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Preparing Globally and Socially-conscious Engineers: International and Human-centred Design Projects and Activities in the First Year*

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In recent years, a number of innovative activities involving early design/hands on experiences have been introduced into first and second semester freshman courses at Virginia Tech. The objective is to excite freshmen about the engineering profession and to provide early exposure to topics essential to their preparation as globally and socially conscious engineers. A number of initiatives including a sustainable development design project, study abroad presentations, and a world population activity have been implemented in the first course. In the second course, a design project with a focus on assistive technologies for third world countries has been implemented.

Keywords: First-year engineering, human-centred design, international design projects.

INTRODUCTION

ABOUT 1200 ENGINEERING FRESHMEN enter Virginia Tech as General Engineering (GE) students every year and are transferred to one of 13 degree-granting departments after successfully completing the 1-year GE programme. All engineering freshmen are required to take a 2-credit Engineering Exploration ENGE 1024 course during their first semester of enrolment. The course focuses on developing problem-solving and critical-thinking skills and provides early exposure to engineering design activities. Students, other than those pursuing electrical and computer engineering or computer science then take a second semester 2-credit course, Exploration of Engineering Design ENGE 1114. This course builds on principles and practice of engineering design introduced in ENGE 1024 and introduces various topics, including: engineering design process, basic project management, written and oral communications, computer assisted design and analysis, graphics, and working in a team environment. One of the main focal points of the course is the successful completion of a team-based design project.

In recent years, a number of innovative activities involving early design/hands-on experiences have been introduced into these courses. The objective is to excite freshmen about the engineering profession and to provide early exposure to topics essential to their preparation as globally and socially conscious engineers. A number of initiatives including a sustainable development design project, study abroad presentations, and a world population activity have been implemented in the first course [1]. In the second course, design projects with a focus on assistive technologies for third world countries have been implemented.

BACKGROUND AND RELATED LITERATURE

Important questions and statements about the global preparation of students have been raised in a growing number of national publications. *The Engineer of 2020* published by the National Academy of Engineering (NAE) [2], questions:

> Do US engineers understand enough culturally, for example, to respond to the needs of the multiple niches in a global market?
> Can we continue to expect everyone else to speak English?

A follow up report of the NAE [3] states the following about the US engineer of 2020 and beyond:

> It is expected that U.S. engineers will be based abroad, will have to travel (physically or virtually) around the world to meet customers, and will have to converse proficiently in more than one language. Flexibility and respect for ways to life different from ours will be critical to professional success.

Further, numerous other quotes by respected academicians and CEOs highlight the importance of global education. For example: Frank Rhodes, President Emeritus, Cornell University states: 'The

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[New American University] . . . will be international in its orientation and cosmopolitan in its character; study abroad will become a norm . . .'[4].

Equally concerning, is the preparation of the engineer of 2020 to be socially conscious. This is clearly important preparation for engineers who are poised to apply their knowledge and skills for the betterment of humankind. At the same time, we also believe that opportunities for students to engage in projects and learning activities, such as human centred design projects, may also have a significant impact on the interest and learning of a more diverse student body, particularly for women students [5]. There is a growing body of research that suggests that by addressing gender differences in learning style and perceptions of technology and interests, a more equitable environment in engineering classes could be created by changing the primary activities used to introduce or reinforce concepts [6–11]. For instance, traditionally class projects in engineering/technology often focus on the artifacts of design such as engines, gears, robots, etc. rather than the motivation behind such devices such as the benefits to humankind. While their male counterparts may find the artifacts alone exciting, females often require a more holistic approach.

Clearly, there is significant motivation and need for preparing globally and socially conscious engineers. Several significant efforts have emerged nationally, with primary focus on human-centered and/or internationally based project learning experiences. Typically, projects are for upper class students, junior and seniors, and in some cases make use of interdisciplinary teams. Moskal, *et al.* [12], provide an extensive summary of such efforts and describe the new curriculum at Colorado School of Mines for juniors and seniors with a focus on *humanitarian engineering*. In a special issue of the *International Journal of Engineering Education (IJEE)*, the topic of sustainability is the focus of how students can become more global and socially conscious engineers [13]. It is our belief that to be most effective, such experiences should begin very early and carry through the undergraduate programme. How is Virginia Tech addressing these needs through project-based learning and hands-on activities focusing on sustainability and human-centered design projects and activities for first year engineering students?

