Designing for Poverty Alleviation: A First-Year Engineering Capstone Project

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Abstract **- The engineering curriculum at Ohio Northern University includes a first-year introduction to engineering course sequence culminating in a semester-long design project. The focus of the project involves the design of a poverty alleviation device to address a specific need of the population of an impoverished country. The project requires multidisciplinary student teams to follow the engineering design process, prepare a formal written response to a Request for Proposals, provide regular verbal and written status reports, give an elevator pitch as part of an entrepreneurial competition, develop and test a prototype of their design, and report their results in both oral and written formats. The poverty alleviation requirement has allowed students to directly experience many of the learning outcomes specified in the ABET EAC criteria, including understanding engineering in a global and societal context, along with criteria typically found in a senior-level capstone course such as the ability to function in teams and to communicate effectively. Quantitative and qualitative assessment of the project showed that students felt the experience positively related to societal and realistic constraints.**

Index Terms – First-year capstone, Engineering design, International, Poverty alleviation

INTRODUCTION

In the 2012-2013 “Criteria for Accrediting Engineering Programs” [1], ABET presents a list of student outcomes that all graduates are expected to attain. Included among these expectations are the ability to design to meet desired needs within realistic constraints and an understanding of the impact of engineering solutions in global and societal contexts; the issues behind these expectations are traditionally covered within the liberal arts. However, first-year engineering students often arrive on campus with focused visions of designing at the forefront of technology: a faster car, a longer bridge, or a slimmer smartphone. This focus can keep students from appreciating the greater picture of engineering as a profession dedicated toward solving the challenges facing humanity. Furthermore, engineering students may not recognize the need to design affordable solutions for the problems facing those who live in poverty, a group that makes up a majority of the world’s population. Visionaries such as Dr. Paul Polak, author of the book *Out of Poverty* [2], do not see this group as “poor people” but as potential customers and entrepreneurs. Through his work in various developing countries, Polak has successfully demonstrated that products focused on technical simplicity, designed in accordance with the realistic constraints inherent to the local population, and manufactured with respect to local empowerment through entrepreneurship can have a marked impact in improving the lives of the less fortunate.

In 2009, inspired by the efforts of Dr. Polak, the instructors of the first-year engineering program at Ohio Northern University redesigned their curriculum to incorporate a capstone project focusing on poverty alleviating product designs for a specific third world country. From an engineering education perspective, this capstone allows first-year students to follow an engineering design methodology, including proposal preparation, analysis of design alternatives, consideration of constraints and criteria, adherence to a project schedule, validation by testing physical prototypes, and the presentation of a final report. Tie-ins to the liberal arts are accomplished in several ways. For example, students are required to identify various social and global impacts of engineering solutions by researching the culture and associated needs of their assigned country. Each student must then prepare a 3-5 page report with details on their specific culture, including any characteristics that could have an effect on their design. Additionally, an individual report containing their interpretation of how their design incorporated various realistic constraints (such as economic, environmental, sustainability, and manufacturability) is due at the end of the term. These two reports are then submitted as artifacts that count toward the student’s general education requirements.

INCORPORATING POVERTY ALLEVIATION

Dr. Polak’s work was meant to apply generally to professionals and, academically, to senior- and graduate-level design; however, incorporating his concepts into a first-year capstone project provided an avenue for emphasizing the real-world aspects of engineering. Additionally, one goal of the first-year sequence is to show engineering in a global context. The use of poverty alleviation as a design theme and requiring research into an impoverished society provides students exposure to real-world problems – not “problems” that are contrived as an end unto themselves. This requirement allows multiple

ABET-specified criteria to be considered, including an experience with real-world examples of the realistic constraints (economic, environmental, social, political, ethical, health & safety, manufacturability, and sustainability) listed in ABET EAC Criterion 3c; and an appreciation of the need for the "broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context," as called for in ABET EAC Criterion 3h [1].

