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Incorporation of Poverty Alleviation in Third World Countries in a First-Year Engineering Capstone Course*

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The engineering curriculum at Ohio Northern University includes a one year introduction to engineering course sequence culminating in a one quarter first-year capstone design course. A requirement for projects to involve the design of a poverty alleviation device was recently introduced. The initial implementation required student teams to identify an impoverished country (using the World Bank's definition) and address a specific need of the population. The project requirements include following and documenting the engineering design process, preparation of a proposal, regular verbal and written status reports, and both development and presentation of a prototype. The poverty alleviation requirement has allowed students to directly experience multiple learning outcomes as specified in ABET assessment criteria including understanding engineering in a global and societal context, along with criteria typically found in a 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 related to societal and realistic constraints. Based on the evaluation of data from the initial offering of this course, recommendations for both course improvements and future research are presented.

Keywords: first-year engineering; capstone; international; poverty; poverty-alleviation

1. Introduction

Engineers can make a difference in the lives of individuals, groups, or whole populations. Typical perceptions of engineering are often that engineers design the next great innovation rather than helping society. However, Dr. Paul Polak, author of *Out of Poverty* [1], has effectively advocated the approach of recognizing impoverished populations as potential customers and entrepreneurs. Through his work in Third World countries, Polak has successfully demonstrated that products designed to applicable constraints and combined with local empowerment can have an impact in markedly improving the lives of the less fortunate. With this ideal in mind, the culminating capstone course in the first-year curriculum at Ohio Northern University was modified, requiring all designs to address some area of poverty alleviation.

2. The first-year engineering curriculum

The first-year engineering curriculum is a year-long (three quarter) sequence. The overall intent of the sequence is to introduce engineering concepts and to integrate the students into their peer community. The first course in the sequence focuses on professional skills such as teamwork, technical communication, entrepreneurial characteristics of engineering (innovation, creativity and novel approaches to solving problems) and global aspects of engineering. The consideration of engineering criteria and constraints and a formal engineering design process is also introduced. Design projects are generally small in scope and focus more on the design process rather than the final product. Among the projects were creating a robot arm out of cardboard, designing a tower of straws [2], and analyzing the timing characteristics for an oscillator circuit based on the 555 timer IC. The second course in the sequence builds on the first with more extensive projects, more emphasis on technical communication and an expanded use of engineering software. The final course in the sequence is the first-year capstone course, which focuses on the conceptual development of a real-world project through use of the engineering design method. Student teams are formed and tasked to prepare a proposal, identify applicable constraints, generate a set of design alternatives, apply a selection process through use of criteria and decision matrices, document and report on the design regularly throughout the term through formal design reviews, develop a prototype device to verify proof of concept, and present their conclusion through both a written report and an oral presentation.

3. Incorporating poverty alleviation into the first-year capstone

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 provided an ideal avenue to emphasize the real-world aspects of engineering. One of the goals of the first-year

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sequence is to show engineering in a global context (through the National Academy of Engineering Grand Challenges [3], for example). 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 allowed multiple ABET-specified criteria to be considered. Specific objectives include:

- an understanding that an engineer can effect positive change for thousands, even millions, by designing for those who are impoverished;
- 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.

A further benefit of incorporating the poverty alleviation requirement is that it provides an interesting 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. Several 'win-win' examples are given where locally produced and distributed devices (which provide the builders and distributers an income) allow the purchasers to earn more money through their own efforts. These examples illustrate to students the impact of engineering solutions in global, societal, environmental, and economic contexts, as called for in ABET EAC Criterion 3h.

Finally, there is an intangible asset when working on problems that affect those in need, which is perhaps best expressed through a quotation from *Out of Poverty*:

> Working to alleviate poverty is a lively, exciting field capable of generating new hope and inspiration, not feelings of gloom and doom. Learning the truth about poverty generates disruptive innovations capable of enriching the lives of rich people even more than those of poor people. [1]

In the first-year capstone course, teams of three to four students majoring in Electrical, Computer, Mechanical and Civil Engineering are assigned at the beginning of the quarter 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. An example RFP, used for soliciting the designs presented in this paper, is shown in Fig. 1.

