Lessons from Senior Design and a Shifting Interpretation of Appropriate Technology

Dr. Greg S Mowry, University of St. Thomas

Dr. Mowry was raised in Iowa and is currently resides in Minnesota. He earned a BS and MS in Metallurgical Engineering from Iowa State University. While working Dr. Mowry continued his education through a non-thesis MSEE degree program at Stanford University that focused on analog electronics and micro-magnetics. Later, while leading the advanced recording head design teams at Seagate Technology, he earned his Ph.D. in Electrical Engineering and Physics from the University of Minnesota. Dr. Mowry spent 25 years in corporate America as an inventor, team builder, R&D scientist, and engineer. His work focused on Nano-technology (both design and processing), materials engineering, micromagnetics, laser optics, and biomedical engineering. Dr. Mowry is also an entrepreneur with experience in several technical startups. He is named on 40 patents along with multiple publications in four different technical fields. In 2003 Dr. Mowry joined the School of Engineering at the University of St. Thomas. He teaches ME, EE, and Physics courses at both the undergraduate and graduate levels. He is the Director of the MSEE program, which has a power emphasis, and the Director of REAL – the Renewable Energy and Alternatives Laboratory. He is the recent recipient of a major $2.1M microgrid research project from the Xcel Energy Renewable Development Fund. Dr. Mowry's research interests vary widely. His current research is focused on reliable, robust, and economic microgrids, alternative energy systems, power electronics, graphene, and biofuels. Microgrids have a wide variety of commercial and humanitarian applications. Humanitarian microgrid projects require non-traditional design approaches since their operation requires minimal human intervention and maintenance. Furthermore, users typically become dependent on the reliable operation of these systems hence premature failures can have serious negative consequences.

Dr. Camille M George, University of St. Thomas

Camille M. George is the Associate Vice Provost for Global and Local Engagement at the University of St. Thomas in St. Paul, MN (USA) and an Associate Professor of Mechanical Engineering in the School of Engineering. Camille George has two Bachelor's degrees, one in Liberal Arts from the University of Chicago, and one in Fluids Engineering from the University of Illinois at Chicago, a M.S. and a Ph.D in Mechanical Engineering from the University of Illinois at Chicago and the University of Minnesota, respectively. Currently, she is interested in global sustainability and engineering for the developing world. Dr. George has worked on projects in the Caribbean and in West Africa. Her projects combine her expertise in thermodynamics and heat transfer with the preservation of food, the cooling of space in hot dry climates, and empowering women's cooperatives to better manage their natural resources.

Lessons from Senior Design and a Shifting Interpretation of Appropriate Technology

Gregory Mowry
Director of Renewable Energy and Alternatives Laboratory
School of Engineering

Camille George
Associate Vice Provost of Global and Local Engagement

University of St. Thomas
St. Paul, MN, USA
gsmowry@stthomas.edu
cmgeorge@stthomas.edu

***Abstract* — In this paper we describe how engineering-for-society and the participatory design process is integrated into our senior design program. Two ongoing projects, the 'Mali Sorghum Project' and the 'Ethiopian Injera Project', are discussed as a means of illustrating how the engineering requirements and constraints, the cultural aspects and gender roles, and the economic and business challenges found in material resource poor populations are addressed in this integration process.**

Keywords—Development engineering, humanitarian engineering

Introduction

Undergraduate engineering programs in the United States require an engineering design experience, often described as, 'senior design', as part of the ABET (the Accreditation Board for Engineering and Technology) accreditation process. The ABET Definition of Design is,

> "Engineering design is the process of devising a system, component, or process to meet desired needs. …... The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specification, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system description. Further it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact."[1]

Senior design is an apprentice-like involvement and the highlight of the undergraduate engineering experience. Most projects are sponsored by local industries or motivated by the needs of the department or a faculty member. Since 2003, UST has tried to offer at least one of its senior design projects to consider the needs of material-resource poor people at the base of the economic pyramid. These projects often bring to life the '*realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact'* in a transformative way.

