Engineering for the Middle of Nowhere (CCE)

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Abstract

Humankind is on the verge of extinction—our life support system, the earth, no longer able to accommodate current human activity. To survive, radical changes in infrastructure and lifestyle are required to ensure future supplies of water, food and energy. First year, first semester students exposed to intractable, open-ended problems, set in resource constrained environments learn to think far beyond accepted practice. Unexpected criteria instinctively emerge as fundamental to all professions and provide the framework for minimalist, sustainable solutions.

Introduction

The Cooper Union's EID101, *Engineering Design and Problem Solving*, class is taken by all incoming engineering students, each instructor free to teach the engineering design process through complete immersion in a student-centered learning environment of their own choosing. A significant yet rewarding challenge, there's nothing like the excitement of standing with your students next to a physical entity created from their imaginations and hands-on labor—the frustrations of the engineering design process forgotten, communication the key to success.

Over a 12-year period, we exposed students to the broader aspects of engineering through design for the extreme poor in resource constrained environments. Projects included a light source for those living in the dark; shelters from garbage for those living on the streets; biodegradable shelters for refugees; standalone crop systems for maximum food yield; and a live-in, living laboratory to explore the coupling of human and natural systems [1]. Complete prototypes or modules were constructed; two were field tested in West Africa by class participants [2].

Combining a rapid introduction to the rigors of engineering design, technical writing, contradictory datasets, prototyping, risk, failure and compromise, EID101 is a class like no other. In finding their voices, students crave intervention by the instructor to provide the *right* answer or *be told what to do*. Through *spinning their wheels* in open-ended, inconclusive class discussions, students discover the iterative and collaborative nature of engineering design. Asked to share ideas and justify rejected approaches, many encounter lack of success for the first time—the instructor treading a fine line between failure as an integral component of the engineering design process and lack of progress arising from limited knowledge and skills.

For those studying engineering when telephones were connected to copper cables, and the college computer had its own building and a diet of punched cards, the practice of engineering was accessible. It was easy, and often necessary, to tinker to fix leaking faucets, maintain old cars and repair anything that ceased to function as expected. The invasion of electronic circuits has introduced *opacity* into function, building a wall between the user and the machine.

The world has also changed markedly: the most significant challenge of our time being the conflict between humankind and the planet in a bipolar world. One has equity, stability, advanced technology and an abundance of materials; the other seeks affordable food and safe shelter, is subject to abject poverty, and often struggles to escape oppression. Together, one in seven goes to bed hungry, one in six lacks access to safe drinking water, just one in five has access to a clean light source and approaching one in a hundred is now classified as a refugee—the remainder consuming natural resources at rates faster than they can be replenished. Further complicating this inequality are the proximate consequences of climate change. Whilst the increasing frequency and severity of warnings might appear new, back in 2008, Sir James Lovelock wrote "*Whatever we do is likely to lead to death on a scale that makes all previous wars, famines and disasters small. To continue business as usual will probably kill most of us during the century* [3]." More recently James Hansen and colleagues presented a bleaker scenario in 2016 in which "*There is a possibility, a real danger, that we will hand young people and future generations a climate system that is practically out of their control* [4]."

Approach

We need radical changes to the core principles of design, for, as John Sterman noted "*there is no purely technical solution for climate change. .... we must now turn our attention to the dynamics of social and political change* [5]." Engineering design must now accommodate the conflicting demands of scientific, societal, cultural, environmental and sustainable needs. Today's engineers must do more with less, live with the land, and use what's at hand, in the least invasive and most efficient manner, to build accessible, functional, naturally driven human support systems.

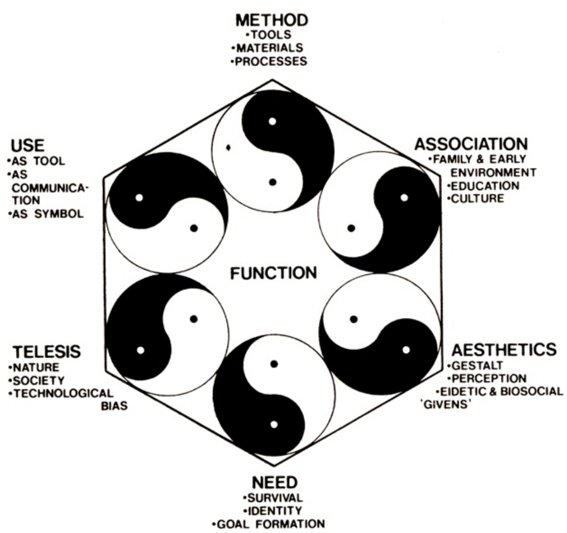

Figure 1 Design Function Complex [8]

Presenting insoluble, intractable, open-ended problems to a heterogeneous, random mix of first year, first semester students, engenders the response "*What can we possibly contribute?* [6]" Mandated to engage the world and its problems [7], students are forced to think far outside their comfort zones, to reevaluate familiar practices and accepted norms. Resource access and usage, habitat, lifestyle, culture and social justice instinctively emerge as integral and fundamental to all professions. Students comprehend that there are no purely technical solutions; they discover design criteria that naturally incorporate minimalism, sustainability, biomimicry, aesthetics, that match function, materials and manufacture to climate, culture and place of use, and that attend to the real needs of all—this holistic approach to design first introduced by Victor Papanek, a Cooper Union graduate, in 1984 as the *Function Complex* [8], shown in Figure 1.

