LESSONS LEARNED FROM AN INTERNATIONAL DESIGN-BUILD PROJECT

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ABSTRACT

During the Spring of 2009 a collaborative project was initiated between the Schulich School of Engineering at the University of Calgary (UofC) in Canada and the College of Engineering at Shantou University (STU) in China. This collaborative effort involved the teaming of a group of 30 students from the University of Calgary with a group of 30 students from Shantou University on a single design-build exercise. The students were given a period of five weeks to work on this design-build exercise, with student teams consisting of an equal number of UofC and STU students. Teams were selected at random, with the students spending the first four weeks of the project at their respective institutions and the final week working together at STU. The building and testing component of the exercise took place during this final week. Students were given a known design solution for a Stirling engine from a project-sharing website entitled Instructables (www.instructables.com). Providing students with a known design solution did not lead to a stagnant experience but rather served as a launching point enabling them to consider and develop more sophisticated designs. All of this was completed with large cultural differences, forcing the students to be both creative and adaptive as they learned how to communicate while solving engineering problems.

KEYWORDS

Design-build exercise, international student exchange.

INTRODUCTION

During National Engineers Week in Spring 2000, the US National Academy of Engineering (NAE) announced the "Top 20 Engineering Achievements of the 20th Century." All of the achievements listed by the NAE have had enormous impact on life in the 20th century, however, the combination of two specific achievements, #8 Computers and #13 Internet, have transformed society in ways that are still being assessed. The use of Computers in industry prior to the advent of the Internet consisted mainly of spreadsheet, database, and word processing applications in the general business community, and computer-aided drafting and numerical simulation in the engineering community. With the rapid growth of the

Internet brought on through the introduction of the World Wide Web in the early 1990's, the utility and impact of the Computer was greatly expanded [1]. These two technologies have enabled individuals and organizations from around the world to find one another and communicate in ways that were previously not possible, facilitating what could be referred to as a transformative change process [2].

As a result of this change process and the implications that it has had to industry, it is not overly surprising to find engineering accreditation bodies from around the world placing new emphasis on the importance of engineering in a global community. Examples of these include ABET 3.h in the United States:

> *The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.*

and CEAB 3.1.9 in Canada:

> *Impact of engineering on society and the environment: An ability to analyse social and environmental aspects of engineering activities. Such abilities include an understanding of the interactions that engineering has with the economic, social, health, legal and cultural aspects of society; the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.*

In response to these new graduation attribute requirements, engineering programs have been working to identify ways by which the global perspective can be integrated into curriculum. Despite the increased efforts, data from the US indicates that over the past decade the percentage of engineering students studying abroad increased by only a small margin from 2% to 2.9% [3,4,5]. If one includes activities beyond studying abroad, it has been estimated that only 4% of US engineering graduates have engaged in some form of international activity during their undergraduate careers [5]. Given that very few engineering students engage in activities that enable them to develop global competency, engineering programs have and continue to seek out new and creative ways by which students can be exposed to the important aspects of globalization [6,7,8]. An excellent summary of some of these activities has been provided by Shuman et al. [9].

Downey et al. [10] describe five educational methods that can be used to help develop global competency. These include:

1. ***International enrolment*** refers to the traditional student exchange where students enrol and study for either one semester or an academic year at an institution located in another country.
2. ***International project*** refers to a senior-year capstone design project with the involvement of another (host) country, often including sponsors and co-workers from the host country.
3. ***International work placement*** involves work at a foreign firm for a duration that ranges anywhere from 4 months to an entire year.
4. ***International field trip*** is usually a short-duration visit (one to two weeks) to one or more foreign countries, often including visits to other universities, research laboratories, and industrial establishments (factories, plants, etc.).
5. ***Integrated class experience*** refers to an at-home effort including activities such as "education in the language, customs, history, and government of the country in question."

The international exchange described in this paper took place during the Spring of 2009 and it spanned five weeks. The final week of the exchange involved sending a group of 30 engineering students from the Schulich School of Engineering at the University of Calgary (UofC - Canada) to work with an equal number of engineering students from Shatou University (STU - China) on an intensive design-build experience. Shantou University served as the host institution during this one-week exchange with the design-build experience comprising four days of the seven-day exchange. In reference to the five educational methods defined by Downey et al. [10], the exchange presented in this paper is best described as a hybrid between an ***International project*** and an ***International field trip***. CDIO [11] was the framework for the exchange, providing a common language for both institutions including intended purpose and desired learning outcomes of the student experience.

