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Engineers, Development, and Engineering Education: From National to Sustainable Community Development

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In October 2007, Norman Borlaug wrote in *Science* magazine that "more than 200 science journals throughout the world will simultaneously publish papers on global poverty and human development—a collaborative effort to increase awareness, interest, and research about these important issues of our time" (Borlaug, 2007). Borlaug, Nobel Peace Prize laureate and father of the green revolution, was demonstrating that the scientific community is at last taking questions seriously of sustainability and development. Borlaug's own contentious role in the history of "development," however, points to the complexity of the term and the contested role scientists and engineers have played in that history. As engineering education initiatives incorporating sustainable development practices proliferate, it becomes ever more important to understand the historical lessons of development and the contributions of engineers. This paper outlines a history of engineering practice and education in relationship to development, sustainable development, and community development to help those committed to making engineering education relevant to environmental protection and community needs to better understand the challenges ahead.

Keywords: history, engineers, development, sustainability, community development, engineering education

1. Engineers and the Development of Empires

The emergence of engineers, engineering practice, and engineering education has a close connection to the development of countries (Downey & Lucena, 2004; Downey & Lucena, 2005). The first school of engineering was founded in France to support state consolidation and expansion. When countries developed as empires and colonies, engineers worked both for the internal organization and expansion of the empires and in the colonies as agents of imperial development (Mrazek, 2002). For example, Spanish engineers, with significant influence from French military engineers, built military and civil infrastructures in Spanish colonies in the Americas (Galvez, 1996). French engineers worked in Egypt in the construction of the Suez canal (Moore, 1994; Regnier & Abdelnour, 1989). Later British engineers worked in Egypt (Mitchell, 1988) and India (Cuddy & Mansell, 1994) to improve transportation and irrigation infrastructures that would facilitate imperial control and the extraction of natural resources (Headrick, 1981, 1988). German and British engineers worked for their imperial companies in mining extraction in Brazil (Eakin, 1989). Although working under different economic and political relationships between Empire and colonies, these engineers shared a primary concern: *permanent transformation*, i.e., the attempt to transform nature into a predictable and lasting machine (infrastructure) that could be controlled and would last to ensure their imperial patrons a return on investment and display superiority over indigenous technology.

2. Engineers and the Development of Independent Nation-States

As independent republics began to emerge in the world scene, as happened first in the American continent in late 18^{th} and early 19^{th} centuries, engineers from these new nations became preoccupied with mapping the territory and natural resources of sovereign countries, developing national infrastructures (roads, bridges, railroads, canals, etc.), mainly to connect widely dispersed and diverse populations into a national whole and to integrate their productive capacity for national and international markets. They also saw a need to shape engineering education to help meet these ends. For example, in 1820 the U.S. government began training military engineers at West Point. Right after independence in 1821, engineers from Mexico's *Colegio Nacional de Mineria* began mapping their territory and building civil infrastructure (Lucena, 2007). In 1847 and with similar purposes in mind, engineers from Colombia's newly created *Colegio Militar* developed the first national system of roads and built the national capitol building (Safford, 1976), chap 7). Immediately after the creation of the Brazilian Republic (1889), military engineers from the *Escola Politecnica de Rio* connected the hinterlands of the Brazilian Amazon with the rest of the country through an extensive telegraph network (Diacon, 2004).

Quite often, foreign engineers were invited to work alongside national engineers when independent countries did not have the financial capital, in-house experience, engineering education institutions or machinery to build infrastructure projects. For example, French engineers were invited by the US government to develop engineering curricula in West Point Military Academy and build and supervise road construction (Hunter & Dooley, 1989). Francisco Cisneros, a Cuban American engineer educated in Rensselaer Polytechnic Institute (founded in 1824), was invited to Colombia to build the railroad and fluvial transportation systems (Horna, 1992). U.S and Canadian engineers were invited to Sao Paulo, Brazil, to develop the automobile industry and construct urban electric rail transportation (da Silva Telles, 1993). Whether carried out by domestic or foreign engineers, these projects were not conceived with environmental or community sustainability in mind. Nature was a place to be controlled and exploited for other purposes, mainly nation building.