Students attempt to design practical solutions to global problems. They are faced with the economic realities of people from a different society and culture. The senior design group must struggle with designing for an unfamiliar community. Concurrently, the community is asked to co-create with the engineering students which for them is an unfamiliar process as well as an unfamiliar community. The faculty and the on-site collaborating organization or project sponsor must facilitate and guide the cultural learning required for good group communication. Despite the evidence that groups are different from each other, we none-the-less have observed that our senior design students tend to believe that deep inside all people are the same. In fact, as they are generally not aware of other countries' cultures, the seniors tend to minimize or ignore cultural differences. Since they are surrounded by other students and people who tend to think alike, they subsequently may be blind to the impact of these assumptions. This leads to misunderstandings and misinterpretations between people from different countries. In order to be able to have respectful cross-cultural relations, we have to be aware of these cultural differences and students must be guided to approach economic, safety, and reliability factors through an unfamiliar cultural lens. We must acknowledge that our 'universal knowledge' is only universal within our own culture. At UST we introduce students to Hofstede's cultural dimensions theory[2] to shed light on these differences. The six-dimension model is used to give a general overview and an approximate understanding of other cultures. Distinctions between 'Individualism vs. Collectivism' and 'Masculinity vs. Femininity' are particularly important for our students.

Invariably the students acknowledge that 'base-of-pyramid' communities have been underserved by the engineering profession. This realization engages the students in their project on a deeper moral level. The students' professional responsibility to the customer becomes amplified as issues of global fairness and the just distribution of resources become internalized. By engaging with populations outside their everyday experience they are asked to examine and confront their own privileged status and their world view. These projects push the students to consider issues that are usually discussed only in the context of the social sciences or the humanities.

Many of the *Peace Engineering* projects at UST have been focused on innovations in appropriate post-harvest processing and on utilizing grid electricity more effectively.[3,4] Two of these social impact projects are described in the next section, followed by a discussion on the unique integration challenges facing senior design projects with realistic constraints that are far from the students' sphere of experience. These projects often require feasibility considerations that include gender roles and adoption risks not normally covered in the standard senior design curriculum. The paper concludes with a reflection on what constitutes "appropriate technology" and how development engineers need to consider the relative benefits of locally produced or locally assembled products in maximizing societal impact.

Project Background

A. Mali Sorghum Project

The 'Mali Sorghum Project' is a joint project between the University of St. Thomas (UST) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).[5] A sorghum hybrid was developed by ICRISAT through a decade long participatory collaboration between subsistence farmers in Mali and scientists from ICRISAT. The hybrid yields acceptable amounts of sorghum grain, the primary product of traditional sorghum farming, and sweet juice, the primary product of sweet sorghum.

Currently in sub-Saharan Africa, sorghum is one of the most important subsistence cereals.[6] It is the only viable food grain for many of the world's most food insecure people living in ecospheres characterized by semi-arid and sub-tropical climatic conditions. Slow cooked with water, sorghum porridge is eaten by over 70 million people across the Sahel-Saharan states.[7] Sweet sorghum is a varietal of sorghum that does not produce much grain but is grown for its sweet stalk. It is consumed as a sugar treat much like sugar cane. In contrast to the hectare scale farming of grain-bearing sorghum, an average farm family may plant only one or two rows of sweet sorghum.[8,9]

There is no history of sweet sorghum stalk post-harvesting in sub-Saharan Africa, consequently the century-long historic processing of sorghum juice in the United States was used as a baseline and reference. In the United States, sweet sorghum stalks are crushed and the fresh juice is concentrated by approximately a 10:1 volume reduction via water removal into shelf-stable syrup. Sorghum molasses is a lucrative boutique product used as a honey, maple syrup, or liquid sweetener substitute. Sorghum syrup is a natural product that unlike refined sugar, uses no chemicals in its manufacture. It is a source of calcium, magnesium, phosphorus, potassium, zinc and vitamin B-6.[10]

The new sorghum hybrid was bred by ICRISAT to be a dual-use crop which simultaneously yields acceptable amounts of both sorghum juice and sorghum grain. However, there are several engineering challenges that must be solved in order for Malian farmers to realize the additional crop-benefits of sorghum juice. Unprocessed and fresh sorghum juice has a short shelf-life of a few days. The shelf-life of the fresh sorghum juice can be greatly extended by a pasteurization-like heating process. The water removal process that transforms sorghum juice into sorghum syrup is energy intensive and in a region that has largely been deforested, methods of open pan thermal evaporation by biomass fire are not considered sustainable. Students were challenged to design a safe, reliable, ecological, and affordable alternative water reduction method for sub-Saharan subsistence farmers to concentrate sweet sorghum juice into syrup.[12,13,14] The project research to-date is ongoing and points to the challenge of developing an economically viable and scalable evaporation process that is not energy intensive.