The paper will begin by providing an overview of the project, including the project selection process. This will be followed by a section describing the logistics and timeline of the project. An observations section will describe selective examples of innovation in the student designs as well as methods used by different groups to help overcome cultural differences while working on the design-build exercise.

PROJECT OVERVIEW

The College of Engineering at Shantou University acted as host during the joint CDIO project. The purpose of the project was to provide Chinese and Canadian students with an opportunity to work together in teams on an engineering project, to increase the knowledge of humanities and culture, to broaden international horizons, and to improve student capacity for communication, teamwork, adaptation, innovation and leadership. Student activities included an innovative design-build project experience, teamwork building exercises, outdoor study / touring, a Chinese cultural display and a Chinese-Canadian cultural exchange.

Project Selection

Given the relatively short timeline associated with the design-build exercise and the fact that the students would be collocated for only one week, it was decided to select a design-build exercise with a high probability for success but still providing a sufficient amount of challenge for the students. Factors that were considered during project selection included:

1. The project needed to be easily understood by both faculty and students at UofC and STU prior to any face-to-face meetings.
2. Ability to complete the project using relatively simple hand tools or small power tools.
3. Project materials readily available in both China and Canada.
4. Ability to complete the project with approximately 24 hours of work.
5. Project budget should be in the range of $25 CAD or 100 RMB per team.
6. Multiple tasks sufficient to engage a team of 8 students over a 24 hour period.
7. A close relation to the field of Mechanical Engineering desirable, although not necessary.

A design-build exercise involving the construction of a Stirling engine from the website Instructables (www.instructables.com), a project-sharing website, was selected for the exercise [12]. The Instructables website provides step-by-step instructions on how to build a wide array of devices, and consequently it can prove to be a very useful resource when planning design-build exercises. The Stirling engine project satisfied all of the above described attributes, and the availability of step-by-step online instructions helped to facilitate communication between UofC and STU faculty members during the project definition phase.

Project Statement

> Student teams were told that they had five weeks to build a Stirling heat engine based on a design solution from the Instructables website. Their goal was to build a Stirling engine that could operate the longest using the heat provided by a single candle. No restrictions were placed on materials, manufacturing methods, or design concepts. The first four weeks involved student teams working at their respective institutions. The final week of the exercise involved student teams working together at STU.

Given that a design solution was already presented in the step-by-step website instructions, it was anticipated that the design-build exercise would be weak on the Conceive-Design elements but strong on the Implement-Operate elements. To the pleasant surprise of the project organizers, many of the student teams used the Instructables design as a starting point rather than a final design solution. Student teams conceived a variety of improvements on the Instructables solution and performed multiple design-build-test iterations, making the project a full CDIO experience. Details of this will be given later in the paper. A picture of one of the Stirling engine models, taken from a group design report, is shown in Figure 1.

Figure 1. Picture of Student-Built Stirling Engine

Instructor Preparation

In order to fully understand the design-build exercise, the authors built their own Stirling engine in advance of the students. This process was valuable as it helped reveal a number of steps from the Instructables website that would provide obstacles for the students. These challenges included: i) the process of casting the piston; ii) maintaining an air-tight seal within the system; iii) preventing sealant from melting due to the heat source; and, iv) crankshaft fabrication to ensure that the stroke of both the displacer and piston did not exceed the vertical dimension of the cylinders.

PROJECT PLANNING AND LOGISTICS

The project involved careful planning at both UofC and STU. Although neither university provided course credit for the exchange, it was still necessary to impose a cap on the number of student participants as student demand exceeded capacity at both universities. The timing of the trip was such that UofC students missed a number of days of classes while travelling, and consequently they were preoccupied completing missed coursework during the two weeks prior to departure. STU students, on the other hand, were in their Spring Festival vacation in the weeks ahead of the co-location project period and consequently they were able to experiment by building prototypes of the Stirling engine in advance of the arrival of the UofC students. Given the different academic calendars, it is often difficult to identify a period of time that works well for students from both universities without having some form of interruption to the regular class schedules.

University of Calgary Planning / Logistics

Student planning began in October 2008, with the list of student participants restricted to 30 students. Student participants consisted of both junior- and senior-year students, and all were from Mechanical & Manufacturing Engineering with the exception of one student from Chemical & Petroleum Engineering. Students applied for funding from the Schulich Student Activities Fund to help cover the costs of airfare. Travel to STU took place during the Spring Reading Week from February 14-22. A meeting was held in Calgary in December 2008 between UofC and STU organizers to discuss the student project. The Stirling engine project was selected as the project and this information was communicated to colleagues at STU. Students and their faculty advisor made travel arrangements and completed Chinese Visa applications in January 2009. Students from UofC were divided randomly into eight teams, with six teams of four students and two teams of three students. Students were given a two-hour briefing in mid January where the Stirling engine project was described. During this meeting UofC students were paired with STU students and told that they could start working on the project. Students were also given a one-hour briefing on expectations and the code of conduct while on exchange.