Reflecting on the ulterior purposes of military engineers during the construction of the telegraph on the eve of the Brazilian republic, Todd Diacon writes

> Rondon [the chief engineer] quickly moved beyond a purely strategic rationale for telegraph construction. For him, the key was to develop the region, to populate it with small farmers, and to build thriving towns where none currently existed. He noted of telegraph construction that "more than the military defense of the Nation that every government seeks to secure…we have come to promote the principal necessities of populating and civilizing our Brazil" (Diacon, 2004), p.132).

Engineers such as Rondon were primarily motivated by the economic and political development of their new countries, significantly altering the landscape and integrating indigenous and rural communities into national wholes without much concern for preserving ecosystems or local communities.

3. Engineers and International Development

After WWII and with a new wave of independent countries emerging in Africa and Asia, engineers engaged enthusiastically in development. Engineers from the US and USSR were motivated by ideologies of modernization in spite of their political differences. After 1945, many American and Soviet engineers came to believe that it was possible to develop and modernize the world through science and technology, i.e., to move "traditional" societies from their current stage of backwardness and launch them through a stage of "take-off" by implementing large development projects (dams, steel mills, urbanization). Their hope was that these countries could join the superpowers in a "modern" stage of consumer capitalism (US) or industrialized socialism (USSR). Quickly, this vision was institutionalized in specific postwar plans (e.g., the Marshall Plan in Europe), technical assistance agencies (e.g., US Agency for International Development or USAID), "independent" regional or international development organizations (e.g., World Bank, Inter-American Development Bank), mega development projects (e.g., Aswan Dam in Egypt, Green Revolution in South East Asia, Itaipu Dam in Brazil), carefully conceptualized and disseminated by economists who heavily influenced engineers' thinking (e.g., Rostow at MIT) and adopted by technocrats in the US, USSR, and China alike (Adas, 2006, chap. 5).

During the 1960s, labeled by the UN as the "first development decade," engineers worked in international development projects as key elements of the Cold War. For example, in Egypt, while US engineers built a fertilizer plant in Suez (Mitchell, 2002), USSR engineers worked in the construction of the Aswan High Dam (Moore, 1994). While US engineers worked in the expansion of the Green Revolution in South East Asia (Adas, 2006), USSR engineers participated in the "sovietization" of industrial development in the new East Germany (Stokes, 2000). Engineers' main concerns were to forge a path of development towards modernization and to contain the expansion of communism, in the case of US financed projects, or the expansion of capitalism, in the case of USSR- or Chinese-financed projects. These concerns dictated the location, size, and reach of projects and neglected any consideration for environmental sustainability or autonomy of local communities.

Ironically, concerns for how technologies fitted in local contexts began emerging among engineers working within the military-industrial complex put in place for the Cold War. In the US, a small group of engineers working at the General Electric plant in Schenectady, NY, and teaching at Rensselaer Polytechnic Institute created a group called Volunteers in Technical Assistance (VITA). They became concerned with the development of technologies that were simple and cheap to build, operate, and maintain so they could be deployed in poor villages around the world (Williamson, 2007). Instead of delivering large aid packages or building monumental infrastructural projects, VITA engineers believed that the key to technology transfer was in the diffusion of technical information to help villagers develop technical expertise (Darrow, 1986; Pursell, 2003). Similar approaches were implemented in humanitarian crises by other engineers concerned with the welfare of people in poor regions of the world (Cuny, 1983; Cuny & Hill, 1999).

In the US, engineering education largely ignored these marginal developments. Most of the engineering education initiatives, including accreditation criteria for engineering programs in place since the 1960s, were aimed at making engineering more scientific. Since the rise of the Cold War and the launching of Sputnik (1957), the dominant concern in the competencies of engineers has been mastery of the engineering sciences (Seely, 1999). This concern was fully evidenced in the Grinter Report (ASEE Committee on Evaluation of Engineering Education, 1955), endorsed by the ASEE (American Society of Engineering Educators) Goals Report of 1968, and enforced by the Accreditation Board for Engineering and Technology (ABET), the organization in charge of accrediting engineering programs in the US. The decade of the 1960s in the US ended with a scientific engineering education void of any impetus for reaching out to Third World villages through technology transfer.