ACTIVITIES AND PROJECTS—ENGINEERING EXPLORATION

In the first semester course, ENGE 1024, two primary activities as well as a 5-week long sustainable development team design project (SDDP) were assigned to students.

Study abroad presentations

In order to expose engineering freshmen to global engineering education and encourage them to pursue study abroad opportunities, an initiative was begun in the spring semester of 2005 to invite upper class engineering undergraduates who have had study abroad experiences to share their experiences with engineering freshmen. This practice has continued ever since. About 20 students with experiences in various countries including Australia, China, India, Ireland, South Africa, France, Spain, Russia, Italy, New Zealand, etc. have met engineering freshmen at the time of writing. Figure 1 shows some images shared depicting cultural and geographic experiences from a New Zealand study abroad experience. Results on the effectiveness of these presentations to generate interest in study abroad, assessed using clicker-based questions are discussed later.

World population activity

In order to motivate the students for the sustainable development design project (SDDP), a world population activity was introduced. Reliable data [14] on population trends, literacy rate, environmental problems, life expectancy, etc. for a number of developing countries were provided to student teams and they were tasked to project future population in these countries and reflect on the environmental and social issues by answering questions on a world population worksheet. Sample questions include: What are the most common 'Environment Current Issues?' What implication do these issues have for people living in these countries? Provide an age range (lowest to highest) for 'Life Expectancy at Birth' among these countries. What factors contribute to life expectancy rates?

Figure 2 shows an example of this activity in action, with students building Lego™ based models of population trends in different countries.

SUSTAINABLE DEVELOPMENT DESIGN PROJECT (SDDP)

SDDP objectives

The primary objectives of the SDDP were to:

- provide the students with a challenging and real world problem for which to have an educational hands-on experience with certain fundamental aspects of the engineering design process. These included the development of a problem definition, performing research, understanding a community's needs, working within constraints, identifying design trade-offs, developing test plans and performing basic analysis, presentation skills, and the writing of a technical report;
- give the freshmen students a team based design assignment in order to experience firsthand the challenges, benefits, and stages of teamwork;
- provide students with material from which they would make connections concerning the impact of technological development on a community.

Fig. 1. Study abroad experiences in New Zealand.

By limiting the building materials, conceptual design and development was stressed, as opposed to an emphasis on construction and material manipulation.

SDDP format and requirements

Teams comprised of four to five students were provided instructions through a web site that included all aspects of the project and all assignment specifications. No specific guidelines were provided for forming project teams. Some instructors assigned students to teams and some let students choose their team members. Students were asked to 'design and construct an educational game, device, or system that can be used to instruct a group of students younger than themselves, in a developing country with a low literacy rate'. They were free to select a country of their choice from which they would address an audience of students with an approximate age range between 11–13 years. Their design needed to address a topic important to the engineering community (for example: math, science, or technology) and aspire to inform and motivate these students to further their education. The student teams were provided a set of materials which included air-hardening clay, a bandana, twine, fishing line, and bamboo skewers in a plastic bag from which they would construct the prototype. They were also allowed to use a limited amount of recyclable materials which

Fig. 2. World population activity in ENGE1024 workshop.

Fig. 3. Student design for the education of dental hygiene.

Fig. 4. Fraction pie sustainable design for improving literacy.

included a soda can, a tin can, a glass bottle, and a small sheet of corrugated cardboard. Time was provided during a later meeting for the teams to trade materials, and all materials were to be reclaimed and recycled at the end of the project. In addition, they were allowed to use a knife and scissors as construction tools.