Shantou University Planning / Logistics

STU organizers recruited a group of 31 students for the project. Student participants included sophomore through senior-year students, with students selected from Computer Science, Electrical Engineering, Civil Engineering, and Mechanical Electronic Engineering. STU students were divided into eight groups, consisting of seven groups of four students and one group of three students. STU student teams were paired with UofC student teams. One STU and one UofC team lead was designated for each team. The agenda for the week-long visit was planned, with the design-build experience covering four days. STU organizers secure materials for the project. STU student teams began working on the project in mid January. This includes construction of the Stirling engine and e-mail correspondence with their UofC team members. Team leads from STU met UofC students at the Shantou airport during their initial face-to-face meeting. UofC students resided in STU dormitories and ate in STU student facilities while at STU.

Project / Exchange Timeline

Weeks 1-4: UofC and STU students are given the project statement and broken into eight UofC-STU student teams. They are told that they can start working on the project and team leads are encouraged to correspond with one another via e-mail.

Week 5:

Day 1 (Sat 14 Feb): Welcome and group meeting – discuss learning manual (1HR 20 min + 2HR)

Day 2 (Sun 15 Feb): Conceive, discuss, and complete design (2.5HR + 3HR)

Day 3 (Mon 16 Feb): Implement the project (All day)

Day 4 (Tue 17 Feb): Implement the project (2.5HR); Implement / group report (3HR)

Day 5 (Wed 18 Feb): Competition: Presentation, demo, conclude and evaluate the project as a group.

Day 6 (Thu 19 Feb): Group dynamics games. Chao-Shan tea – learn tea art and taste.

Day 7 (Fri 20 Feb): Exhibition of arts of Chao-Shan region. Games and sports - billiards, ping-pong, basketball, volleyball. Chinese and Canadian music - folk songs and popular music.

Day 8 (Sat 21 Feb): Students submit final reports. UofC students depart STU for return travel to Canada.

OBSERVATIONS

Table 1 provides information on the eight student teams, including composition, whether or not they were able to build a working Stirling engine, the number of design-build iterations completed by the team, and the number of design modifications made over the base design provided by the Instructables website. As noted, all but one of the teams was able to get their engine to run successfully.

All of the teams constructed two or more Stirling engines, mainly driven by STU students building one engine per team prior to the arrival of the UofC students. Some of the UofC teams were also able to build engines prior to their departure, however, not all of the teams. This was an important aspect in the design-build exercise as students were first able to build and test a design developed by another person (Instructables website). The process of building another persons design provided students with an experience in technical communication as they deciphered step-by-step instructions into a working system. This provided students with insight into how the detailed design could be communicated with more clarity. The experience of building another persons design also provided them with a large number of new ideas for design improvements, and the second design-build iteration involved integration of these new design ideas. The number of new ideas has been listed in Table 1 in the last column.

Table 1
Team Configuration and Results

Team #	# of UofC / STU Students	Working Engine?	# of Design-Build Iterations	# of Design Modifications
1	4 / 4	Yes	2	3
2	4 / 4	Yes	3	5
3	4 / 4	Yes	3	10
4	4 / 3	No	2	3
5	4 / 4	Yes	2	6
6	4 / 4	Yes	2	4
7	3 / 4	Yes	2	5
8	3 / 4	Yes	2	1

Design Modifications

Given that the instructors had also previously built a Stirling engine following the design on the Instructables website, it was relatively easy for them to identify new design ideas in the student work. This information has been summarized in Table 2 where each design modification is listed along with the team(s) that implemented the design modification(s). This approach makes it evident for an instructor to quickly note if teams are borrowing design ideas from one another. The design modifications in Table 2 are listed in order of the number of teams implementing a particular modification. It can be seen that many of the teams opted to put a horizontal support between the two vertical uprights that were holding the crankshaft. The fact that the x's do not correlate well between teams (columns) indicates that the student teams were thinking independently rather than borrowing ideas from one another. A number of the design modifications listed in Table 2 can be seen in the student designs shown in Figures 2 and 3.