B. Ethiopian Injera Project

The 'Ethiopian Injera Project', was a project brought to UST from a member of the Ethiopian diaspora. Injera has sometimes been described as the 'national bread' of Ethiopia; a staple food consumed daily by over 90 million people.[15,16] Traditionally, the bread is made from a fermented batter poured onto a very hot clay surface heated by an open fire.[17] In the urban areas of Ethiopia, it is estimated that the power consumed by existing Injera 'electric cookers' (~ 6 kW per cooker) consume approximately 60 – 70 % of the Ethiopian hydro-based grid-power.[18] The project objectives were to design an energy efficient (~ 2 kW) electrically powered Injera cooker (a 'mitad') for commodity-scale volume production and sales that would further business development in Ethiopia via direct employment. The students were challenged to design an affordable energy efficient mitad (Injera cooker) for urban consumers that if adopted, would also free up significant percentages of available grid power for other uses.

Discussion

A. Challenges in obtaining customer and engineering specifications

At the heart of senior design is the establishment of customer and engineering specifications for a client that ultimately translate into parameters that the deliverables must meet. Obtaining realistic constraints is a challenge when working across cultures – both technically and culturally.

In the Mali project, ICRISAT had a long-term working relationship with several farmers groups and facilitated on-site discussions between the senior design students and both male and female subsistence farmers. These participatory design meetings were very important in helping the students understand the context and operating conditions for the project. The student team was asked to design or recommend capital equipment for post-harvest processing with the requirement that it fit into the current labor practices of the sorghum harvest. A part of the project was having the students and faculty spend time with the farmers and associated groups in Mali where the boundary conditions and needs could be personally assessed. The farmer groups supported the adoption of a two-income crop. The farmers envisioned a processing system that could be transported by donkey carts to the fields. Men would cut and crush the stalks (most likely in the field) while women would concentrate the juice (most likely at a village or central processing location). There would be no grid-level electricity available. We guided the students to respect the economic realities of the farmers, their sensitivities to gender roles, and their impression of appropriate technology. The meetings between the students and the farmers fostered student discussions of the inordinate differences in access to both material and energy resources.

As engineers, we determined the need for significant energy input to stabilize the raw sorghum juice and remove water from the raw juice in the process of transforming sorghum juice into sorghum syrup. This led to multiple competing challenges in meeting the customer specifications at an economically viable scale; i.e. at the hectare farm scale vs. garden scale.

The first senior design team designed a linear-trough style solar thermal concentrator that could be stacked on a donkey cart and set up on a walking path.[19] The cultural aspects and gender roles were respected by the senior team in their deferential design. The students successfully 'checked off' many boxes for "appropriate technology" from the perspective of portability, simplicity, and size. The small scale troughs used renewable solar energy and could be manufactured, controlled, and maintained by the community. However, economic analysis led to the conclusion that while this system could economically process garden-scale volumes of sorghum juice, the system did not scale appropriately to hectare-scale farms.

At UST, we have learned through experience that projects take several iterations of student engagement. A single senior design team is insufficient for a comprehensive solution. To move forward, projects must be supplemented by in-depth efforts from individual undergraduate and graduate research students or continued over multiple senior design teams.

In addition to the initial senior design research, a second follow-on undergraduate engineering summer research team tested the human-scaled solar thermal system and concluded that a solar concentrating solution would always have serious safety issues related to heat and concentrated solar energy in the visible spectrum and was too inefficient and impractical to have a substantive economic impact on the community.[20,21,22] Processing only small batch volumes in a day, the design failed from a practical point of view in that it could not process juice quantities at the tens of hectares scale. The economic and business challenges were also not solved. These conclusions indicated that we needed to re-visit the original customer specifications.

To process tens-of-hectares of stalks we began to critically consider modifying existing small scale commercial systems common to the maple syrup or sugar cane processing industries. To maximize impact, it may be more appropriate to consider system solutions with higher capital and operating costs, or solutions that need more extensive local training or labor rearrangement.[23,24] We discussed with our student team the need for development engineers to explore solutions that use a pre-existing supply chain (ex. incorporate a diesel generator as a power source to run a low pressure evaporator) or have proved their safety, reliability and durability in other locations (ex. the use of biomass as a fuel source using open pan evaporators). We strongly acknowledged the need for village level participatory design to ensure community adoption, however, we also recognized the challenge of obtaining realistic customer specifications with regards to capital costs or process scale.

