AC 2012-3396: SCAFFOLDING UNDERGRADUATE ENGINEERING DESIGN EDUCATION WITH THE WELLBEING FRAMEWORK

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Scaffolding Undergraduate Engineering Design Education with the Wellbeing Framework

Increasingly engineering design educators articulate wanting to embed social sustainability into student projects. Some educators observe that global calls, such as the Grand Challenges of Engineering and the Millennium Development Goals, foster social consciousness while supporting open innovation environments.[1-4] Engineering design requires an ill-structured problem in a complex context.[5, 6] Professors of engineering design use a range of tools, from industrial sponsorship to flights of the imagination, to develop a context for student design challenges.[7] Increasingly, service-learning programs support engineering students designing for community needs.[8, 9] Some engineering design educators invite their students to design innovations that can alleviate poverty.[1, 10-14]

Even when designing for poverty alleviation, engineers frequently overlook the social context of poverty in order to create working technical solutions.[15] Engineers quickly represent the goal of alleviating poverty as an instrumentally accessible task. A statement like "alleviate poverty" functions as a goal whereas a statement like "filter 20 liters of water per person per day to a potable standard" represents an instrumentally accessible task. When designing to alleviate poverty, students must use a different kind of thinking to connect their instrumentally accessible objective to the goal of alleviating poverty. Therefore, engineering educators must scaffold this thinking for students. ABET, articulating the core competencies developed in undergraduate engineering education, describes this style of thinking as "understanding the impact of engineering solutions in a global, economic, environmental, and societal context."[16, 17] Designing for poverty alleviation facilitates a need to consider the economic, environmental, and social context.

In 2008, the freshmen engineering instructors at Ohio Northern University attended Paul Polak's Distinguished Lecture at the ASEE annual conference. Polak[18] argued the people living in marginalized communities have resources to purchase various products, but the market lacks products that meet the unique needs of people living in poverty. In his lecture, Polak challenged engineers to broaden their conceptions of design. This lecture catalyzed framing the freshman capstone project in a poverty alleviation context. As the professors piloted this innovative course,[13, 19-21] they discovered a need to use design personas and community profiles rather than statistical income measures of poverty.

This paper introduces theoretical frameworks of wellbeing while explaining the program evolution at Ohio Northern in order to support engineering educators developing community engagement programs. The theoretical frameworks of wellbeing[22] synthesize diverse definitions of poverty such as basic needs, human capabilities, basic freedoms, sustainable livelihoods, and happiness over time. These comprehensive frameworks define poverty as the *systematic failure to achieve wellbeing objectives*, mapping to a multi-dimensional understanding of poverty. The wellbeing definition arose from a large-scale participatory process with people living in poverty.[23] People living in poverty experience state of ill being mediated by various factors. *Wellbeing*, or "the good life," consists of material sufficiency, bodily health, social connectedness, security, and freedom to make choices around action.[23] This paper identifies how theoretical frameworks of wellbeing 1) span existing definitions of poverty used by engineering designers working with marginalized communities, 2) guide classroom based student learning, and 3) provide insights for thoughtful community engagement strategies.

Defining Poverty within Marginalized Communities
Defining poverty remains a challenge owing to its tacit dimensions. The World Bank defines poverty as "the inability to attain a minimum standard of living."[24] When trying to alleviate poverty, many people tend towards tacit definitions of poverty that make sense in a given context. Conventional models to poverty alleviation target critical dimensions of securing a minimum standard of living. Copestake finds four basic models used to indicate a minimum standard of living: income, needs, rights, and community.[25] Wellbeing frameworks synthesize these existing models. Neoliberal economic models of international development rely on income-based measures of poverty in an increasingly globalizing labor market.[26-28]. Models that note persistent poverty in rural areas focus on asset-based measures of poverty to ensure households can meet their basic needs.[3, 29, 30] Other models consider that complex localized factors define a standard of living. Some development models see systematic structures of oppression that deny fundamental human freedoms.[31-33] Because international assistance can be seen as a systematic structure of oppression, other models assert that locally-led community initiatives play an essential role in alleviating poverty.[11, 34, 35] Having briefly introduced the four basic models, I will now describe how engineers designing for poverty alleviation have built these four mental models into the design process.