Three examples of sustainable development design; namely, a sari cloth water filter, a pot-in-pot cooling system, and an experimental coal made from bagasse (a waste product of sugarcane processing that has the density of wood charcoal yet burns more cleanly) were discussed to clarify sustainable development design related questions. Sari cloth water filters have shown promise in removing plankton from contaminated drinking water known to cause cholera according to research in the United States. Tens of thousands of people a year die from cholera, affecting most profoundly those communities who do not have access to safe drinking water or sanitation [15]. The pot-in-pot cooling system was developed in response to food spoilage in a rural community of subsistence farmers [16]. Charcoal made from bagasse is especially beneficial in areas of Haiti which have been heavily deforested and where communities rely primarily on charcoal for cooking [17].

SDDP example projects

There were many instances of creativity in design projects, for example, one student team designed a model of a mouth to teach dental care with a toothbrush made from the twine and a dental floss dispenser from the can and bandana (see Fig. 3), another team designed footwear with cleats made from the can, twine and bandana for climbing muddy hills.

Yet another creative project design involved the design of a simple airplane to teach simple fundamentals of physics. Several designs focused on teaching basic math fundamentals through board games (see fraction pie game shown in Fig. 4).

SPRING ACTIVITIES AND PROJECTS—ENGINEERING DESIGN

In the second semester course, students from the first year Exploration of Engineering Design course, ENGE 1114, pursued design projects based on assistive technology devices for third world countries. The teams were formed in such a way as to create research studies to:

1) assess the perceptions and outcomes of design teams consisting of only engineers as compared with those of interdisciplinary teams where

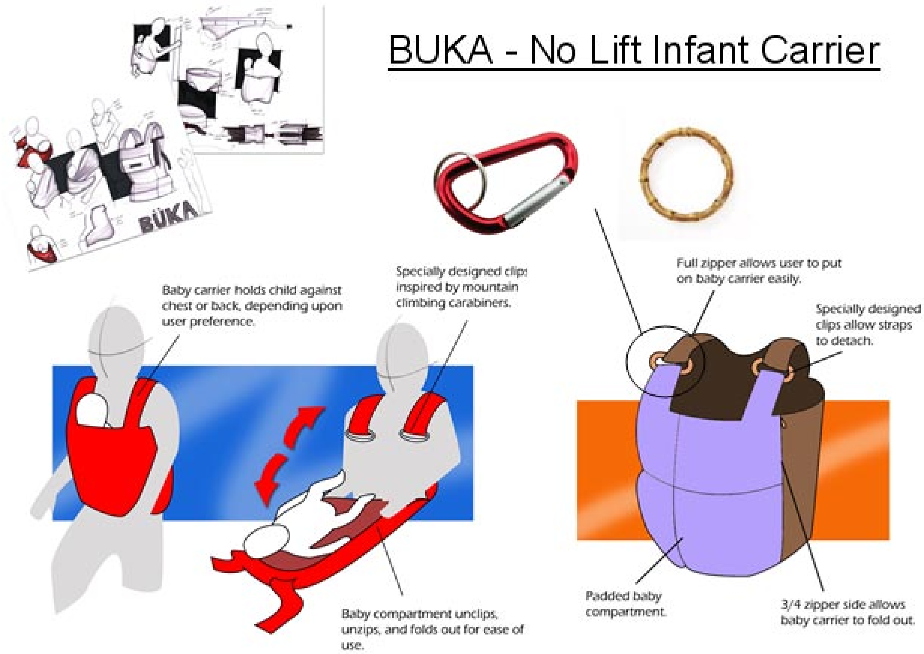

Fig. 5. Buka—'No lift' infant carrier.

engineering students partnered students from the second year Industrial Design Studio in the College of Architecture and Urban Studies;

2) compare human-centred projects focused on assistive technologies for third-world countries with other types of projects.

Two engineering instructors and two industrial design instructors collaborated in the creation, administration, and assessment of the projects and experiment. The assumption of third-world conditions directed students to focus on needs that could be addressed through low-technology, affordable materials and fundamental processes. In their teams, they were to consider daily living situations where humans need assistance of some sort, especially where people need to get materials from 'point A to point B'. This need could involve moving water, food, or agricultural products from one location to another or it could be an access situation where people need to reach for something, low or high. Or, it could be the need is one where people may need assistance moving their bodies from one location to another, such as in and out of a bath-tub. The context was one where a device is needed that meets day to day needs. Student teams were free to research and select the third world country and the particular problem they would tackle.