4. Engineers and the Questioning of Development

In the US, beyond the exemplary efforts of VITA volunteers, alternative technology practices did not become institutionalized in engineering academic or governmental programs until the US demonstrated its technical superiority to the USSR with the Apollo moon landing in 1969. The celebration of this technological feat coincided with the questioning of the military-industrial complex, the impact of industrial technologies on the environment, and the use of military technology in the Vietnam War. Science and engineering were questioned for their lack of relevance to solve domestic problems (Cass, 1970; Heilbroner, 1970). Efforts at making technoscience relevant to society pressured companies and government agencies to find ways to apply military technologies, such as the systems approach (Dyer, 2000), and academic R&D to societal problems like poverty eradication and urban renewal (Gershinowitz, 1972).

On the international stage, the United Nations and other international organizations shifted their approach to development toward fulfilling basic needs and eradicating social problems (Rist, 2002, p. 162). The questionable outcomes of the Green Revolution, particularly the negative impact of fertilizers and monocultures on ecosystems and local economies, brought widespread attention, probably for the first time, to the long term sustainability of large-scale technical projects (Pearse, 1980).

The "social and environmental impact" and appropriateness of technology to local settings and communities also gained widespread attention thanks to books like Schumacher's *Small is Beautiful* (1973). Engineering societies and schools organized conferences linking appropriate technology and development (American Society of Civil Engineers, 1978; Cook, 1973; Universidad Centroamericana José Simeón Cañas, 1979), while some US universities created programs in appropriate technology, as was the case at the University of California at Davis (Pursell, 1979), and science, technology and society (STS) programs. Many of these programs were developed in conjunction with engineering faculty and attracted some engineering students who were concerned with the social and environmental impacts of technology (e.g., Stanford, Cornell, SUNY Stony Brook, Penn State, Lehigh, MIT, Virginia Tech, and Rensselaer) (Cutcliffe, 1990). In sum, in the 1970s, appropriateness and social and environmental impact emerged as concerns for at least a few engineering professionals, educators, and students.

5. Engineers and the "Lost Decade" of Development

In the 1980s, the rise of neoliberal economics and the decline of the Cold War altered the nature of international development. In the US, the election of President Reagan sparked the elimination of governmental programs for appropriate technology, such as Appropriate Technology International (ATI), part of USAID, and science and engineering programs for societal needs (Lucena, 1989, 2005). The AT movement suffered the consequences of this political change (Winner, 1986, chap 6). The rise of neoliberal economics and neoconservative politics in many parts of the world brought a transformation of international development by eliminating the basic-need strategy and forcing countries into policies of "structural adjustment" where most social programs in health, education and employment would be significantly reduced. International development programs were aimed at dealing with the problems of poor governance, reducing government intervention and spending, and reducing state ownership. Consequently, the UN has labeled the 1980s as the "lost decade for development" after "employment and basic needs strategies…incorporated in the Third Development Decade Strategy were swept off the global and national agendas"(United Nations Intellectual History Project, 2005).

With the disintegration of the USSR and the end of the Cold War, many countries became preoccupied with economic competitiveness, including the former communist countries of Eastern Europe which focused on reconstruction of their Soviet-age infrastructures and economies to "catch up" with the West (President's Commission on Industrial Competitiveness, 1985; Pudlowski, 1997). In the US, engineering societies and educators became preoccupied with enhancing US economic competitiveness, particularly with respect to Japan, which not only was conquering consumer markets around the world but was apparently educating a larger number of engineers than the US (Business-Higher Education Forum, 1982; MIT Commission on Industrial Productivity, 1989). The brief impetus for appropriateness and socio-environmental impact of technology achieved during the 1970s was lost to the geopolitical realities of the 1980s.