Income first approaches bring together market-led development and globally comparable definitions of poverty. *Income first* approaches for poverty alleviation rely on targeting people living below recognized poverty lines. When Polak interviewed smallholder farmers living on less than 1USD a day about their poverty, the farmers said they were poor because they did not have enough money.[18] He developed a marketing and distribution scheme for pumps that enabled off-season irrigation. According to Polak, increasing the income of these farmers provided a direct route out of poverty. *Income first* approaches also involve better integrating small producers into global value chains.[36, 37] For engineers to engage effectively with *income first* approaches, initial conditions matter. Communities have different livelihood strategies, connectivity to markets, and relational dynamics affecting labor norms and expectations.[12, 28, 38, 39] Said differently, the engineers' role is to ensure that communities have the needed assets to take advantage of a new technology.

Income first approaches have several disadvantages in engineering design for poverty alleviation. First, income poverty only provides a rough concept of potentially relevant geographies.[23] Increasingly, the majority of the world's poorest households are found in middle-income countries because of uneven development and rising inequalities.[40] Additionally, income poverty often separates the developed from developing world because most income poverty exists in the developing world. Second, income poverty interventions often lack regard for contextually appropriate solutions.[41, 42] Engineering efforts can focus indiscriminately on creating agricultural gadgets,[43] neglect risks taken by technological adopters,[44] and overlook the broader sociopolitical contexts associated with job creation. Third, income-based measures of poverty can overlook the multiple dimensions of poverty.[45]

Engineers designing for poverty alleviation frequently incorporate *needs first* approaches. E.F. Schumacher founded the "appropriate technology" movement by calling for technological development that conserved fossil fuels, respected the tolerance levels of nature, and affirmed human dignity.[43] Furthermore, the Millennium Development Goals and their associated targets represent an international commitment towards billions of people who lack access to a minimum standard of nutrition and other basic necessities.[46] *Needs first* approaches have inspired agricultural engineers to work more closely with smallholder farmers,[47] environmental engineers to develop water and sanitation technologies,[3] civil engineers to design novel wastewater treatment systems,[48] and mechanical engineers to craft new cooking technologies that reduce indoor air pollution.[49]

Needs first approaches invite engineers to craft solutions to problems that differentially affect people living in poverty. Yet, engineers frequently fail to consult with the intended users.[33, 50-52] Engineering activities aimed at alleviating poverty frequently involve designing for a stranger[53] rather than as a result of responding to a lived experience, as professional engineers rarely find themselves living in poverty. This approach situates power and agency amongst professionals rather than with local communities,[41] where the intended audience are passive recipients of charity, rational consumers operating within a scope of choices, or active citizens within socio-technical systems.[52] Within *needs first* approaches, engineers can easily lose sight of end users.

Occasionally, engineering design organizations advocate for *rights first* approaches. These societal-led approaches struggle to affirm universal norms.[25] Some engineers fear that technical advancement has left people behind, requiring broad-based commitments to create more human-centered technological systems.[54, 55] These broad-based commitments include acknowledging the centrality of technology in society[56] and providing pathways for greater participation in technical development.[38] Some authors advocate change within the profession such that engineers respect people living in marginalized communities as co-constructors of a new future.[11, 28, 52, 57] *Rights first* approaches have motivated engineers to create stronger adaptation strategies for climate change,[58] begin non-governmental organizations,[55] and bring perspectives of marginalized communities to global technology policy debates.[59]

Rights first approaches invite engineers to be mindful of the interconnections between society and technology. As such, engineers should partner with other disciplinary professionals when advocating for various legal reforms. Engineers working with *rights first* approaches can be constrained by current political priorities. Additionally, engineers have capabilities to connect their global activism to local change. Yet, many technologies help people realize human rights. While the Millennium Development Goals track people with access to information and communication technologies,[46] does a right to information or a right to education translate into the right to a mobile phone? In a time of growing technological access, engineers may benefit from considering rights to empowerment and security.[60]