In the first-year capstone course, teams of three to four students majoring in either Civil, Computer, Electrical, or Mechanical Engineering, or in Engineering Education, are assigned using the Team-Maker / CATME system [3] at the beginning of the term and remain together throughout the design, development, construction and demonstration of the project. Student teams are given the overall theme for their design, along with constraints and grading criteria, via the distribution of a Request for Proposals (RFP) document. Impoverished countries, defined as those where 40% or more of the population earn less than the World Bank's relative poverty threshold of $2/day, are identified and selected beforehand by the course instructors. An example RFP is provided in Figure 1.

Request for Proposals
Design of a Humanitarian Device

<u>Summary</u>

Your team is to develop a proposed design for The Other 90 Design, Inc. (TO9D). The first step is a proposal, presenting your proposed design to the company. The complete design package will include complete documentation of the design, presentations on the design, test plan, prototype and presentation at the end of the semester.

<u>Background</u>

TO9D is a not-for-profit multinational corporation whose mission to develop products to benefit the 90% percent of people on Earth who live in "absolute poverty", defined by the World Bank in 1990 as the earning of an equivalent income of $2 a day or less. TO9D works toward this goal through focusing development efforts on products that either allow people to earn their way out of poverty or allow people to spend less time, money and/or effort on the necessities for life. TO9D is now accepting proposals for new products designed for alleviating effects of poverty and improving lives in one or more impoverished countries.

<u>Specifications</u>

The proposal must identify a real world poverty situation in a specific population (which will be assigned in class) where at least 40% of the population earns less than $2 a day. Your proposal must identify and examine the realistic constraints associated with both the target audience and your proposed design, and provide an appropriate cost analysis. Given that your design is targeted toward poverty alleviation, the estimated per-unit cost of production, the affordability of the design for the targeted population, and the expenses incurred in the development of the prototype will all figure prominently in the grade assigned to the group.

FIGURE 1
EXAMPLE REQUEST FOR PROPOSALS.

At the time of the RFP distribution, each team is randomly assigned a continent, then an impoverished country located on that continent, to assure appropriate geographical distribution for the projects within each section. Through their research, each team is to find pertinent characteristics of the people who live in their assigned country and identify five significant issues which may be explored for development of a poverty alleviation device. Based on the RFP, teams prepare a written proposal and present an oral presentation based on that proposal for approval. This oral presentation is given in a "closed door" format; only the team members and the instructor are present, in order to allow for a frank discussion of the merits (or lack thereof) of the proposed design. It is often the case that probing questions are asked by the instructor, requiring the team to either elaborate upon certain elements of their proposed design, or to select another design entirely.

COURSE MECHANICS

Teams are required to follow a real engineering process throughout their design. As mentioned earlier, teams first develop and present a formal written proposal with a proposed timeline and budget. Once their proposal is accepted, teams document each group meeting, building a project notebook. Teams also meet regularly with their supervisor (*i.e.*, their instructor) for formal design reviews. Each team is required to prepare an agenda for each formal design review meeting, covering both the meeting process and items to discuss. The agenda is provided in advance to the instructor. Students are expected to present themselves professionally in both conduct and attire, follow the meeting agenda, summarize their progress, present their design notebook, and ask any pertinent questions. It should be noted that questions from the teams are not limited to these meetings: assistance is available during regular class meetings and through office hours as with any course. Meeting effectiveness is assessed using a rubric, allowing teams to receive meaningful feedback following each design review.

One benefit of incorporating the poverty alleviation requirement into the first-year capstone design project is that it provides an introduction to the principles of entrepreneurship. In *Out of Poverty*, Polak details how a grassroots, entrepreneurial approach can help people out of poverty by focusing efforts on unexploited market opportunities through the development of innovative, low-cost tools. Entrepreneurial aspects of design are emphasized in this course in multiple ways. Introductory business concepts are introduced through guest lectures by an entrepreneurship professor from the Ohio Northern University College of Business Administration. Students are also exposed to the business concept of elevator pitches, concepts regarding what constitute effective poster designs, and how to give effective oral presentations. This culminates in each team participating in a university-wide

Entrepreneur Poster Competition. Among the four competition categories is "Ideas the Improve Society", where the idea being pitched should have a positive impact on the local or global community. As part of the competition, a team member gives a concise and well-thought-out presentation of no more than two minutes of a new business or product idea to a panel of judges. The team then answers questions regarding such items as the problem being addressed, to what extent does the idea fulfill a consumer want or need, and the feasibility of the proposal.