As has been reported previously [18–21] innovative collaborative design projects have been developed and presented to students in ENGE 1114 for many years. This is the 10th year of this project and the third year of human-centred assistive technology projects. The focus in 2005 and in 2007 on third-world countries brings context and global relevance to these student design projects.

For spring 2007, three different design projects were assigned for the ENGE 1114 Exploration of Engineering Design course. The total population is roughly 900 students. ENGE 1114 is taught in three large 300 seat lecture sections that meet for 50 minutes once a week followed by 32 seat workshops that meet for almost two hours once a week. Two lecture classes of roughly 300 students each completed a combination of product dissection with design improvement and pumpkin launcher projects. A third lecture class of roughly 300 students completed an assistive technology project for third-world countries. All projects were completed by teams of four to five students and consisted of three design progress reports that included writeups of their journey through the design process, project management, hand sketches and computer graphics. There were also oral presentations of the design projects. Nineteen teams from two of the workshops built working prototypes of their designs. Eleven of these teams were collaborative teams joining engineering students with students from the Industrial Design Programme.

The projects included a wide array of devices from mobility devices, water carriers and filtration systems to vaccine refrigerators and no-lift infant carriers, all inspired by situations experienced in third world countries. Figures 5 and 6 illustrate the Buka, an infant carrier based on baby carrier wraps found in Africa. The big advantage of this carrier is that the infant can be placed on the carrier horizontally and gently raised to vertical for clip in without waking the baby. The student team, Team ID-Engine, consisted of three engineers and two industrial designers.

Another example project is the Hydrovest, Fig. 7. By taking on this type of project, students were addressing one of the biggest problems of third-world countries, the need for methods and devices for water gathering, storing, and transportation.

ASSESSMENT INSTRUMENTS AND ANALYSIS OF RESULTS

A number of assessment tools were used, including: student background survey, learning style survey, exit survey, in-class clicker based assessment, and focus group interviews for assessing the learning outcomes of the freshman ENGE courses. A description of these tools and results for the first year courses are provided below.

Engineering exploration, ENGE 1024

Student background surveys

Starting in the fall of 2004 and continuing through the present, a survey has been administered in the ENGE 1024 course at the beginning of the semester to document the background and prior experiences of first year students. In fall 2005, a study abroad related question was added to this survey. A summary of data collected along with the question is given in Table 1.

Students could select multiple answers and were instructed to "check all that apply" in this survey question so that all relevant motivating factors for pursuing study abroad could be determined. It is interesting to note that finding financial aid is among the least chosen option. Further, it is clear that a majority of students join engineering with an open mind about pursuing study abroad options.

SDDP projects

During the third week of the SDDP project, following the submission of the team's design proposal, the students were given a brief survey in which they were asked to evaluate the challenge level of the assignment on a scale of 1 to 5 (1 = not challenging, 5 = extremely challenging), countries their team had considered and a brief description of their team's idea generation process. 152 students completed the survey. As shown in Fig. 8, students' responses indicated that they felt the assignment was more challenging than not, with an average of 3.54 out of 5.

In the final week of the project, student teams presented their final designs to the class. The quality of final designs was diverse in terms of actual construction and functionality. Many students expressed frustration using the low tech materials given, for example, using air-hardening clay that shrinks and using only scissors and knives to craft the prototype. For several students, the design project presented a unique opportunity to actually 'make stuff'. Students were asked in an exit survey: 'What have you learned in this class that you think will be useful in your engineering studies?' Several responses indicated an appreciation for sustainability, teamwork and international issues.

> "One thing is the importance of teamwork and realizing how hard it can be to do well. Also, I was very glad to learn that sustainability and international concerns are being taken seriously in engineering, because those are things I am interested in working with in the future."