Practicalities prevent location of the class in a resource constrained, rural community living in extreme poverty, so other routes were sought to place students in the shoes of those whose infrastructure they seek to improve. Our goal was to assist students gain insight to, and empathy for, the inhabitants of the target communities enabling discovery of "*approaches ... open to the* *unexpected, and able to see into, and out from, the predicament of the rural poor themselves.* [9]" For this, we were fortunate to have contact with communities in East and West Africa, mentors in the same locations and a program to support extension of these projects to Africa.

Execution

In the first week, each instructor presents their project—the class is then split into equally populated sections with 25 to 30 students, self-selected through preference. Section class time is used for extensive discussion, sharing research and ideas through written submission and oral presentation, and prototype critique. Section presentations for midterms and finals are critiqued and *graded* by the entire class and the results subsequently shared.

This section's classes started with a series of exercises that seeks answers to question after question: *who and where*—to build a picture of the geography and infrastructure, resource availability, climate, culture, habitat, way of life and community organization; *why*—to understand the reasoning for the project; *how*—to figure out the information required to implement a solution. As the answers emerge, students comprehend that inputs to engineering design are almost infinite, that available data do not always correlate, and that loose specifications are a major hinderance. The intrinsic beauty of an *insoluble* problem is that an infinite number of solutions presents so many approaches. Intractable challenges allow deep immersion into design, enabling a connection to engineering in its purest and most holistic form.

During the initial one-month research period, students are switched into different groupings to change dynamics and help them get to know each other. This concludes with an introduction to Homer Atkins and Jeepo, fictional engineers in *The Ugly American* [10], who, working with poor, resource constrained communities, teach us important concepts and provide role models to approach the final design. Students then organized themselves into groups, working as a single team, that addressed design, materials procurement, test, manufacture, delivery, operation and so on. Giving the class complete responsibility for, and control over, their project proved very successful—the students taking proud ownership of the outcome. Fortunately, there was always a cluster of individuals willing to take on the challenging role of the *management or coordination* team. From the outset, it was clear that this lineup was essential in facilitating communication between the groups to ensure that information was shared and overall deadlines met.

Projects

The approach described was introduced in 2006 with a challenge to design and build a rechargeable lantern for the poorest of the poor, that could be used as a flashlight, for general lighting and for reading, that ran for two days on a single charge, and that cost <$10; supply lines, manufacture, delivery, installation and operation implicitly included. With surprise and delight, we witnessed the class embrace the challenge. Quickly deciding to share resources by powering the lanterns from a central, solar powered, charging station, they turned soda bottles into parabolic mirrors embedded in bamboo cylinders into working lanterns. Pitiful in the practical sense, these early prototypes were immensely attractive in another—the design philosophy incorporated the elements sought. The first prototype system was installed in Ghana in 2007 and the project continues to this day as a 501c3, SociaLite Lighting Systems Inc. [11]

In 2008, looking to provide useful shelter for the poorest of the urban poor, the Reuse of Available Garbage for Shelter (RAGS) project was born—the design and circulation of a template for the construction of a functional, climate responsive self-build habitat using universal, freely available garbage—plastic bags and bottles, cardboard, newspaper and plasticized food containers. RAGS is off grid; provides a comfortable interior environment using passive heating and cooling; incorporates facilities for the collection, purification and storage of water, and the collection and disposal of human waste. Having proved the necessary structural elements such as the floor, walls, roof, windows and tarps in 2008, succeeding classes developed the ideas to build a 3:2 scale model in 2010—a full scale version vetoed by administration.

Encountering the appalling conditions endured by endless streams of refugees across sub-Saharan Africa in 2011 through the plight of those living under plastic sheets supported by twigs in Mogadishu, we realized that hundreds of thousands in flight might benefit from better emergency shelter. RAGS became RAMESSES (the Reuse of Available Materials, Energy, Supplies and Structures for Emergency Shelter), a locally sourced biodegradable shelter kit available in large quantities on short notice for self-build by those on the move. The design, addressing extreme affordability and minimal environmental impact, had to be incredibly robust from a perspective alien to most outside the region. It had to accommodate both the immediate needs of refugees—personal security, protection from the elements, insects, wildlife—in addition to the intangible demands of a space within which dignity and self-determination can be nurtured and restored. The solution had to meet these needs within the severe restrictions imposed by available materials, the political and cultural environments, and the trauma of the displaced individuals.