Teams must formally demonstrate the functionality of their designs at the end of the semester. These demonstrations usually involve the presentation of a prototype in action (such as a scale model of a drip irrigation system) or a video presentation if the device is not suitable for use in a classroom (such as a solar cooker). Final demonstration presentations are given to both instructor and fellow classmates, and are assessed using multiple rubrics. The effectiveness of the presentation and the technical aspects of the design are assessed both by the instructor and by other students.

QUANTITATIVE ASSESSMENT

Quantitative assessment results were obtained through an end-of-term survey administered to all students enrolled in the Spring 2009, Spring 2010, and Spring 2012 offerings of the course. Ohio Northern switched academic calendars in Fall 2011; prior offerings of the course had 30 contact hours under the 10-week quarter system whereas the current offering has 45 contact hours under the 15-week semester system. The survey instrument included 10 Likert-scale items (Strongly Agree – labeled **SA** in tables, Agree - **A**, Neutral - **N**, Disagree - **D**, and Strongly Disagree - **SD**) regarding perceptions on the project and learning the engineering contexts listed in ABET Criterion 3h. The instrument also contained eight items asking for the students' perception of the influence of each specific ABET-defined realistic constraint on their project using a 4-point scale (Strongly, Moderately, Minimally, None). The sample size was for Spring 2009, 89 students; for Spring 2010, 99 students; and for Spring 2012, 86 students. All tabular data are reported in percentage response from that term's sample size; due to rounding, not all rows add up to 100%.

I. Awareness of the Engineering Profession

Three of the survey questions related to the students' awareness of the engineering profession and its applicability to society. As shown in Table I, students agreed that the poverty alleviation project provided them with insight regarding what it is like to be an engineer. However, there is a noticeable shift in those who either agree or strongly agree, from 90% in 2009 down to 76% in the 2012 offering of the course.

TABLE I
PROVIDING INSIGHT ABOUT ENGINEERING

Question	**Year**	**SA**	**A**	**N**	**D**	**SD**
This project provided me with insight as to what it is like to be an engineer.	2009	37	53	9	0	0
	2010	26	53	14	7	0
	2012	28	48	18	6	0

Table II shows that the project supported the students' decision to become engineers, but with some growth noted in the amount of students who disagreed with this statement.

TABLE II
REINFORCING DECISION ABOUT ENGINEERING

Question	**Year**	**SA**	**A**	**N**	**D**	**SD**
This project reinforced my decision to become an engineer.	2009	29	54	15	2	0
	2010	23	46	27	4	0
	2012	34	31	22	8	4

Finally, Table III indicates that in every year at least 89% of the responses supported the statement that the project allowed them to apply the engineering design method to a real-world problem, with a maximum of only 1% of the students registering disagreement.

TABLE III
APPLYING THE ENGINEERING DESIGN METHOD

Question	**Year**	**SA**	**A**	**N**	**D**	**SD**
This project allowed me to apply the eng. design method to a real-world problem.	2009	44	53	4	0	0
	2010	35	54	10	1	0
	2012	42	51	6	1	0

Overall, these response patterns are not necessarily surprising, as ample evidence exists that the integration of real world design problems into the curriculum is beneficial to an appreciation for engineering.

II. Impact of Engineering on Society

ABET Criterion 3h calls for students to have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context. Four questions were asked on the survey to ascertain the degree to which the students believed that the project that they worked on contained these contexts. Given that the design project theme is poverty alleviation in a third world country, one expects a highly positive response, as evidenced by the data in Tables IV and V.