Table 2
Uniqueness of Design Modifications

Design Modification	Team Number							
	1	2	3	4	5	6	7	8
Horizontal spacer for uprights	x	x			x	x	X	
Sleeve to limit lateral motion of crankshaft		x	x	x		x		
Ballpoint pen for guide bearing		x	x	x				
Syringe for cylinder	x		x					
Compression fit using bolts			x		x			
Construction using fasteners			x		x			
Stainless steel pipe for small cylinder				x			x	
Two flywheels					x		x	
Bearings in uprights for crankshaft					x			x
Copper pipe for guide bearing	x							
Machined piston down to diameter		x						
Fan for flywheel		x						
Unique gasket material			x					
Leather packing ring for large cylinder			x					
Coiled ring in displacer			x					
Adjustable brackets for uprights			x					
Flywheel with slots			x					
Unique bracket for guide bearing					x			
Thick flywheel						x		
Tape around piston for a seal						x		
Unique material for guide bearing							x	
Copper for large cylinder head							x	
Total Number of Modifications	3	5	10	3	6	4	5	1

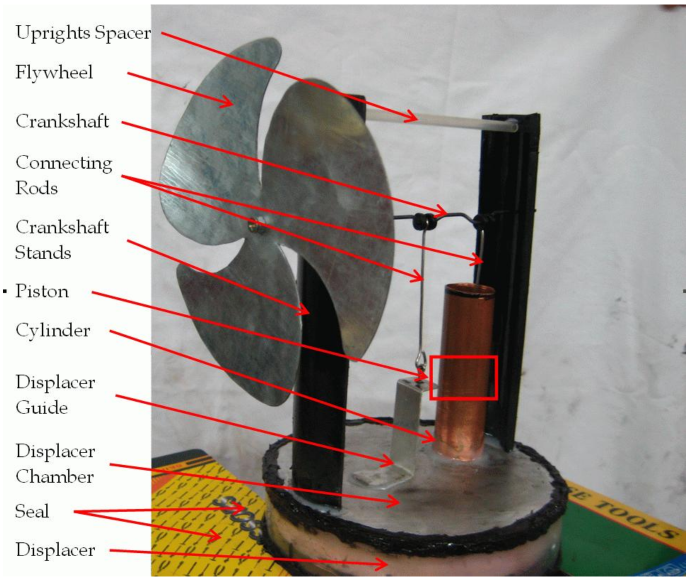

Figure 2. Example of Several Design Modifications

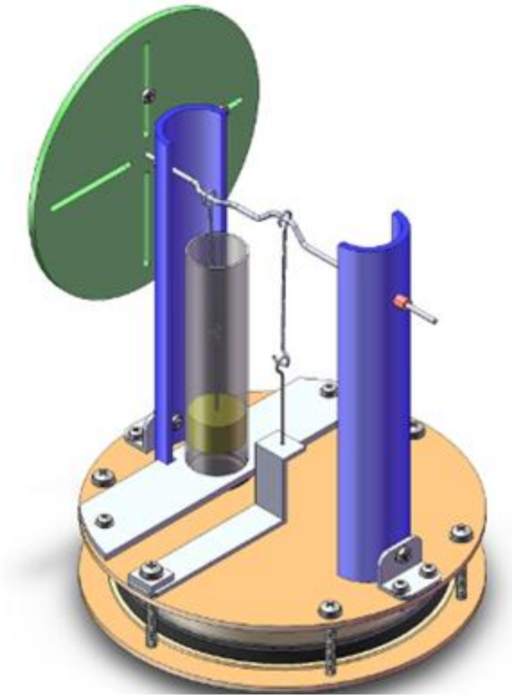

Figure 3. Example of a Design with Numerous Innovations

Student Comments

The best way to summarize the student experience is through the words of the students themselves. The following provides a brief summary of some of the student comments. The comments have been broken into four categories: cultural exchange; communication; engineering problem solving; and overall experience. Based on the content, it is obvious that the students gained a tremendous amount in the short period of time spent working on this project.

Cultural Exchange

We chatted, played basketball, had meals, built the Stirling engine, and smiled with each other. Two different cultures met with each other, at last it sparkled.

After the arrival, we shared the time we had and communicated face to face, and therefore learned more form each other, such as language, environment, music, festival, accommodation, tea culture, calligraphy, etc.

It was very interesting for both sets of students to compare the differences and similarities between our two cultures. Although there are many differences, the similarities between our cultures became increasingly apparent as time went on.

Chinese songs sound like water, they make you calm down to do everything well. Canadian songs sound like fire, they make you feel strong to have a good spirit to work.