Based on the RFP, teams prepare and present a proposal for approval. Specific project requirements to be incorporated to each team's proposal include the identification of an impoverished country and the identification of, and supporting research for, a specific need relevant to their country to address. Impoverished countries are defined as those where 40% or more of the population earn less

Request for Proposals:
Design of Poverty-Alleviating Devices

Summary

The Other 90 Design, Inc. (TO9D), is a not-for-profit multinational corporation that has as its mission to develop products that will benefit the 90% percent of people on Earth who are poor by helping them out of 'absolute poverty', which was defined by the World Bank in 1990 as the earning of an equivalent income of $2 a day or less. TO9D attempts to accomplish this goal through focusing development efforts on products that either allows people to earn their way out of poverty or allow people to spend less time, money and/or effort on the necessities for life. Among the products developed to date are:

- Solar-powered flashlight for nighttime illumination (replacing kerosene lamps)
- Low-cost drip irrigation and water storage systems (for locations with both rainy and dry seasons)
- Donkey carts (for material deliveries in roadless areas)

TO9D is now accepting proposals for new products designed for alleviating poverty in one or more impoverished countries.

Specifications

The proposal must identify a real-world poverty situation in a specific nation where at least 40% of the population earns less than $2 a day…

Fig. 1. Summary of Request for Proposals.

than the World Bank's relative poverty threshold of $2/day.

Teams are required to follow a real engineering process throughout their design. Teams first develop and present a formal written proposal with a proposed timeline and budget. Once their proposal is accepted, teams document each meeting, building a project notebook. Teams also meet regularly with their supervisor (i.e., their instructor) for formal design reviews. Students are expected to present themselves professionally, follow a 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.

Teams must formally demonstrate the functionality of their designs at the end of the quarter. 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 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 [4].

4. Assessment of course effectiveness

Quantitative assessment results were obtained through an end-of-quarter survey administered to all 109 students enrolled in the Spring 2009 offering of the course, consisting of 10 Likert-scale items (Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree) and items asking for the student perception of the influence of each specific ABET-defined realistic constraint on their project using a 4-point scale (Strongly, Moderately, Minimally, None). Qualitative assessment results were taken from open ended questions on the survey plus a reflective essay assigned in one of the four offered sections. Similar quantitative items are grouped together for presentation.

4.1 Awareness of the engineering profession

Three of the survey questions related to the student's awareness of the engineering profession and its applicability to society. Specific items were:

1. This project provided me with insight as to what it is like to be an engineer.
2. This project reinforced my decision to become an engineer.
3. The project I worked on allowed me to apply the engineering design method to a real-world problem.

As shown in Table 1, students agreed that the poverty alleviation project provided them with insight regarding what it is like to be an engineer, with 90% in agreement, and none in disagreement with the statement. Furthermore, the project supported their decision to become engineers, with 83% of students responding with either 'strongly agree' or 'agree' to the statement, and only 2% in disagreement. Finally, 96% of the responses supported the statement that the project allowed them to apply the engineering design method to a real-world problem, with none in disagreement. 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. It is worth noting that none of the students polled strongly disagreed with any of these items.

4.2 Impact of engineering on society

Questions meant to assess student perception on the impact of engineering on society included:

1. I learned about the impact of engineering solutions in an economic context.
2. I learned about the impact of engineering solutions in an environmental context.
3. I learned about the impact of engineering solutions in a societal context.

The results, presented in Table 2, show a strong positive response, which is significant given that these are some of the more difficult constructs to integrate into first-year courses as well as capstone courses.

Most students correctly recognized the economic factors involved with the project, with 81% agreeing

Table 1. Relationship of Project to Student Awareness of the Engineering Profession

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Provided insight into being an engineer	33 (37%)	47 (53%)	9 (10%)	0 (0%)	0 (0%)
Reinforced decision to become an engineer	26 (29%)	48 (54%)	13 (15%)	2 (2%)	0 (0%)
Applied design method to real-world problem	39 (44%)	47 (53%)	3 (4%)	0 (0%)	0 (0%)

Table 2. Relationship of Project to Selected Contextual Issues

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Economic context	27 (30%)	45 (51%)	14 (15%)	3 (3%)	0 (0%)
Environmental context	16 (18%)	43 (48%)	25 (28%)	5 (6%)	0 (0%)
Societal context	12 (13%)	47 (53%)	24 (27%)	6 (7%)	0 (0%)

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. Students also showed strong agreement for the statements in the environmental and societal categories. Again, it is worth noting that there were no 'strongly disagree' responses received from the students for this set of questions.