TABLE IV
IMPACT OF ENGINEERING IN A GLOBAL CONTEXT

Question	**Year**	**SA**	**A**	**N**	**D**	**SD**
I learned about the impact of engineering solutions in a global context.	2009	27	56	15	2	0
	2010	30	58	8	4	0
	2012	34	55	10	1	0

TABLE V
IMPACT OF ENGINEERING IN AN ECONOMIC CONTEXT

Question	**Year**	**SA**	**A**	**N**	**D**	**SD**
I learned about the impact of engineering solutions in an economic context.	2009	30	51	15	3	0
	2010	27	60	11	2	0
	2012	29	54	15	2	0

Most students correctly recognized the economic factors involved with the project, with at least 81% each year agreeing that they learned about the impact of engineering solutions in an economic context. However, given that students were involved with a poverty alleviation project, nearly 100% agreement with this statement should be expected.

Due to the nature of the project, one would expect that, while environmental and societal contexts are present to some degree, their impacts are not as prevalent as the global and economic contexts are with respect to the variety of student project designs. Tables VI and VII show that this is in fact the case.

TABLE VI
IMPACT OF ENGINEERING IN AN ENVIRONMENTAL CONTEXT

Question	Year	SA	A	N	D	SD
I learned about the impact of engineering solutions in an environmental context.	2009	18	48	28	6	0
	2010	21	56	17	5	0
	2012	31	54	14	1	0

TABLE VII
IMPACT OF ENGINEERING IN A SOCIETAL CONTEXT

Question	Year	SA	A	N	D	SD
I learned about the impact of engineering solutions in a societal context.	2009	13	53	27	6	0
	2010	21	48	24	7	0
	2012	23	51	23	2	0

It is worth noting that the levels of disagreement between Tables IV-V and Tables VI-VII are similar and that, over the survey period, no student has expressed strong disagreement with any of these assertions.

III. Influence of Realistic Constraints

The use of poverty alleviation as a design theme provides students exposure to real world problems, instead of "problems" that are contrived as an end unto itself. The very nature of poverty – the lack of earning potential and dealing with limited resources – forces consideration of several realistic constraints. Furthermore, these constraints serve to narrow the scope of the project such that it is approachable for a first-year engineering student, as the mass application of modern technology is not a requirement for poverty alleviation. In many cases, a simple, low-tech, well-designed solution will make a considerable positive impact in ways that large-scale, bureaucratically-intensive projects cannot hope to do. The assessment of items asking for the students' perception of the influence of each specific ABET-defined realistic constraint on their project was conducted using a 4-point scale (Strongly – labeled **Str** in tables, Moderately - **Mod**, Minimally - **Min**, and None).

First, solutions have to be affordable (economic), addressing basic human needs relevant to a particular socio-economic group (social, health & safety). Tables VIII-X indicate that most students believed that there were moderate to strong economic constraints placed upon their designs, but were less affected by social and health & safety constraints. As expected, the response to economic constraints was the strongest, with at least 92% of the students each year indicating a moderate to strong influence on their design; however, ideally this should be at 100%.

TABLE VIII
PROJECT AFFECTED BY ECONOMIC CONSTRAINTS

Question	Year	Str	Mod	Min	None
The project was affected by the following realistic constraint: economic	2009	65	27	7	1
	2010	67	30	3	0
	2012	67	27	6	0

TABLE IX
PROJECT AFFECTED BY SOCIAL CONSTRAINTS

Question	Year	Str	Mod	Min	None
The project was affected by the following realistic constraint: social	2009	18	49	25	8
	2010	20	43	27	9
	2012	29	38	26	7

TABLE X
PROJECT AFFECTED BY HEALTH & SAFETY CONSTRAINTS

Question	Year	Str	Mod	Min	None
The project was affected by the following realistic constraint: health & safety	2009	55	30	12	2
	2010	52	36	10	2
	2012	53	34	12	1

An ideal design would use locally obtainable materials (sustainability) in an environmentally-conscious manner (environmental) that can be assembled from a small number of components by those possessing limited skills and/or tools (manufacturability). Tables XI-XIII present the survey results for these constraints. Due to the focus placed on poverty alleviation, students performed considerable research on the natural and manufacturing resources locally available for a given society. Accordingly, they were more sensitive to these constraints, as reflected by the majority responses in the "strongly affected" category. Many, but not all, projects had a noticeable environmental component, yet that constraint still rated highly with the students.

