdisciplinary and cross-disciplinary inquiry, extended time frame and reliable performance-based assessment. Lessons learned from this study were that the teacher should step back and let the students create a way of gathering data and learning for themselves, whether it is through the Internet or from the community; the teacher would then rather serve as a monitor, directing students to the most relevant resources.

These studies indicate that project-based learning is effective in teaching engineering at the pre-college level. When combining this with the results from the other sections, it indicates that project-based learning which incorporates SEE may be effective and motivate students to study engineering.

RENEWABLE ENERGY TECHNOLOGY EDUCATION

This section covers articles that report the importance of renewable technology education to encourage the shift to sustainable development. Pavlova (2009) argues that sustainable development can be conceptualized and used to advance technology education practice:

> It has been argued that valuing the other of both human and non-human nature should be the basis for developing design projects in technology education. In this paradigm, the main aim of education should be the development of a new attitude that is oriented towards a system of social and ecological wealth, rather than the wealth of the consumer society. Only a society that unites people with new values will be capable of sustainable development. As a result, education should provide both an instrument for, and a method of transformation for sustainable development. (Pavlova, 2009, p. 128)

Technological education is still some distance from keeping up with the shift that sustainable technology currently undertakes, yet the challenge must be met if the students' experience in technological education is to remain relevant and beneficial (McGarr, 2010). These readings question whether technology education promotes social and economic progression or profit.

Developing country areas are most in need of the transition to clean energy (United Nations, 2007). Furthermore, millions of rural communities in developing countries still lack access to safe and reliable energy; access to energy is as fundamental to human welfare as clean water, agricultural productivity, health care, education, job creation and environmental sustainability. Rural communities in Nepal spend more than one-third of their household expenditure on energy services (Sapkota & Wang, 2014). The reinforcement of renewable energy education is an effective way to promote renewable energy development (Bin, Wenjuan, Yan & Guangming, 2006). Unavailability of skilled technicians and mechanics has hindered the acceptance of several renewable energy technologies in many areas that users could not get proper repair and maintenance; lack of renewable energy education could, henceforth, hinder not only sustainable development but also job creation (Garg & Kandpal, 1996).

In all, articles suggest that renewable energy technology be included at all levels of education in order to create energy consciousness among the public and provide exposure to the basic concepts of their applications. Some main objectives of renewable energy education commonly described in the readings included enabling students to become aware of the nature and cause of the energy crisis, the various types of non-renewable and renewable sources of energy and their potential capacity and alternative strategies towards solving the energy crisis in the future. In summary, education into renewable energy technology has the potential to lead to sustainable development, but it is important that it be in the broader context. We hypothesize that, by providing a new outlook on how an engineer can create change, this kind of focused education will motivate students to study engineering further in order to apply their skills to sustainable development. A study by Wittig (2013) monitored learning outcomes of collegiate students within an Engineers without Borders community project. In the words of a student within the study, '*Engineering should not be about the biggest building, the money, or the largest structure. For me it is about making the biggest impact to the less fortunate*' (p. 11).

SUMMARY AND ANALYSIS OF THE ARTICLES

Table 1 summarizes the results of the literature review; it displays the number of papers which fall into each category of a SEE element (listed in left column) within a corresponding educational environment (bottom row). Notice how seven of the 27 papers gathered have methods useful for teaching within a SEE element, but are implemented at a collegiate level. Some papers fall into more than one category of SEE element or educational environment. Each study is counted only once within a categories total.

We can see that of the readings gathered, there are limited SEE articles pertaining to urban schools. Furthermore, there were only articles for realistic energy projects implemented at the collegiate level. We also see that studies that include engineering education are concentrated more within project learning and at the collegiate level. Oppliger (2010) was the only article we reviewed that compared across more than one school environment. While results could not measure whether students had a grasp of engineering concepts within the short time of the study, the article reported positive interaction and engagement across both developing and urban school demographics for the introduction and struggle of using the engineering design process.

In regard to our main question raised in the Introduction, there are many articles that provide insight as to which methods and practices work best when implementing aspects of SEE in developing, suburban and collegiate schools. However, there is very little quantitative research on how the methods impact interest in or pursuit of a field in engineering or sustainability.

DIRECTIONS FOR FUTURE RESEARCH

Taken together, the studies above—and the gaps therein—indicate some key areas for research. The majority of papers we found were primarily qualitative in nature and focused on curriculum design. Thus, there is a need for evidence, and especially quantitative evidence, on whether implementing SEE into the curriculum impacts interest in engineering and/or sustainability, and especially whether it impacts the

Table 1 Comparing Literature within each SEE Element and School Demographic

8 (*25%)	**Awareness and Motivation**	Gottlieb et al. (2012), MacDonald (2012), Ojala (2012)	Riel (2007)	Schelly et al. (2012), Fujihira and Osuka (2009)	*Ahn (2014), *Khalaf (2013)
13 (*15%)	**Environmental Education on a Local Perspective**	Barrett (2006) Gottlieb et al. (2012) MacDonald (2012) Metz et al. (2010) Yan (2004)	Siegel (2006)	Fujihira and Osuka (2009), Kumler (2011), Pavlova (2009), Schelly et al. (2012), *Toolin & Watson (2010)	Jennings & Lund (2000), *Weber (2014)
3 (*100%)	**Realistic Energy Projects**	–	–	–	*GREEN Program (2014), *Wittig (2013) *Youakim (2005)
5 (*83%)	**Problem-based Project Learning**	*Oppliger (2010)	*Oppliger (2010)	*Billiar (2014) Fujihira and Osuka (2009)	*Khalaf (2013) *Wittig (2013)
9 (*22%)	**Renewable Energy Technology Education**	Bin et al. (2006) McGarr (2010) Sapkota & Wang. (2014) Singh, D (2002)	–	Pavlova (2009) Garg & Kandpal (1996), *Toolin & Watson (2010)	Jennings & Lund (2000) *GREEN Program (2014)
		Developing Country Secondary School	**Urban Secondary School**	**Suburban Secondary School**	**Collegiate**
	Total Articles	11 (*9%)	3 (*33%)	7 (*29%)	7 (*86%)

Source: University of Massachusetts of Amherst, 2015.
Notes: *Denotes articles that incorporate engineering education. Percentages of total articles that include engineering education are also listed for each category on both axes.

number of students who go on to study engineering. Ideally, studies would include careful controls—for example, studies that include Project-Based-Learning with one community-based renewable energy project compared to a standard project. To the degree that SEE is effective in inspiring interest in engineering, the next step is carefully structured studies to determine which SEE elements are most impactful in increasing the number of students pursuing a career in engineering and sustainable development. This could lead to the design of widely-applicable educational tools.

There is a dearth of studies in urban schools, and, it has been not been shown in any study, that what works in suburban schools may not work in urban schools. Thus, evidence on the impact of SEE in urban schools is of particular interest. Of the total 4-year undergraduate enrolment in 2012, less than 13 per cent of undergraduate engineering students were Black and Hispanic, respectively; as compared to about 56 per cent for white students (National Center for Science and Engineering Statistics, 2014). It would be valuable to measure if incorporating aspects of SEE would lead to more participation from under-represented minorities in STEM fields than students exposed to traditional classroom curriculum. Studies that consider the effectiveness of specific SEE methods across demographics can additionally give insight into how SEE programmes should be designed, especially for under-served students.

A longer-term question is whether incorporating SEE education at the secondary level is likely to lead to more engineering students focused on making a significant impact in their communities. Answering such a question may require a significant longitudinal study, but may be worth it.

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