6. Engineering and Sustainable Development

Sustainable development (SD) was a trend that developed largely out of the failures of the "development decades" of the 1970s and 1980s. One of the key events in this history was the 1992 United Nations Conference on Environment and Development in Rio de Janeiro (also known as the Earth Summit), out of which came the Rio Declaration (Rosenberg & Thomas, 2005). There are two theories of SD—the weak and the strong. Weak sustainability, also called "constrained growth," emphasizes economic models that do not differentiate between types of capital (between natural resources, for example, and human-made capital). This approach suggests that scientific and technological advancement will address natural resource depletion and emphasizes the importance of economic and social gains in the face of environmental degradation. Due to its reliance on the "technological fix" and quantification of different types of capital, many engineers support this approach. Strong sustainability, by contrast, acknowledges that because of natural constraints such as irreversibility, natural capital cannot always be treated like human-made capital. This approach, also called "resource maintenance," argues for the protection of natural resources even at the cost of some "development opportunities" (Hamstead & Quinn, 2005; Roseland, 2005).

Lacking the nationalistic luster of economic competitiveness, which challenged nations and their technical elites to compete for market shares around the world, weak SD emerged as a marginal preoccupation for engineers. Among a myriad of reports linking technological development to economic competitiveness, one on *Technology and Environment*, by the U.S. National Academy of Engineering (NAE), called for the "creators of new technological developments and policymakers…to develop guidelines and policies for SD that reflect for the long-term, global implications of large-scale technologies and that support the innovation of less intrusive, more adaptable technologies at all levels" (Ausubel & Sladovich, 1989). While economic competitiveness clearly challenged engineers to develop technologies for ever growing markets, SD did not provide the market demand that would justify investments on new sustainable technologies. These markets had to be created through policy decisions at the national level such as those highlighted by President Clinton's Council on Sustainable Development (1993-96) (Zwally, 1996).

Engineering organizations in the early 21st c heeded the call to SD and have begun taking actions, ranging from hosting regional and world conferences to declaring their position with respect to SD, to revising their codes of ethics and requiring members to address SD principles in their work, and creating international professional partnerships such as the World Engineering Partnership for Sustainable Development (Federation of African Organisations of Engineers, 1994; Prendergast, 1993; World Congress on Sustainable Development--Engineering and Technological Challenges of the 21st Century, 2000). For example, in 1999, the American Society of Engineering Educators released a “Statement on Sustainable Development Education.” In addition, as a part of its code of ethics, the American Society of Civil Engineers (ASCE) has declared that its engineers shall “strive to comply with the principles of SD,” which is defined as “the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development." Other professional societies and organizations have followed suit.

Although SD did not challenge engineers to compete in the international arena in the same way that the Cold War did in the 1960s or economic competitiveness has done since the 1990s, it became an interesting problem for some engineers to solve through a systems approach. Engineers appropriated “sustainable development” as an effort to be achieved through the use of technologies to clean up the mess that previous industrial practices had created and positioned themselves as “central players” in the success or failure of this effort (Prendergast, 1993). Interestingly, the systems approach that emerged in the 1950s out of military technological development (Hughes & Hughes, 2000) was favored again as a key engineering tool to solve the challenges of SD. By highlighting the main characteristics of systems engineering, engineers clearly identified that the main constraints in the engineering of SD products or services were cost and time.

During the late 1980s and 1990s, most US engineering educators were preoccupied with the challenges of economic competitiveness and responded mainly through recruitment and retention initiatives (Lucena, 2003). Hence the challenge of SD came to engineering education through the concerns of a small community of activist engineering educators that annually puts together the International Symposium on Technology and Society (ISTAS) of the Institute of Electrical and Electronics Engineers (IEEE). This community, which also includes engineering faculty making incursions into ethics and humanities faculty teaching in engineering programs, responded with the 1991 ISTAS symposium titled “Preparing for a Sustainable Society.” SD became a core theme around which engineering educators proposed new curricula in engineering ethics, economics and the academic field known as science, technology, and society (STS) (IEEE, 1991). Many of these curricular areas had become secondary in engineering programs at a time when economic competitiveness was shaping curricular development.