> "I have always understood the fact that the Earth has limited resources but not to the extent that this class showed me. I think Sustainable design was something that will be very important for engineers for years to come. We need to make sure to conserve our resources so that they will last for many generations to come."

> "Working in groups toward a multifaceted goal. Also the creativity involved in the sustainable design project."

In order to obtain quantitative response, an exit survey question 'Do you see the relevance of sustainability in engineering design? was asked in spring 2006. Fifty-seven per cent of students chose 'yes, definitely' and 35 per cent of students chose the 'yes, probably' option. The remaining eighjt per cent of students opted for 'not sure', 'no, probably not' and 'no, definitely not' options (from a total of 113 student responses). In order to assess students' performance, a series of individual and team assignments were specified in the SDDP document. Overall, the SDDP accounted for 17% of the students overall grade in the course. Results of final team topics from nineteen of the forty-one workshops show a disproportionately high preference for 'Nutrition' and low preference for 'Energy'. The sari-filter example was probably responsible for the high preference for 'Nutrition' topic. Under the topic of 'Agriculture' the most common design solution was a 'drip irrigation system', and for the topic of 'Education' a common design solution was the 'abacus'. As mentioned previously, there were many instances of student creativity.

Exit survey

An exit survey has been administered in the ENGE 1024 course starting spring 2005 to assess learning outcomes. A relevant exit survey question and samples responses are quoted below:

Question: What, if anything, did you learn in ENGE 1024 that you didn't expect at the beginning of the semester?

Sample responses:

> "I learned a lot concerning ethics and sustainable design which I did not expect to be the primary focus of ENGE 1024."

> "I learned more about engineering as a field than I expected to. I didn't expect to learn what each department does, or about ethics and sustainable design. I think that these things were beneficial."

> "We learned about sustainable development which I knew was important but did not expect it to show up."

> "I learned about Sustainability which is something I knew nothing about beforehand."

> "I did not realize that we would be working in teams as much as we did. I think that this was a good experience because I had very little team experience in the past."

> "Programming, Sustainability, and that engineering not only consists of modern technology but engineering can also be applied to the most simplest things such as making something out of clay, a soda can, and bamboo sticks."

> "I didn't expect to spend half a semester designing something from rope, cloth, and bottles."

> "I learned how important the engineering process is. The whole thing about teamwork and all the beginning steps to a successful design and construction of a prototype were all interesting and I did not expect to see them."

Focus groups

In the spring 2006, two focus group sessions (with 12 students in each group) were conducted with the aid of the Department of Psychology to assess the learning outcomes of various activities in the ENGE 1024 course. Some comments related to SDDP, quoted from the focus group report [22], are listed below:

In regards to how important/valuable the sustainable project was in learning the design process, students stated:

- *It was important; it forced you to take the design process all the way through to the end.*
- *It helped to analyze each aspect of the project.*
- *The only way to learn the design process is though hands-on experiences.*

To a question that asked what students understood about sustainability, students stated that sustainability involves:

- *Building something that lasts forever (or at least a long time) and is environmentally friendly.*
- *Using materials that are readily available.*
- *Benefiting the future, leaving things better than how you found them.*

In-class clickers

In the fall 2005, for the first time, radio-frequency (RF) response pads (i.e. clickers) were used in the ENGE 1024 course to collect prior awareness and in-class assessment data from students during lectures. An example of a clicker survey question regarding student response to

Fig. 6. Team ID-Engine infant carrier inspired by African sling carriers.

study abroad presentations in fall 2005 is shown below (~120 respondents):

Please recall when an engineering senior shared his/her study abroad experiences with you a few weeks ago. I found this presentation:

- *Very useful and it motivated me to consider study abroad options in future (19%)*
- *Useful but it's too early to make plans for studying abroad (48%)*
- *Useful but I'm not interested in studying abroad (25%)*
- *None of the above (5%)*
- *Invalid response (3%)*

Fig. 7. Team Dark Star Hydrovest project design.