We had a very happy time when we worked as a team. Although sometimes we have different working methods, we all think that we have learned a lot from each other. Secondly, we all learned a lot of things about the different culture and different lifestyle. Even though the Shantou University's students don't go to Canada, they all get a lot of things from communication with the students of Canada. Canadian students have learned a little Chinese from this project. And Chinese students have taken the chance to practice their English.

Communication

While the Chinese students spoke very good English, it was not at the same technical and working level as the Canadian students. Therefore, an inevitable communication hurdle needed to be cleared. Patience and finding different ways to explain the same concepts was necessary to successfully complete the project.

The students from the U of C were impressed with the Chinese student's ability to explain technical knowledge and ideas in a foreign language. The group was also able to communicate using the prototype constructed during the initial planning and design and pictures and videos on the internet. The group did not experience any detrimental communication issues.

Collaboration between the two teams was key, and even though members were from opposite sides of the earth, with both culture and language barriers between them, successes were made.

Body language and pictorial demonstration were essential for understanding.

There was also a communication barrier between the Canadian students and the students from Shantou University. This barrier had to be overcome to efficiently proceed with the project. With some team building events and daily interactions, the communication barrier was overcome and ideas were exchanged efficiently between team members. The team members were also adaptable and creative which helped reduce the gap between the Canadian students and Chinese students. Overall, this project helped to bring two cultures together and helped globalize the engineering education of the students.

Engineering Problem Solving

The engine did not continue to move after it was started. The test was stopped because smoke was coming from the engine.

It is important to note that while everything can be planned for in the conceive and design steps, when actually constructing the machine, problems can occur that cannot be otherwise accounted for.

The project shows that constructing a project can be very difficult in a practical sense, especially in order to get the components to work properly and efficiently together.

This project was an invaluable learning experience for all students involved and particularly, the members of team five. Perhaps the most important lessons learned were that language and cultural differences are not necessarily barriers to communication. Although we were not always able to communicate using words, we were able to maintain understanding throughout the project. Good teamwork is an integral part of a successful project and mutual understanding is vital for this to occur. It has become obvious that building a successful Stirling engine leaves little room for error and we learned early on that precision is a necessary quality. Patience is a virtue when dealing with the high temperature, slow drying epoxies. Finally, it is essential to test each individual part of the engine prior to final assembly. It is very difficult to make changes or to pinpoint sources of error after the entire machine has been assembled and fixed in position.

Throughout the project it was evident that the Shantou students tended to focus on precision (i.e. paying attention to details, considering possible areas of failure and trying to do things right on the first try), while the Calgary students tended to believe in problem solving by trial-and-error (i.e. putting together a prototype for testing as soon as possible, finding flaws and making alterations along). This allowed all the team members to learn to consider things from different perspectives.

We tested the engine a second time and it finally worked. That was the moment for all of us. All our teamwork and communication by a group of students from two different cultures, different universities, and different countries coming together for a cause had finally succeeded. At that moment it didn't matter if we were building a pin or an airplane, a car engine or a Stirling engine, it was all about our efforts that we had put together leading to a positive conclusion of the project.

This program has been very beneficial for all the participants. Through collaboration between the two universities, students were able to overcome differences in language, culture, and ways of thinking, and enjoy a brand new experience and learn from people they do not normally interact with. Our team was satisfied with not only the success of our engine, but also the lasting bond that we created with one another.

Overall Experience

In the end I would like to thank the engineering faculty and all other people who helped organize this trip because this trip has been a lifetime experience for me and I am glad I decided to come to China. I don't regret any moment of being here and will remember these students forever.

Everything from the warm welcome by the students to working on the project was an experience beyond imagination. This Stirling engine holds a special place in my life because it was not like any other project I have ever worked on and there won't be any project like this in my life again.

The project was an incredible leaning experience for our team and provided a once in a lifetime opportunity to learn and make new friends in a very unique setting. We like it!

CONCLUSIONS

The project presented in this paper is best described as a hybrid between an international project and an international field trip. The use of a project with a known design solution from the Instructables website provided an easily accessible information source for both UofC and STU students and faculty. The use of a known design solution proved to be rewarding as the students were able to build self-efficacy during their first build exercise, providing them with both the confidence and knowledge to build more complex second-generation engines. The use of a known design solution also made it easier to identify innovation in the student-built engines. The quality of student interaction proved to be very high during the one week when the students were co-located, mainly derived from the challenges associated with fabricating, building, testing, and operating a rather complex device in a short period of time. The UofC-STU exchange project was assessed as being a resounding success.

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