Outside the US, examples of engineering education for SD can be found in Latvia (1993), the first initiative of this kind to appear in *EJEE*, and in the University of Eindhoven, Netherlands (1996) (Valtere, 1996; Van Kasteren, 1996). In 1994, a New Zealand workshop on “The fundamentals of environmental education in engineering education” was sponsored by the Association of Engineering Educators of South East Asia, the Centre for Advanced Engineering at the University of Canterbury, and the World Federation of Engineering Organizations (Thom, 1996). Other initiatives were being formed around the same time at Delft University in the Netherlands (Lemkowitz, Bibo, Lameris, & Bonnet, 1996), in an environmental management course for professionals in Bahia, Brazil (Clar, 1997), a university-community collaboration at the University of Tampere in Finland (Dyer, 1997), and at Brunel University, West London (Van Der Vorst, 1998). Several of these programs were all the more cutting-edge because they included STS-related themes such as social aspects of risk (at Delft) and ethical dimensions of sustainability (at Brunel) before it was considered fashionable or necessary to do so.

As the end of the century approached, engineering educators incorporated SD in the desired set of knowledge and skills for the engineer of the 21st century (Velazquez, Munguia, & Romo, 1999). The emergence of new accreditation criteria for engineering programs in the US in 2000 facilitated this adoption. Furthermore, the influential *Engineer of 2020* report challenges engineers in the 21st century to adopt the tools for sustainable designs to the local conditions of developing countries in order to ensure equity in the benefits from using these tools across the world (*The Engineer of 2020: Visions of Engineering in the New Century*, 2004, p. 21)

7. Future Steps and Challenges

Since the early 1990s, engineering activities dealing with humanitarian and community development activities have proliferated. Stimulated by the involvement of other professions in humanitarian relief, such as Doctors Without Borders (1971), Reporters Without Borders (1985), and Lawyers Without Borders (2000), engineers took up the challenge and independently organized a number of groups under some form of the name "Engineers without Borders": France's Ingénieurs Sans Frontieres (late 1980s), Spain's Ingeniería Sin Fronteras (1991), Canada's Engineers Without Borders (2000), Belgium's Ingénieurs Assistance Internationale (2002), and others. In 2003 these groups organized "Engineers Without Borders—International" as a network to promote "humanitarian engineering ... for a better world," now constituted by more than 41 national member organizations (http://www.ewb-international.org/members.htm).

Simultaneously, many other engineering activities trying to address the challenges of SD have emerged. There are NGO-driven organizations such as Engineers for a Sustainable World (ESW) as well as student organizations, such as Engineers in Technical, Humanitarian Opportunities of Service Learning (ETHOS). We see the growth of engineering education programs, such as Purdue's Engineering Projects in Community Service (EPICS), Michigan Tech's Masters International Peace Corp Program, University of Colorado's Engineering for Developing Communities, and TU Delft's Project Education in Sustainable Development, and the rise of journals, such as *Environment, Development and Sustainability* (2002-present), *Engineering Sustainability* (2003-present), and *Journal of Engineering for Sustainable Development* (2006-present). Perhaps, recognizing the limitations that foreign and corporate policy constraints impose on the potential of engineers to contribute to humanitarian and SD endeavors, many engineering professionals and educators have ventured into the creation of these new organizations and programs. As has been argued elsewhere, engineering educators involved in these organizations are also motivated by the desire to develop global competencies in their students (Lucena, Downey, Jesiek, & Ruff, 2008).

7.1 The elusiveness of community in engineering practice and education

At the same time, there is an emerging recognition of the need to engage the communities in question in more inclusive and participatory ways. Since the relationship between engineering and development began to take shape, first for their fellow country men and women since the 19^{th} century and then for an international community since 1945, engineering work in local communities has been "top-down," i.e., the planning, design, development, and implementation of projects have been done mostly without consultation with the peoples that these projects are supposed to serve. This attitude toward local and indigenous communities has been reinforced by the ideology of modernization that has motivated most development work since the 1950s (Adas, 2006; Escobar, 1995). Recognizing this problem, social scientists and development critics have been advocating participatory practices since the 1980s to include and engage communities in meaningful participation and equal partnership instead of passive receptivity of development (Salmen, 1987). This call for participation has evolved into a full fledged approach and institutionalized in development agencies under the names of Participatory Action Research (PAR) and Participatory Learning and Action (PLA), sometimes adopted by individual engineers (Burkey, 1993).