Engineers working with particular communities frequently use *local first* approaches. These engineers maintain long-term relationships with communities discerning local needs, working with local designers, and constructing local solutions.[11, 50, 51, 61] While *local first* approaches can combine best practices of user-centered design and community participation, engineers must consider both ideological[32, 33, 52] and practical[50, 51, 61, 62] facets of working with communities. Engineering education service-learning programs incorporate *local first* approaches towards selecting community projects.[8]

Observant readers may note clear overlaps between the four types of approaches and assorted engineering activities. The table below highlights some critical strengths and limitations of the four models. A project to bring clean water to a community might use an *income first* approach or a *needs first* approach because clean water may arrive through improved irrigation technologies. Similarly, a project to improve cook stoves may use a *rights first* approach if the intention is to shift gender relations or a *needs first* approach if project desires to improve indoor air quality. The experience of engineering students at Ohio Northern shows that engineering educators cannot rely on one type of approach.

	Income first	*Needs first*	*Rights first*	*Local first*
Strengths	Relevant to conducting global business. Considers economic capacity within communities.	Provides strong thematic objectives for engineering design activities. Many engineers resonate with this approach.	Highlights structural features of communities at multiple scales. Encourages greater community involvement.	Encourages greater community involvement. Provides a context for improvements to technological systems.
Limitations	Requires engineers to make many assumptions about how an innovation increases income. Overlooks structural features of communities.	Often develops piece-meal solutions that emphasize technology over community. Situates power and agency with engineering professionals.	Difficulties arise when connecting policy change to improved technological systems in communities. Can involve considerable political activism.	Requires extended engagement with particular marginalized communities. Travel-based programs rarely provide the necessary community immersion.

Theoretical frameworks of wellbeing offer one way to bridge the gap between approaches. These frameworks situate diverse definitions of poverty such as basic needs, human capabilities, basic freedoms, sustainable livelihoods, and happiness over time in a unified model.[63-65] International development professionals concerned with community-centered development synthesized definitions of poverty to create rigorous theoretical wellbeing frameworks.[25, 66] The wellbeing frameworks have flexibility to privilege the analytical frame that makes sense in a particular design context. Additionally, the wellbeing frameworks define wellbeing processes as "the interplay over time of: goals formulated, resources deployed, goals and needs met, and the degree of satisfaction in their achievement," a definition that connects closely to engineering design processes.[67] Advocates for participation stress repeated contact within communities to gain trust and learn which issues the community considers important.[33, 50, 51] In the next section, I show how instructors at Ohio Northern encountered the limitations of using a single approach. Then I discuss how *theoretical frameworks of wellbeing* might be used to inform engineering design.

Discovering Limitations of a Single Approach at Ohio Northern

The freshmen engineering instructors at Ohio Northern stylized their design challenge upon the axiom, "design for the other 90 percent."[13, 19, 21] The request for proposals invited students "to develop products that will benefit the 90 percent of the people who are poor by helping them out of 'absolute poverty,' which was defined by the World Bank in 1990 as earning an equivalent income of $2 a day or less."[13] Inspired by Polak's ASEE lecture, the instructors adopted Polak's *income first* approach to poverty alleviation.[18] The initial offering of the course showed that students encountered difficulty in gathering information, problem scoping, and evaluating their design. I contend that as instructors supported students, the instructors began to adopt a more holistic innovation framework.