Table 1. Study abroad data from students' background survey

Survey Question:	I would consider study abroad as part of my engineering program at Tech provided the following (check all that apply)?	
Options:	Fall 2005 (%) (n=~1000)	Spring 2006 (%) (n=~150)
No, I am not interested in a study abroad program.	33.7	31.5
Yes, if the courses I take transfer to Tech	45.5	49.7
Yes, if I find an interesting study abroad program	48.5	44.8
Yes, if I find financial aid	34.6	31.5

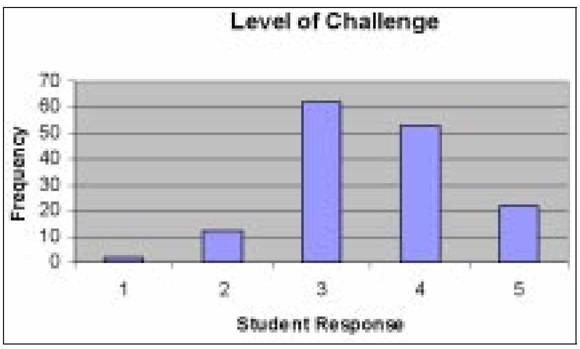

Fig. 8. Results from student survey.

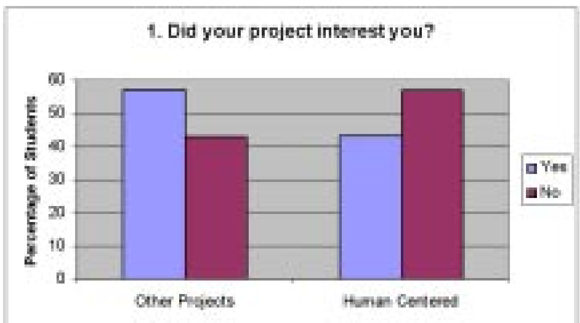

Fig. 9. Project interesting?

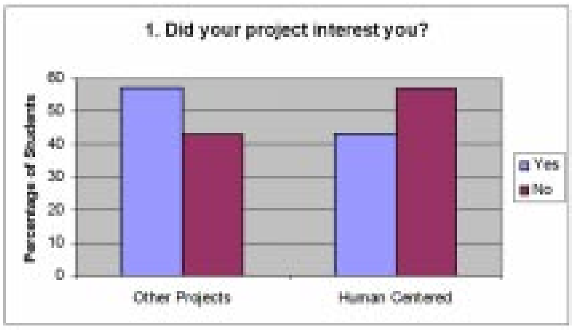

Fig. 10. Project challenging?

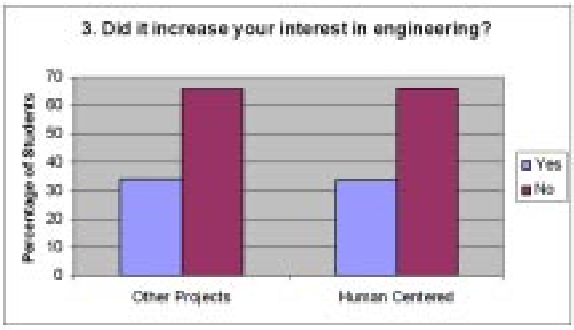

Fig. 11. Increase interest in engineering?

Fig. 12. Increase global awareness?

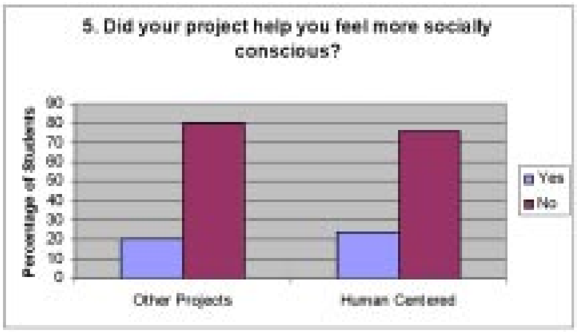

Fig. 13. Increased social consciousness?