In summary, the first small scale solar system designed by the senior team was portable, affordable and respectful of the current labor practices. Unfortunately, that system could not process sorghum juice into molasses at an economically viable scale.

B. What are the unique aspects of designing in a different culture?

In the Injera project, the students did not travel to Ethiopia but interviewed and interacted with members of the Ethiopian diaspora as cultural liaisons and co-creators. Female users impressed upon the senior design team the importance of a uniformly hot cooking surface temperature as the key to making perfect Injera bread and that all traditional mitads have a cooking surface made from a red clay.

The first senior design team strove to respect cultural traditions and designed a modern appliance around the customary terracotta cooking surface. Their hybrid-mitad design combined both old and new technologies; a red clay cooking surface was placed over an aluminum plate heated by electric heating coils. The design met the energy usage specifications and the students emphasized the appropriateness of using locally sourced materials in a simple design. Regrettably, the design did not have a sufficiently uniform hot surface temperature distribution and the brittle clay surface made the appliance heavy and difficult to manufacture.

A second senior design team tried to improve the performance of the hybrid-mitad design by exploring different manufacturing approaches to better integrate the clay and the heating coils. Unfortunately, every hybrid-mitad design iteration failed due to thermally cracking the clay cooking surface. This forced the sponsors and the students to re-consider the use of clay, which was one of the initial design and cultural requirements. It was subsequently concluded that the design should primarily focus on simply cooking Injera, the ease of manufacture, durability, and price.[25] The appliance could only make a difference in efficient energy usage if it were produced in large volumes and adopted by many people. The second design did succeed in reducing the require power consumption for cooking Injera to a few kilowatts.

The subsequent faculty-student and user discussions challenged our collective perceptions of appropriate technology. As long as the unit produced an evenly hot surface temperature, did the consideration of using historical materials such a red clay cooking surface really matter? If consumers were already considering buying a 'modern electric appliance' do they care if the cooking surface is traditional clay or coated aluminum? Were we too focused on cultural appropriateness at the expense of stepping back to consider a more flat world?[26] For example, we were clearly too focused on a design space that excluded the use of many mitad subcomponents that could be inexpensively manufactured in China or India and then imported and assembled in Ethiopia at a lower cost.[27,28]

Reflections

We are attempting to transform the engineering educational process at UST by offering students' design projects for customers in developing societies. These projects increase awareness of world issues far from the students' sphere of experience. The students are exposed to different cultures, economic constraints, and lack of justice or fairness in resource availability or societal infrastructure. Solutions necessitate flexibility in thinking where we need to challenge yesterday's definitions of appropriate technology. The 21st century development engineer may need to consider the benefits of modifying or assembling existing imports over locally produced alternatives when considering impact or system scaling.

Our experience has also shown a need for a more comprehensive and expansive effort beyond a single senior design project team. In recognition of the reality that the reach of undergraduate students has a limit, we have begun engaging combined graduate and undergraduate senior design and research teams on these projects. UST is laying the foundation for expanding these projects to include interdisciplinary collaborations with colleagues in business, law, and the social sciences to engage in a wider spectrum of services that can augment the design process. Currently our program is insufficient in these critical skills and broader collaborations are needed with students across campus that combine cultural considerations with business, law, and engineering expertise, at both the graduate and undergraduate level.

Finally, we have observed that one of the outcomes for the students involved in the humanitarian senior design projects is that their world-view changes. Many of these students, anecdotally after-the-fact, indicate that they want to reorient their career goals to pursue careers that have humanitarian objectives. These outcomes line-up with the objectives of the 'Peace Engineering'[29] and REAL[30] outreach programs in the School of Engineering at the University of St Thomas.

Acknowledgements

In order to be successful, projects like those just described require the integrated efforts of many groups and individuals. We would like to thank the ICRISAT-Mali teams for the opportunity to participate in the sorghum project through the senior design experience. We would also like to thank Ame Gelalecha and Dr. Greg Mowry for sponsoring the Injera senior design project. And finally we would like to thank and express our gratitude to Dr. Don Weinkauf for supporting 'peace engineering' and summer student interns.