Yet these participatory approaches to community development remain elusive to most engineering projects for a number of reasons. Historically, we have seen how engineering practices for development have emerged in alliance with specific foreign policies, located within national and international agencies and organizations, and inspired by the ideology of modernization. This history continues to shape many of the practices of engineers in development projects and the approach that even students take toward communities. One professor involved in the development of the EWB handbook told us that the language in the first edition was condescending toward communities, communicating the idea that "we will go and we will teach them [the villagers] how to be sustainable." One recent article on community service planning for engineering students outlined the steps that students need to take to identify project objectives, select projects, and solicit projects. Student satisfaction and the application of engineering knowledge are paramount criteria while community participation is marginal at best (Evans & Evans, 2001).

7.2 Who is engineering education in SD for?

The relatively few US engineering educators that are involved in educational opportunities in humanitarianism and/or SD have been primarily motivated by the needs of students and curricula. For example, many of these educators want to provide students with an international experience in a "real life" situation, have to comply with accreditation criteria for their engineering programs, particularly those that are difficult to incorporate in engineering courses (e.g., "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context"), and want to make their engineering programs relevant to society in order to increase recruitment and retention. In the United States, in other words, SD is slowly becoming part of engineering curricula as a result of many factors: changes in accreditation criteria, shifts in faculty interests, changes in industrial and political practices context, and an increasing focus on engineering ethics (Manion, 2001).

These are worthy and noble causes, but they potentially place the participatory role of communities as secondary. As one committed engineering professor with many years of experience in student-led community projects recently confided to us,

> What I found is people in the villages are smart, they know what's happening, they know what they need. They may not have funds to do certain things that they want to do, but you know this whole thing of going and doing all this is actually benefiting our students more [than the villagers] because it's opening their eyes. So let's be honest and say 'Yeah it's a good international exposure for our students but do you want to risk these communities?' I don't know. I don't know. I seriously don't know….I still wonder if [we] left [the villagers] alone, if they would be fine.

In other words, SD programs that do not shine a critical, self-reflective light on their work may risk replicating the dangers of traditional development projects which disempowered the communities that they were meant to serve.

Historically, engineering professionals and students are identified primarily as problem-solvers (Downey, 2005; Pritchard & Baillie, 2006). This is highly problematic for community development projects when the dominant approach to problem solving is the Engineering Problem Solving Approach (EPS) learned throughout engineering curricula. As Downey and Lucena (2006) have argued,

> the technical five-step engineering method (Given, Find, Diagram, Equations, Solution) that is still taught regularly in engineering science courses at the core of engineering curricula includes no mechanism for addressing the routine non-technical problem of working with people who draw boundaries around problems in different manners… students who complete hundreds of problem sets on graded homeworks and exams are simultaneously receiving intensive training in dividing the world of problem solvers into two parts, those who draw boundaries around problems appropriately and those who do not. The first group becomes capable of being "right," while the second is, by implication, "wrong." Quality students emerge from engineering curricula knowing that engineering problems have either right or wrong answers, that the chief metric of ability is the frequency that one is right, and that difference is usually a sign of error. In the process, they have acquired solid grounds, seemingly mathematical, not to trust the perspectives of co-workers who define problems differently. In other words, learning the five-step engineering method appears to make a diversity of viewpoints suspect by definition (Downey & Lucena, 2006).

The role of engineers in the challenges and failures of development, as seen in this brief history, suggests to us that sustainable development is a complex term that deserves critical appraisal. We argue, in fact, that SD has significant limitations, particularly when it does not include theoretical and practical considerations of *community*. We would like to see community made central in "sustainable community development" (SCD). As SD projects in engineering education evolve into SCD projects, faculty and students should incorporate communities' histories, voices, concerns, conflicts, knowledges and desires by learning how to listen and recognize value in the perspectives of others, including non-experts. This may require rethinking the preparation students receive to participate in such projects, to include courses in development studies, fieldwork methods, regional history, or others. We suggest that the long-term success and ethical integrity of these projects will largely depend not on their technical components, but on the critical involvement of community members. Including community remains a largely unmet challenge in engineering education; a challenge that hopefully will not become invisible, as happened in the 1960s, or marginal, as in the 1970s, but one that will come to define the core of engineering education.

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