A similar question asked after study abroad presentation in spring 2006 yielded following responses (~130 respondents):

- *Very useful and it motivated me to consider study abroad options in future (43%)*
- *Useful but it's too early to make plans for studying abroad (27%)*

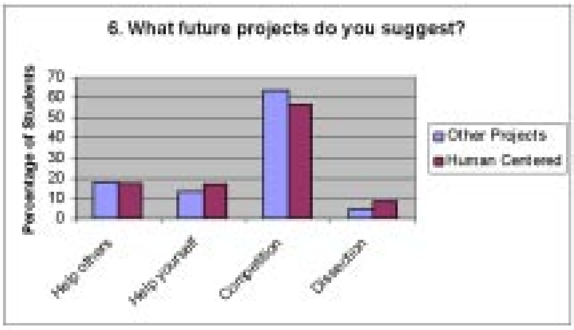

Fig. 14. Future project suggestions.

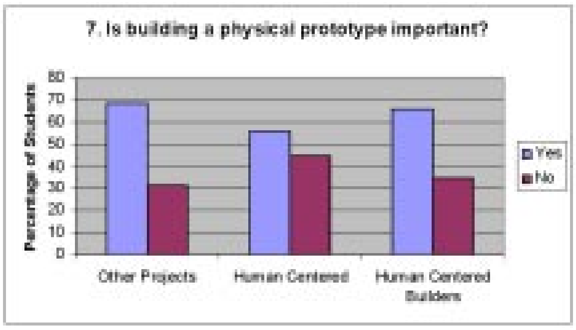

Fig. 15. Should prototypes be built?

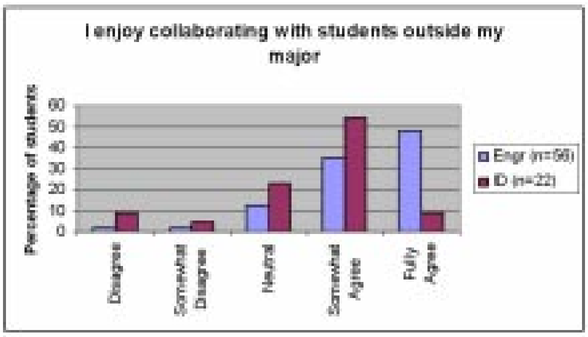

Fig. 16. Is collaboration enjoyable?

- *Useful but I'm not interested in studying abroad (21%)*
- *None of the above (8%)*
- *Invalid response (1%)*

When comparing the above results with the students' background survey (refer again to Table 1), it can be seen that the number of students who were not interested in exploring study abroad options reduced by ~9%. However, it should be noted that the results presented in Table 1 are from an online survey that students completed at their leisure and the above survey questions were asked during class periods using clickers with immediate responses. Also, the above in-class results came from students enrolled in the class section taught by the third author of this paper, who has significant international engineering education experience and emphasized the importance of international education using personal examples.

V.B Exploration of engineering design, ENGE 1114

A similar question asked in the second engineering course, ENGE 1114, after a student study abroad presentation on global awareness and competitiveness and their trips to China and India in spring 2007 yielded the following responses (~200 respondents):

- Very useful and it motivated me to consider study abroad options in future **(19%)**
- Useful but it's too early to make plans for studying abroad **(35%)**
- Useful but I'm not interested in studying abroad **(27%)**
- None of the above **(16%)**
- Invalid response **(3%)**

When considering the results of both courses, roughly 25 per cent of students listening to one or more presentations from students who had a study abroad experience are interested and likely to pursue a study abroad experience themselves and another 36 per cent found the presentations useful, but felt it was too early in the first year to consider studying abroad. As one might expect, there is likely some impact on these results due to the presentation skills of speakers.