Bibliography

1. Accreditation Board for Engineering and Technology, Inc. Annual Report 1998.
2. http://www.geerthofstede.nl/index
3. Von Grebmer, K., Nestorova, B., Quisumbing, A., Fertzinger, R., Fritschel, H., Pandya-Lorch, R., Yohannes, Y., "2009 Global Hunger Index: The Challenge of Hunger—Focus on Financial Crisis and Gender Inequality", International Food Policy Research Institute, November 2009, Brief 62.
4. Wood, A., "Design for Developing World: Eight Principles Derived from the Engineering Literature", Design Exploration Research, Brigham Young University, 12 Dec 2013.
5. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), www.icrisat.org
6. http://www.afripro.org.uk/papers/Paper01Taylor.pdf
7. Senegal, Mauritania, Mali, Burkina Faso, Niger, Nigeria, Chad, and Sudan
8. Doggett, H., "Sorghum, Tropical Agriculture Series", UK, 1988. ISBN: 0-582-46345-9.
9. Paterson, A.H., Bowers, J.E., Bruggmann, R., Dubchak, I., "The Sorghum bicolor genome and the diversification of grasses." Nature, Issue 457: 551-556, 29 January 2009.
10. http://ndb.nal.usda.gov/ndb/foods/show/6281
11. Gross, M., "Converting sweet sorghum into ethanol", Oklahoma State University Press Release, March 2006.
12. "Sweet Sorghum: A smart multipurpose crop." ICRISAT, 2008. <http://oar.icrisat.org/id/eprint/5673.> 20 Oct. 2013.
13. Undersander, D.J., Lueschen, W.E., Smith, L.H., Kaminski, A.R., Doll, J.D., Kelling, K.A., Oplinger, E.S., "Sorghum—for syrup: Alternative Field Crops Manual", November 1990.
14. "Processing Sweet Sorghum for Syrup." AGR_123.
15. "Country Profile: Ethiopia", April 2005. Retrieved from http://lcweb2.loc.gov/frd/cs/profiles/Ethiopia.pdf.
16. Ofcansky, T., Berry, L., "Ethiopia", 1991. Retrieved from http://lcweb2.loc.gov/frd/cs/ettoc.html.

17. Adams, A., "How to Make Injera (Ethiopian Sourdough Flatbread)", 2009. Retrieved from http://dairyfreecooking.about.com/od/cookingtipstools/ss/injerahowto.htm.
18. "Injera Electric Baking: Energy Use Impacts In Addis Ababa Ethiopia", Dave Sood, World Bank funded study, 10 May 2010. http://www.ethioenergyauthority.gov.et/attachments/article/62/Ethiopia_Injera_May_17_2010_FINAL_Report1%20(1)%20DAVE%20SUD%202007.pdf
19. "Windshield Shade Solar Funnel Cooker", Windshield Shade Solar Funnel Cooker, 2004. http://solarcooking.org/plans/windshield-cooker.htm.
20. Kreith, F., Kreider, J.F., "Principles of Solar Engineering", McGraw-Hill, New York, NY, 1978.
21. Kenisarin, M., Mahkomav, K., "Solar energy storage using phase change materials", 2007. Retrieved from http://www.sciencedirect.com/science/article/pii/S1364032106000633.
22. "Hitec heat transfer salt", 2013. Retrieved from http://coal2nuclear.com/MSR - HITEC Heat Transfer Salt.pdf.
23. "Dynalene ms-2", 2013. Retrieved from http://www.dynalene.com/v/vspfiles/templates/210/datasheets/Dynalene_MS-2_Technical_Data_Sheet.pdf.
24. "Mylar Polyester Film", DuPont Teijin Films, 2003.
25. Hanlon, J. "1st edition Handbook of Package Engineering", Lancaster, Pennsylvania, Technomic Publishing, ISBN 01-87762-924-2, Chapter 3: Films and Foils, 1992.
26. "Induction heating", 7 Aug., 2013. Retrieved from http://en.wikipedia.org/wiki/Induction_heating.
27. "Radiant heat", 2013. Retrieved from http://www.smartkitchen.com/resources/radiant-heat.
28. Rebernak, T., "Thermal Insulation in Appliances", 2013. Retrieved from http://www.morganthermalceramics.com/resources/technical-articles/thermal-insulation-in-appliances/
29. Peace Engineering; http://www.stthomas.edu/engineering/outreach/peace/
30. REAL, the Renewable Energy and Alternatives Laboratory; http://www.stthomas.edu/engineering/faculty/greg-s-mowry-.html