Figure 2 RAMESSES, Mentao UNHCR Refugee Camp, Burkina Faso (July 2014)

Starting with a biodegradable alternative to the traditional UNHCR tunnel tent, better matched to place of use, RAMESSES comprised a geodesic bamboo dome covered with a close fitting, natural, breathable skin. A waterproof *umbrella,* integral to the roof, rolls down to cover the exterior in the event of heavy rain. Working with Malian refugees, students from the original class built two prototype RAMESSES in the UNHCR Mentao Refugee Camp in Burkina Faso in the summer of 2014 (Figure 2). Although the knowledge gained gave us RAMESSES 2.5, the political situation precluded further visits. In 2017, returning to our original idea of a portable, completely biodegradable shelter for those in-flight, manufactured close to the point of end use, RiFSK (Refugee in-flight Shelter Kit) was born and is still very much alive today.

Taking a break from shelter in 2012, we started GAIA—a standalone, crop growth system to deliver fresh fruit and vegetables from seeds and waste biomass. Designed to produce the maximum yield per unit volume, these off grid machines were intended to operate year-round in the harshest environments with no external infrastructure. After two years addressing this difficult challenge we segued into the coupling of human and natural systems by investigating a Live In, Living Laboratory— L^3, a volume enclosed by an imaginary membrane in which the impact of every single human activity on the surrounding environment was measured and characterized—the overall intent to design a habitable space with minimal intervention.

Assessment

Students discover that *right* answers are elusive and difficult to quantify in impoverished, resource constrained, culturally unfamiliar and geographically remote environments. Conventional metrics for success and failure take on new meaning—assessment is quantified by the quality of student participation in class discussions and critiques, their engagement with technical writing and oral reporting, their contribution towards the final design and build, and ultimately *have you learned from, and actively participated in, every stage of the engineering design process?* In their final assignment, a 4-page analytic response to *"What is Your Understanding of Engineering Design and the Engineering Design Process?"*, students, free and actively encouraged to critique any aspect of the class and teaching without penalty, were able to share their innermost reactions. In their candid responses many concluded that they *"now understand what it is to be an engineer and why I chose engineering"*.

Outcomes

Students arrive in this class as high school kids and emerge as undergraduates having lived the engineering design process—having learned to listen, gained the confidence to give voice to their ideas, accept and provide critical feedback, take risks and fail. Constrained to use the resources and indigenous expertise to hand, these students have demonstrated the ability to deliver viable solutions to open-ended problems that satisfy a very different set of criteria. Exposed to an environment inhabited by communities with poor to non-existent infrastructure where the facilities and resources we take for granted are either in short supply or don't exist, students connect to the essence of engineering and comprehend that an abstraction of calculations can have very real impact. The most rewarding outcome of this class is that all the projects remain active in various incarnations—kept alive for years by students who have come to understand that one of the roles of an engineer is "*to recognize the struggles of the seemingly distant and help those who, through no fault of their own, can no longer help themselves.*" [Courtney Chiu, ChE '21]. What better outcome could an instructor ask for?

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References

[1] *The Cooper Union's SEA^{2}M^3*. (2018). Excellence in Innovation Competition. Phi Kappa Phi. Accessed: 09/23/19. [Online]. Available: http://bit.ly/2l5stZU
[2] T. J. Cumberbatch, YouTube. RAMESSES EOYS 2015 3. Accessed 10/31/19. Available: https://youtu.be/n5iQTQfniMI.
[3] J. Lovelock, "A Geophysiologist's Thoughts on Geoengineering," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* vol. 366, no. 1882, pp. 3883-3890, 2008.
[4] J. Hansen *et al.*, "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous," *Atmos. Chem. Phys.,* vol. 16, no. 6, pp. 3761-3812, 2016.
[5] J. D. Sterman, "Risk Communication on Climate: Mental Models and Mass Balance," *Science,* vol. 322, no. 5901, pp. 532-533, October 24, 2008 2008.
[6] S. Shellenbarger. *The Power of Unsolvable Problems*. (2016). The Wall Street Journal. Online: Dow Jones & Company Inc. Accessed: 09/23/19. [Online]. Available: https://on.wsj.com/2kxnYa7
[7] J. Scheffran, M. Brzoska, J. Kominek, P. M. Link, and J. Schilling, "Climate Change and Violent Conflict," *Science,* vol. 336, no. 6083, pp. 869-871, 2012.
[8] V. J. Papanek, *Design for the Real World: Human Ecology and Social Change*, 2nd ed. New York: Van Nostrand Reinhold Co., 1984, pp. xxi, 394.
[9] R. Chambers, *Rural Development: Putting the Last First*. London; New York: Longman, 1983, p. 246.
[10] W. J. Lederer and E. Burdick, *The Ugly American*, 1st ed. New York: Norton, 1958, p. 285.
[11] J. Gay, J. Tan, and O. S. Hong, *Lighting People's Cities*, First edition. ed. 2014, p. 126