TABLE XI
PROJECT AFFECTED BY SUSTAINABILITY CONSTRAINTS

Question	Year	Str	Mod	Min	None
The project was affected by the following realistic constraint: sustainability	2009	55	37	6	2
	2010	58	33	9	0
	2012	50	43	5	2

TABLE XII
PROJECT AFFECTED BY ENVIRONMENTAL CONSTRAINTS

Question	Year	Str	Mod	Min	None
The project was affected by the following realistic constraint: environmental	2009	43	43	13	1
	2010	43	42	11	3
	2012	65	27	7	1

TABLE XIII
PROJECT AFFECTED BY MANUFACTURABILITY CONSTRAINTS

Question	Year	Str	Mod	Min	None
The project was affected by the following realistic constraint: manufacturability	2009	61	36	2	1
	2010	52	39	7	1
	2012	55	41	3	1

IV. Cultural Awareness

Two survey questions that were posed related to how the project affected the students' cultural awareness. The results are provided in Tables XIV and XV.

TABLE XIV
PROJECT INCREASED AWARENESS OF POVERTY

Question	Year	SA	A	N	D	SD
This project increased my awareness regarding how people are affected by poverty.	2009	21	47	25	6	1
	2010	32	47	17	4	0
	2012	42	44	12	2	0

TABLE XV
PROJECT INCREASED CULTURAL KNOWLEDGE

Question	Year	SA	A	N	D	SD
This project increased my knowledge of the culture(s) of another country.	2009	7	36	37	17	3
	2010	27	46	24	3	0
	2012	34	60	6	0	0

The authors believed that an insufficient amount of time was spent in the first offering of the course in Spring 2009 in these two areas, hence the relatively poor Likert responses for that year. Additional material and assignments were added, such as the aforementioned cultural research project that each student must undertake, which has resulted in the highly positive responses received in 2012.

QUALITATIVE ASSESSMENT

Qualitative assessment results were taken from open ended questions on the survey. Similar qualitative items are grouped together for presentation.

Overall, students expressed satisfaction for the engineering design aspects of the first-year capstone course. Comments on the overall structure of the course included:

> "It is one thing to sit in a class and learn about the design process, but it was a very rewarding experience to go out and be able to implement the things we learned in class. It was also a great learning experience to work with one group for a very big project throughout the entire quarter."

> "The project was great and definitely served its purpose to familiarize the students with engineering methods."

> "The most beneficial aspect was the knowledge of what goes into doing a design project. I was under the impression it was easier, and there were not as many constraints, and that it was mostly design and inventing. It is quite evident now that it is a lot of extra work aside from those tasks."

> "I feel this project is very helpful and a good project for a first year engineering student because it gets us into the door of engineering and it helps us to start thinking and acting as an engineer would think and act."

Specific comments on the opportunity to work with a socially-oriented engineering project were also very positive. For example:

> "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."

> "I thought it was a really good idea. This project opened my eyes to the world. I had no idea that some people around the world didn't even have access to clean drinking water. It is amazing how we take things like this for granted here in America."

> "I have learned that engineering is more than just sitting in an office crunching numbers and thinking up designs. It is an application of knowledge into worthwhile solutions to better groups of people; possibly the entire world."

> "I believe this was a good topic for the project in that it allowed for us as developing engineering students to see the way in which engineers actually try to help alleviate some of the major problems in the world, such as poverty."

The general education aspects of the course were also evidenced by student comments, including the following:

> "It was a good experience to see what other people have to deal with on a daily basis. It opened my eyes to how valuable the simple things we take for granted are to them, such as water."

> "This focus for this project was from a different point of view as compared to the typical engineering products that are made in the United States. I am used to thinking of engineering in terms of expensive, sophisticated product development. This project offered a new perspective."

Some students expressed that they initially found the scope of the project overwhelming; however, most of these comments did (correctly) say that the projects were eventually successful:

> "At first, we had no idea what it was we were doing. The most frustrating part of the course was trying to determine the problem that our team was trying to solve. With such a broad topic of 'poverty' it was difficult for us to get a grasp on a single idea. It was only after careful and patient research and re-research that we were able to decide on a viable problem to find a solution for."

