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CHINA MEGA-STRUCTURES: LEARNING BY EXPERIENCE

Abstract

A study abroad program for senior and graduate civil engineering students is described. The program provides an opportunity for students to learn by experience. The program includes a two-week trip to China to study mega-structures such as skyscrapers, bridges, and complexes (stadiums, airports, etc). The program objectives and the methods for achieving those objectives are described. The relationships between the program objectives and the college educational emphases and the ABET outcomes are also presented. Student comments are included from the first offering of the program in 2008.

Introduction

This paper summarizes the development of a study abroad program to China where civil engineering students learn by experience. Consider some of the benefits of learning by experience. Experiential learning increases retention, creates passion, and develops perspective. Some things can only be learned by experience. Once, while the author was lecturing his teenage son for a foolish misdeed, his son interrupted him with a surprisingly profound statement, "Dad, leave me alone....sometimes you just got to be young and stupid before you can be old and wise". As parents, it's difficult to patiently let our children learn by experience.

The author traveled to China for the first time in 2007. He was blindsided by the rapid pace of change in that country, and by the remarkable new mega-structures. More than half of the world's tallest skyscrapers, longest bridges, and biggest complexes (stadiums, airports, etc) are in China, and most of these have been constructed in the past decade. Many innovative green technologies are employed in these mega-structures. These mega-structures are the result of a global process of competitive selection of designs submitted by international architectural/engineering firms. China represents civil engineering on steroids. The author immediately thought that his students needed to experience this.

The author organized a study abroad program titled "China Mega-Structures" that was offered for the first time in May-June, 2008. China Mega-Structures is a senior or graduate technical elective course in civil engineering. Prerequisites include completion of undergraduate courses in structural analysis and either structural steel or reinforced concrete design. The program includes four weeks of intense instruction on mega-structure analysis and design followed by a two-week trip to China, including visits to Beijing, Shanghai, Guangzhou, Shenzhen, Hong Kong, and the Three Gorges Dam. In 2008, eighteen students (including two women) completed the program, and in 2009, twenty students (including four women) have registered for the program. In both 2008 and 2009, the program cost was about $4000, of which the students paid $2500 and the college/department paid $1500 with funds coming primarily from off-campus donors.

A new aspect is planned for the 2010 program. The author will continue to offer the China Mega-Structures program, and another professor will offer a new China Mega-Cities program that will focus on transportation and city planning of large mega-cities. Students in both programs will go on the same two-week trip to China. This works well since the China Mega-Structures program already visits several mega-cities and visits the city planning exhibitions in Beijing and Shanghai. Students will be encouraged to take both programs concurrently. A unique opportunity will be available in 2010, as Shanghai hosts the Shanghai World Expo during the time of the scheduled visit. The theme of the Expo will be "Better City, Better Life", and the focus will be on planning cities for the future.

College Educational Emphases and Program Objectives

The Fulton College of Engineering and Technology at Brigham Young University makes significant financial contributions towards the travel costs of each student in engineering study abroad programs such as the China Mega-Structures program. For graduates to be competitive in the fast-changing global marketplace, the College has established five educational emphases, often referred to by the acronym "LIGHT":

1. Leadership
2. Innovation
3. Global awareness
4. cHaracter development
5. Technical excellence

The objectives of the China Mega-Structures program are aimed directly at these college emphases. This is why the College supports the program so generously. Each of these five emphases will now be discussed in conjunction with the objectives of the China Mega-Structures program. The methods for achieving these objectives and emphases will be explained. During the first year of the program, assessment of these objectives has been limited to student reports, student self-evaluations, and student comments at the end of the program. A few student comments from the 2008 program will be given in the following discussion of the objectives. The relationship between the program objectives and ABET outcomes A-K will also be discussed.

College Emphasis: Technical excellence
Program Objective #1: Teach students the analysis and design of remarkable structures.

One of the most important parts of the China Mega-Structures program is that each student is assigned a specific skyscraper, a specific bridge, and a specific complex in China when they apply for the program in December, five months before the program begins. During those five months, students gather information about their three mega-structures from the literature and from the internet.

After the program begins in May, each student makes a half-hour presentation to the rest of the class before the trip to China. For their skyscraper, they must describe the structural system (i.e. core, mega-columns, belt trusses, outrigger trusses, cap trusses, mega-braces, mega-piles, etc). They must also describe the human impact of their skyscraper including its use and visual impact, and they must describe its environmental impact including any green features in its design. Likewise for their complex, they must describe the structural system, the human impact, and the environmental impact. For their bridge, they must describe the structural system (suspension, cable-stayed, arch, type of anchorage) as well as the construction sequence.