4.3 *Influence of realistic constraints*

Questions meant to assess student perception on the influence of realistic constraints upon their project included the following:

1. Please indicate the degree to which your project was influenced or affected by the following realistic constraint: economic.
2. Please indicate the degree to which your project was influenced or affected by the following realistic constraint: environmental.
3. Please indicate the degree to which your project was influenced or affected by the following realistic constraint: social.

The results, presented in Table 3, again show a strong positive response from the students.

Most students correctly recognized the economic factors involved with the project, with 92% agreeing that their project was either moderately or strongly influenced by economic constraints, and only one of the 109 respondents indicating that economic constraints played no role in the process. Among those constraints for which the incorporation of poverty alleviation was hoped to influence besides economic were environmental and social. Success in these areas was also shown by the strong student responses received, with 86% of the students indicating that their project was moderately or strongly influenced by environmental constraints and 68% indicating that it was moderately or strongly influenced by social constraints.

Results for some of the other realistic constraints contained in ABET Criterion 3c are also of interest. Manufacturability (97% strong to moderate influence) and sustainability (92% strong to moderate influence) were the two more influential constraints according to the results of the survey, with economic coming in third. The influence from the political constraint varied by the country chosen; overall, only 27% of the students indicated their project was strongly to moderately influenced by political constraints, while an additional 45% (for a total of 72%) felt it was minimally influencing their design.

4.4 *Cultural awareness*

Two survey questions that were posed related to how the project affected the students' cultural awareness:

1. This project increased my awareness regarding how people are affected by poverty.
2. This project increased my knowledge of the culture(s) of another country.

At first glance, the results presented in Table 4 do not appear overwhelmingly positive.

Compared to previous responses, only 68% of students agreed that they were made more aware of the effects of poverty, and only 43% reported an increased cultural awareness. However, it should be

Table 3. Relationship of Project to Selected Realistic Constraints

Realistic constraint:	**Strong**	**Moderate**	**Minimal**	**None**
Economic	58 (65%)	24 (27%)	6 (7%)	1 (1%)
Environmental	38 (43%)	38 (43%)	12 (13%)	1 (1%)
Social	16 (18%)	44 (49%)	44 (25%)	7 (8%)

Table 4. Relationship of Project to Multiculturalism

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Increased awareness of how people are affected by poverty	19 (21%)	42 (47%)	22 (25%)	5 (6%)	1 (1%)
Increased knowledge of the culture(s) of another country	6 (7%)	32 (36%)	33 (37%)	15 (17%)	3 (3%)

noted that typical first-year engineering projects are not related to poverty alleviation; therefore, there is typically no expectation for generating an increase in cultural awareness. Furthermore, these questions did not take into account the knowledge base that students brought with them into the courses. This is best illustrated by the following statement made by one student: 'I know Third World countries need the most help . . .' This comment indicates that some students may not have experienced an *increased* or *improved* perception due to their project; instead, the project could have *supported* and *reinforced* their existing perceptions on poverty and culture. Future research in this area will require appropriate pre- and post-testing constructs to properly ascertain the effect that this design project area has on developing these perceptions.

4.5 Qualitative assessment

Two forms of qualitative summative assessment were conducted during the Spring 2009 quarter. First, in the aforementioned survey, several 'open response' questions were posed to the students, including a request for comments regarding having projects based on the design of poverty-alleviating devices. The second qualitative assessment tool was a reflective essay assignment given in one of the four sections of the course. For the essay, students were instructed to reflect upon the following points:

- the individual contributions made to the team effort,
- the skills found to be most useful in completing the project,
- the most rewarding aspect of the course,
- the most frustrating aspect of the course, and
- suggestions for improving the overall experience in future offerings of the course.

Overall, students expressed satisfaction for the design aspects of the 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 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.

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

> 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.
>
> 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 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.

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.

An additional 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.