PROJECT SURVEY

On April 10th, 2007, toward the end of the semester design project in ENGE 1114, several questions were posed to the three large lecture sections of the classes that consisted of workshops containing the teams completing the three distinct design projects. The following seven questions were posed to the students:

1) Did your project interest you?
2) Did your project challenge you?
3) Did it increase your interest in engineering?
4) Did your project increase your global awareness?
5) Did your project help you feel more socially conscious?
6) If you could select the type of project that future students in coming years will work on which one would you recommend from the following list:
   (a) Devices that could help someone or a group (examples: aids to daily living such as reaching/grabbing, walking, carrying things, eating, gardening, etc).
   (b) Devices that could be helpful to you (examples: lap desk, shelf, organizer, etc).
   (c) Design competitions such as egg-drop, glider plane launcher, etc.
   (d) Product dissection activity followed by design improvement suggestions?
7) Do you think having the ability to build a physical prototype of your final design is important? (Yes or No)

Project survey results

The following are the results of the survey of approximately 460 students. Roughly 300 students doing dissection and pumpkin launchers and roughly 160 students designing assistive technology devices for third-world countries. The data are reported separating the assistive technology for third world countries projects from the other projects.

It seems that a larger percentage of students found the other projects to be interesting (n=300) as compared to the human centered projects (n=160), Fig. 9. It is thought, this is due to the fully specified nature of the dissection and pumpkin launcher projects as compared with the ill specified nature of the human centered projects. A large percentage of both groups found the projects challenging, Fig. 10.

Roughly two to one, students did not think that the projects, regardless of the nature of the project, increased their interest in engineering, Fig. 11. The percentage of students reporting increased global awareness was very low for the other projects, Fig. 12. This result is not surprising since the other projects had little to do with global issues. The human centered projects however were focused on third world countries. Roughly 30 per cent of the students working on assistive technology devices for third world countries reported an increase in global awareness.

There was a slight increase in feeling of social consciousness by students working on human centered design projects, Fig. 13. Because students had a similar response pattern regardless of project, it is felt that students may not be clear about the meaning of the term 'socially conscious'. They may be becoming socially conscious without realizing it. Further clarification is clearly needed here.

When students were asked about suggestions for future projects, they overwhelmingly chose 'Design competitions such as egg-drop, glider plane launcher, etc.', Fig. 14. Here both groups showed a marked preference for competition type projects even though neither group had participated in a competition based project in the current semester. Surprising is the very low percentage of students who suggested product dissection. Particularly those who had done product dissection did not suggest it. Also surprising and disappointing was the low percentage of students working on human centered projects who thought that similar projects should be done in the future. These results suggest that students would prefer competition-based projects regardless of the focus of the project. This may be a result of the prior semester design projects in ENGE 1024 that were evaluated and also judged in a sustainable design competition. There are other possible explanations for these results, but determining the validity of any of these conjectures will require future studies and analyses beyond the data currently available. For instance, competion based projects may be due to the familiarity and training students have from fully specified problems in their prior k-12 educational experiences and in other traditional problem working sorts of courses taken in the sciences and mathematics as freshmen. It may also be possible that gender plays some role in the preference of competition type projects. Clearly, this set of questions led to 'interesting' results and interpreting the student responses to these questions requires further study.

It is very interesting that students who were working on improving products and pumpkin launchers (n=300) felt stronger about building prototypes than the human centered assistive technology teams (n=120), Fig. 15. However, students who were actually building prototypes (n=32) of their assistive devices felt more strongly about building than students who were not building. Designing pumpkin launchers without building and launching probably contributed to the desire to build as reflected in the 'other projects' response.

A survey question asked in 2005 of the collaborative teams was 'I enjoy working with students outside my major'. The responses to that question are shown in Fig. 16. It is clear that both the engineering students and the industrial design students enjoyed working with students from other specialities. The engineers were more positive than the industrial designers.

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

The conclusions that can be drawn from this work are that student responses to international awareness and human centered activities in the first year are quite positive. These activities are contributing to the engagement of students of diverse backgrounds and interests. The engineer of 2020 requires an education that prepares students for life and work when they graduate. The continuation of the activities discussed seems assured. It appears from the results that giving students a choice of projects as well as creating a competition challenge seems to appeal to them. Clearly if students are engaged in their design projects they will produce better results and learn more. It also appears that interdisciplinary collaborative projects are well received by students. The challenge is finding enough other majors such as industrial design to collaborate with engineering teams. In the future more evaluation and comparisons will be made between human-centered projects and other projects.

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