While the instructors seemingly advocated an *income first* approach, they presented a range of approaches within the proposal. The axiom of "design for the other 90 percent" describes the world's poor as the 90% of the population that has "little or no access to most of the products and services many of us take for granted."[68] Cooper-Hewitt's "Design for the Other 90%" exhibition features appropriate technology innovations in shelter, health, water, education, energy, and transport.[68] Engineering design organizations used a *needs first* approach when developing many of these innovations. Additionally, some advocates for socially just forms of medical research highlight the "90-10 gap," a shorthand notation that highlights the mismatch between medical research spending and the global disease burden.[69] "Design for the Other 90%" encourages engineers to extend this idea towards engineering activities, especially in biomedical engineering.[49] This viewpoint supports using *rights first* approaches. When providing guidance to students, the instructors at Ohio Northern University suggested the students propose "new products designed for alleviating poverty in one or more impoverished countries."[13] The instructors cited World Bank definitions where impoverished countries have more than 40% of the population living on less than 2USD a day. Inviting students to think expressly about specific countries has some resonance with the *local first* approaches. From the outset of the project, the instructors used definitions of poverty that supported a range of approaches.

The freshmen students at Ohio Northern University encountered an expansive problem statement. The proposal requires students to undertake several tasks before proposing a product: identify a country, articulate an operational definition of poverty, determine routes to alleviate poverty, and research existing products available to insure their proposal represents a new product. Even taken independently, these tasks can be daunting. End-of-course surveys revealed students found the challenge overwhelming. One student commented, "[Poverty] is such a broad and overwhelming topic that I feel that most of the students including myself missed your message" while another student articulated, "With such a broad topic of 'poverty' it was difficult for us to get a grasp on a single idea."[13] Students operated with prior conceptions about the nature and location of poverty, targeting countries in sub-Saharan Africa.[21] Early student projects suggest students employed a *needs first* approach when developing proposals. During the first offering of the course, over half of student projects focused on clean water access.[21] To deal with these challenges, instructors integrated explicit instruction about poverty, global, and social issues earlier in the curriculum.[13] Furthermore, the instructors started to develop design personas highlighting the realities of people living in poverty to guide student brainstorming.[13, 19] As instructors reflected on what students produced, the instructors provided windows into the lives of people living in poverty to help students produce stronger designs.

Professionals attempting to alleviate poverty should be wary of always seeing the "success" of their projects.[42] New cook stoves or solar-powered lanterns will never, of their own accord, eradicate poverty. However, a new cook stove could alter susceptibility to lung diseases by improving indoor air quality or change household labor dynamics to make it easier for women to take children to health clinics. Conversely, a new cook stove could require fuel not readily obtainable by people at and below the poverty line or increase expectations that women cook complicated meals.[15] The same technology can have markedly different impacts in different social environments. The success of an innovation needs to be evaluated within a complex social landscape. Engineers encounter hazards of fixating on concepts too early. While acknowledging that learning to iterate designs comes with experience, engineering design educators should be cautious of design arrogance. When completing an end-of-course survey, one student described the experience as follows:

> "In less than ten weeks time, our group met, designed, assembled, and is in the process of testing a functioning prototype. Using the engineering design process, our group successfully engineered a solution to a problem half a world away. Even though our design may never actually be used in Niger, our group has discovered it is a very plausible, less time-consuming method of cooking."[21]

While this student rightly celebrates the achievements of the group associated with meeting, designing, and assembling a testable prototype, she or he extends the evaluation to a successful implementation. Equally, the instructors consider using these projects to create international service opportunities where first-year engineering students will "attempt to implement, and document the implementation of, selected designs from the first-year capstone course."[13] As engineers at Ohio Northern gain experience in working with particular communities, the engineers should to see how their innovations fail over time. Using integrated theoretical frameworks of wellbeing may support further learning by engineering service-learning initiatives at Ohio Northern and elsewhere.