5. Recommended course improvements

Although the project was evaluated to have been very successful, opportunities for improvement were identified through feedback received through both the in-class assessment instruments and end-of-quarter course evaluation comments. These included:

1. Earlier introduction of contextual concepts: While poverty, societal and global issues were raised in the capstone course, resources are now introduced more systematically earlier in the course sequence. This should prove to be useful as students form their initial design concepts. Dr. Polak's Web site [5], the IEEE Global Water Challenge [6] and similar sites offer excellent online resources for courses prior to the capstone.
2. Improved team selection: Teams were intended to be interdisciplinary, but some teams were self-selected, or formed by the students themselves. In addition, students most frequently reported problems related to team formation, especially availability of team members for collaboration outside of class. To address this problem, the instructors selected the Team-Maker application [7], available with The Comprehensive Assessment of Team Member Effectiveness (CATME), for use in future offerings of the course. This application was developed to form balanced teams based on student responses to instructor-supplied criteria. Collectively, CATME/Team-Maker applications provide tools appropriate to the task of organizing and managing a collection of student teams.
3. More management, fewer lecture periods: The capstone course as implemented had two formal review sessions, where teams would meet with the instructor to present their current progress. The formal reviews were an excellent opportunity for formative assessment, and were of great benefit to the students. The course will be slightly modified to include one additional formal review session.
4. International service opportunity: 'Northern Without Borders' is a student organization at Ohio Northern offering students the opportunity to travel on medical mission trips. A pilot program offering the opportunity to implement designs developed in this capstone course is planned. 'Freshmen Without Borders' members will accompany this group and attempt to implement, and document the implementation of, selected designs from the first-year capstone course.
5. Implement pre- and post-testing to further assess changes over the course: A pre-course assessment will be conducted to establish a baseline for comparison to the post-course assessment to better evaluate the effects of the course on the students.

6. Future research: the incorporation of personas

Some design projects suffered from a lack of interaction with, and superficial knowledge of, those for whom the students were designing. Making a connection between the design team and those for whom they are designing, in a fiscally prudent and viable manner, can lead to a more effective design. Organizations often found on college campuses, such as 'Engineers Without Borders' (EWB), offer the opportunity to perform service work akin to that done through similar organizations such as Habitat for Humanity. Jaeger and LaRochelle [8] present a wealth of data in support of the benefits of student EWB involvement, including a greater appreciation for other cultures, a stronger appreciation for teamwork, and an increased awareness of the role of ethics and personal responsibility in engineering.

Personas are detailed descriptions of individual, fictionalized customers often used in marketing and software development. The customer is constructed with attributes considered common to a particular class and are then embodied into the description of an individual, Additional information such as details of a typical day, educational background and personal interests which may have an effect on a design are also given to encourage the designer to focus on the needs of the customer as an individual [9, 10]. Specific personas include a fictionalized name and picture of the individual and may also include pictures illustrating their housing and/or lifestyle. Some needs may be mentioned within the descriptions, but the complete persona illustrates that there are clearly multiple needs for the individual.

Personas will be incorporated into the first-year capstone to encourage student teams to focus on the needs of an impoverished individual, both to help make the problem more realistic and to better develop empathy for those for whom the students are designing. By having a persona character to refer to, it is expected that students will be further engaged with the 'human side' of engineering due to the literal personification of relevant tasks and associated societal criteria. Further, it is expected that the design will appear to be more open-ended as multiple needs may interact with one another.

The first set of personas is being created with data collected by a senior capstone group that has recently traveled to the site of their project in Kenya. They were able to capture sets of pictures of people and their living conditions, along with detailed descriptions of their surroundings, needs, attitudes and societal expectations. Additional personas are being created based on data from other impoverished countries. The development of a second set of personas has been facilitated through travel by one author as part of a summer 2010 medical mission trip to the Dominican Republic, where pictures and information on people, occupations, schools and typical housing was gathered. Information based on a survey of residents of the barrios (neighborhoods), where residents were asked to define 'good health', will allow additional attitudinal information to be included with some personas. Future mission trips will provide additional data which will be used to form still more personas.

7. Conclusions

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 EAC 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 as documented are planned with the intent of further emphasizing realistic constraints and various societal components of engineering. The experience should help integrate students into their engineering community and inspire them to design for the betterment of mankind.

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