> "When the problem was first introduced to us it seemed like we were given 10 weeks to solve the world's problems for $25 as college freshmen. Even though we got through it, the project seemed very daunting at first."

> "My first day in class, I was in shock that we were thrust into such a big responsibility of designing a poverty alleviating device."

One cause for concern was establishing a relationship between the needs in a developing country compared to the typical environment in which students were raised. The vast majority of engineering students attending Ohio Northern University come from in-state, middle-class households, and so have little, if any, personal experience either with experiencing poverty or with seeing the effects of poverty upon others. Accordingly, some comments reflect the inability for some students to fully relate to the design goals of the project:

> "I wish we had a little more time or assistance in seeing what real needs others had."
>
> "For me it was hard to relate to these people and their needs, compared to designing a product for middle class Americans."

Another area of concern involves the concept of "design arrogance," where the designer confuses the success obtained with a laboratory proof of concept with an assumed successful-in-the-field deployment [4]. While occasionally some students will succumb to such hubris, for the most part the first-year students are aware of the differences, as evidenced by the following comments:

> "I think this is a good idea. I just wish the impoverished area chosen was closer so that I could have visited it before designing the prototype and also to test the prototype."
>
> "I felt as though many of the designs would probably not actually work in the specified country. It would also be very hard to commercialize the products. I don't know if commercializing would be one of the goals for implementation of a project or not. When doing my own project I was not always completely sure if what I was proposing was even possible or workable. I would need to be much more confident in my project to implement it in an impoverished country."

Finally, there are a few students who choose not to buy into the concept of the interdisciplinary nature of engineering, but would rather focus on just their particular branch of engineering, as expressed by the following:

> "This project would be much more beneficial if it were broken down by each engineering major's specific discipline and the students weren't limited by the requirement to construct prototypes and based in a third world country. It needs to become more creative in relation to real projects they may tackle as future engineers - it would be essential in getting them internships, co-ops, and jobs. They need to spend the first semester at ONU getting a thorough introduction of their respective discipline from their department chair and apply their general knowledge to a project in the second semester. It is highly unlikely any of us future engineers would be involved in a project like this - this is about a realistic education and true applicable knowledge to prepare us for the future."

CONCLUSION

The implementation of a first-year engineering capstone project focusing on poverty alleviation as a design construct has been proven to be very successful. The evaluation of the quantitative and qualitative assessment showed that the integration of poverty alleviation was effective in providing an early "real-world" exposure to many of the realistic constraints outlined in ABET Criterion 3c and the contextual impacts of engineering solutions outlined in ABET EAC Criterion 3h. Ample evidence was found indicating that students appreciated the opportunity to work through each phase of the engineering design process from proposal to prototype development. The incorporation of the poverty alleviation requirement also allowed students to develop or solidify their awareness of how engineers as professionals and engineering as a profession can benefit society. While the project itself was very successful, areas for improvement are planned with the intent of further emphasizing realistic constraints (primarily by going beyond the limited framework provided by ABET) and various societal components of engineering. The experience has helped to integrate students into their engineering community and, in some case, inspire them to design for the betterment of humanity.

POSTSCRIPT: NORTHERN ENGINEERS WITHOUT BOUNDARIES

Students who were particularly inspired by this assignment have had the opportunity to travel to the Dominican Republic to implement selected designs [5]. Among these was a briquette maker, easily transforming combustible trash to cooking briquettes. These students then formed Northern Engineers Without Boundaries and recently returned to the Dominican to refine the process of introducing the briquettes and to assist in teacher workshops held in schools surrounding San Juan de la Maguana. Ohio Northern has established a partnership with Solid Rock International (www.solidrockinternational.org) ensuring that students who want to further investigate the implementation of their design have an opportunity to do so.

ACKNOWLEDGMENT

Some of the material in this paper was reported earlier in a paper by Estell, Reid and Marquart [6] in 2010, and in papers by Reid and Estell in 2010 [7] and 2011 [8].

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