Using Theoretical Frameworks of Wellbeing

Theoretical frameworks of wellbeing define poverty more broadly as *the systemic failure to achieve wellbeing objectives*.[63, 67] This integrated definition provides students with analytical frameworks for contextually informed design. The wellbeing approach incorporates three primary design elements. First, it focuses on the important expertise of people living poverty rather than on externally-based "expert" opinion ungrounded in the local context.[23] Second, it illuminates the community dynamics.[70] Third, the breadth of wellbeing objectives facilitates interaction with policy makers and enables a rich combination of wellbeing objectives that might inform creative design brainstorming.[71]

Development professionals working with wellbeing frameworks seek to understand change at both the household and community level. These frameworks consider that wellbeing has material, social, and human dimensions that can be objectively and subjectively assessed.[65] An enumerator can number such things as homes with tin roofs, water tap stands, children enrolled in school, latrines, village council meetings, people with firearms, clinics, and migrant workers. But making sense of these numbers requires deeply engaging with people in the communities.[72-74] Wellbeing approaches foster greater community engagement to understand how a particular community has changed, is changing, and desires to change. I now discuss how theoretical frameworks of wellbeing can support classroom learning of engineering students.

Engineers designing for poverty alleviation need to connect their engineering activities to their goal of alleviating poverty. The engineers need to define poverty and propose potential pathways for change. A wellbeing approach provides alternative supports to students needing to define and identify routes out of poverty.[63, 67] The approach focuses designers on lived experiences of poor persons, rather than on "expert" opinion. Because the wellbeing approach articulates poverty as a failure to achieve certain localized objectives, designers can begin work with these localized objectives in mind. Discovering localized objectives requires information gathering.

The wellbeing framework helps engineers gather information about communities. As a context-rich framework, wellbeing analyses try to make the community visible.[70] Wellbeing analyses employ research methods that require explicitly describing the method. Because wellbeing researchers desire to effect social change, the researchers actively decide what information to make accessible to policymakers. The reports of the Wellbeing in Developing

Countries[71] initiative describe four different countries spending less than 35 pages describing any one country. For example, the Ethiopia country report contains 106 bullet points that make clear to the reader that Ethiopian people living in poverty rely nearly exclusively on farming livelihoods, rich farmers tend to employ poorer farmers for a range of agricultural labor, the communities lack services for pregnant women, various groups compete to control resources, protecting land rights represents a significant concern, women and girls work very long hours to complete domestic work, children lack nutritional balance, the social dimensions of the country undervalues industrial jobs, and Ethiopians assign low social status to jobs related to making and selling alcohol. The wellbeing approach articulates so many *potential* wellbeing objectives at the outset that engineering students can leverage *any* combination of wellbeing objectives as their core engineering design objectives. Therefore, the wellbeing approach provides information that supports divergent thinking processes of design brainstorming.

Engineering design occurs across many levels.[7, 75, 76] The entire process continuously iterates. One characteristic of expert engineers is searching for ways to improve their solutions.[77] Evaluating designed concepts, whether through prototyping or through revisiting the problem definition, fuels this iteration. Over time, engineers learn to iterate through various designs, treating each design as a learning opportunity. Theoretical frameworks of wellbeing can help engineers evaluate their designs.[67]

Conclusion

In this paper, we have discussed how engineers design for poverty alleviation. Traditionally, engineers have relied on models that assign unique priority to one dimension of poverty such as income, needs, or rights. While many engineering organizations have used these models to bring positive change to communities, successful efforts feature flexible engagement with specific communities to ensure the innovations match with the context. The freshmen engineering design professors at Ohio Northern University have adopted a flexible learning approach to craft a course where students design for poverty alleviation.

As Ohio Northern revised their course design, the revisions began to align more with *theoretical frameworks of wellbeing*. These frameworks could offer guidance to the freshmen engineering professors at Ohio Northern and other engineering educators engaging various communities. Theoretical frameworks of wellbeing provide analytical tools that integrate diverse perspectives of poverty. These frameworks help assess how a community functions and where communities fail to achieve their wellbeing objectives. Local objectives guide the design process and help match proper innovations to proper contexts. Wellbeing frameworks could help identify communities, both domestically and internationally to contextualize bringing particular innovations to “scale.” Because wellbeing frameworks combine material, social, and human dimensions, these frameworks provide critical insights when understanding “successful” innovation efforts.

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