During the trip to China, all of the assigned skyscrapers, complexes, and bridges are visited, and the students record observations and measurements in preparation for their final report. The final report is a written report due at the end of the program after returning home from China. The final report includes the information given during their oral presentation as well as assigned analysis calculations. For skyscrapers, the assigned analysis calculations include: 1) the lateral deflection at the top, 2) the stress in the base of a mega-column, and 3) a check of global buckling. The top lateral deflection is calculated on a spreadsheet using flexural and shear, story-wise, stick models under wind and seismic loads. These stick models are taught to the students in the first weeks of the course, and are contrasted to more rigorous finite element and nonlinear pushover models. For bridges, the assigned analysis calculations include: 1) axial stress in the main cables or arches, 2) support reactions at anchorages and piers, and 3) a check of global buckling. For complexes, the assigned analysis calculations include a calculation of internal forces in a key member selected by the student.

This program objective contributes to the following ABET outcomes: (A) an ability to apply knowledge of mathematics, science and engineering; (E) an ability to identify, formulate and solve engineering problems; (K) an ability to understand the techniques, skills, and modern engineering tools necessary for engineering practice.

This is the first time during their college education that students are turned loose on an in-depth case study of a real, and big, structure. Most become quite attached to their mega-structures, and many go the extra mile in gathering information and learning about their mega-structures. It is rewarding to see their reactions when they see their mega-structures face to face. Their written reports and oral presentations have been very impressive. Here are some of their comments at the end of the program:

> "I became an expert on my assigned building and bridge."
>
> "Studying these very large projects and very tall structures is something that isn't really offered in other courses."
>
> "I feel like I now have a pretty good understanding of how large structures are designed and constructed."

College Emphasis: Innovation
Program Objective #2: Inspire students to think innovatively.

This was accomplished by giving the students up-close and personal exposure to many creative and jaw-dropping structural designs and concepts. Students not only learn about their own three mega-structures, but they learn about the mega-structures assigned to the other students. With 20 students assigned 3 mega-structures each, 60 mega-structures are studied and visited. Pictures will be presented at the ASEE Conference, but could not be included in this paper.

Here is a list of the skyscrapers that will be studied and visited in 2009:

TV and Sightseeing Tower, Guangzhou (pinnacle height = 610m, roof height = 454m)
Shanghai Center, Shanghai (pinnacle height = 580m, roof height = 580m)
Shanghai World Financial Center, Shanghai (pinnacle height = 492m, roof height = 492m)
International Commerce Center, Hong Kong (pinnacle height = 484m, roof height = 484m)
Oriental Pearl Tower, Shanghai (pinnacle height = 468m, roof height = 350m)
West Tower, Guangzhou (pinnacle height = 438m, roof height = 438m)
Jin Mao Tower, Shanghai (pinnacle height = 421m, roof height = 366m)
2 International Finance Center, Hong Kong (pinnacle height = 416m, roof height = 407m)
CITIC Plaza, Guangzhou (pinnacle height = 391m, roof height = 322m)
Shun Hing Square, Shenzhen (pinnacle height = 384m, roof height = 325m)
Central Plaza, Hong Kong (pinnacle height = 374m, roof height = 309m)
Bank of China, Hong Kong (pinnacle height = 367m, roof height = 305m)
The Center, Hong Kong (pinnacle height = 346m, roof height = 292m)
Shimao International Plaza, Shanghai (pinnacle height = 333m, roof height = 247m)
World Trade Center III, Beijing (pinnacle height = 330m, roof height = 330m)
Nina Towers, Hong Kong (pinnacle height = 319m, roof height = 319m)
Pearl River Tower, Guangzhou (pinnacle height = 310m, roof height = 310m)
One Island East, Hong Kong (pinnacle height = 308m, roof height = 308m)
Tomorrow Square, Shanghai (pinnacle height = 285m, roof height = 238m)
Lippo Center, Hong Kong (pinnacle height = 186m, roof height = 186m)

Here is a list of the complexes that will be studied and visited in 2009:

National Stadium (Bird's Nest), Beijing
National Aquatics Center (Water Cube), Beijing
National Convention Center, Beijing
National Grand Theatre (Bird's Egg), Beijing
Guangdong Science Center, Guangzhou
Shenzhen City Hall, Shenzhen
Hong Kong Convention and Exhibition Center, Hong Kong
New Poly Plaza, Beijing
South Rail Station, Beijing
Capital International Airport Terminal 3, Beijing
Chek Lap Kok International Airport, Hong Kong
Pudong International Airport Terminal 2, Shanghai
Linked Hybrid, Beijing
The Elements, Hong Kong
Zhujiang New Town, Guangzhou
CCTV (The Pants) and TVCC (The Boot) Headquarters, Beijing
Parkview Green, Beijing
Temple of Heaven and Forbidden City, Beijing
LDS Temple and Church, Hong Kong
Three Gorges Dam, Yichang

Here is a list of the bridges that will be studied and visited in 2009:

Tsing Ma Bridge, Hong Kong	(suspension, main span = 1377m)
Huangpu Bridge, Guangzhou	(suspension, main span = 1108m)
Yichang Bridge, Yichang	(suspension, main span = 960m)
Xiling Bridge, Yichang	(suspension, main span = 900m)
Humen Bridge, Guangzhou	(suspension, main span = 888m)
Liede Bridge, Guangzhou	(suspension, main span = 219m)
Stonecutters Bridge, Hong Kong	(cable-stayed, main span = 1018m)
Chongming Bridge and Tunnel, Shanghai	(cable-stayed, main span = 730m)
Yangpu Bridge, Shanghai	(cable-stayed, main span = 602m)
Xupu Bridge, Shanghai	(cable-stayed, main span = 590m)
Tin Kau Bridge, Hong Kong	(cable-stayed, main span = 475m)
Kap Shui Mun Bridge, Hong Kong	(cable-stayed, main span = 430m)
Nanpu Bridge, Shanghai	(cable-stayed, main span = 423m)
Badong Bridge, Yichang	(cable-stayed, main span = 388m)
Panyu Bridge, Guangzhou	(cable-stayed, main span = 380m)
Hong Kong Shenzhen Western Corridor, Hong Kong	(cable-stayed, main span = 230m)
Lupu Bridge, Shanghai	(arch, main span = 550m)
Xinguang Bridge, Guangzhou	(arch, main span = 428m)
Yanjisha Bridge, Guangzhou	(arch, main span = 360m)
Yichang-Wanzhou Railroad Bridge, Yichang	(arch, main span = 275m)

There is a story behind each of these remarkable structures. The China Mega-Structures program teaches innovative design by observing innovative design. Site visits are made to some of the structures under construction so that students can learn about innovative construction. This program objective contributes to ABET outcome (C) an ability to design a system, component or process to meet desired needs. Here are some of the student comments at the end of the program:

> "I think differently about engineering now – it's possible to design amazing, beautiful, and different structures."
>
> "In China, we saw a society that knows how to dream, and for two weeks, we became a part of it."

College Emphasis: Leadership
Program Objective #3: Involve students in professional interaction.

This was accomplished by getting students to interact with professors, designers in leading international firms, Americans and students in China, and with each other. They also increased their oral and written communication skills in many activities including their oral presentation and written report.

Multiple contacts were made with the international design firm, Arup, headquartered in the United Kingdom. This is a multi-disciplinary practice of designers, engineers, planners, and business consultants with over 90 offices in 37 countries[1]. The firm was founded in 1946 by the Danish designer, engineer, and philosopher, Sir Ove Arup, who brought together like-minded individuals from a broad range of disciplines and encouraged them to look beyond the constraints of their particular specializations to work in a fully integrated and holistic way, which the firm calls "total design"[1]. In 2008, China Mega-Structures students met at the Arup office in Beijing to hear engineers talk about the new Bird's Nest Stadium, the Olympic Water Cube, the Beijing airport, and the CCTV building, all of which are unique in their design[1]. Arup Engineers also met with the students and took them on a tour of the construction site of the Stonecutters Bridge (second-longest cable-stayed span in the world), and the construction site of the International Commerce Center (tallest building in Hong Kong). In 2009, it is hoped that tours can be arranged with Arup to the construction sites of the remarkable TV and Sightseeing Tower in Guangzhou, and the sustainable Parkview Green complex in Beijing.

Another key contact that was arranged in 2008 was with Professor C.-M. Chan at the Hong Kong University of Science and Technology. Professor Chan's research specialty is the application of structural optimization to skyscrapers. His optimization algorithms have been used in the design of the tallest skyscrapers in Hong Kong. He gave a wonderful lecture to the students on that subject, and helped arrange the construction site visits with Arup, bringing students from his own university along to mingle with the China Mega-Structures students.

The China Mega-Structures students were also given the opportunity to talk with American families that live and work in China. This helped them to understand the day to day aspects of life, and to seriously consider an international career.

Finally, travelling as a group for two weeks allowed valuable group dynamics and relationships to fully develop, which are essential for understanding leadership. This program objective contributes to ABET outcome (G) an ability to communicate effectively and ABET outcome (D) an ability to function on multi-disciplinary teams. Here are some of the student comments at the end of the program:

> “The experiences I've had in this course have helped me improve my communication skills and enhanced my ability to interact with my peers and professors."
>
> "I felt a uniting between the students and the faculty, [both] individually and as a group"
>
> "I also believe it was a good experience for the undergraduates to get to know the graduate students."

College Emphasis: Global awareness
Program Objective #4: Expose students to the culture, politics, and economics of China.

China is one-fifth of humanity, is the world's largest carbon emitter, has the world's fastest growing economy (soon to be the largest), and is the world's biggest consumer of construction materials[2]. By 2020 the urban population of China is expected to increase from 42% to 60% of the total population in the country[2]. This movement of people from rural farms to urban factories is the largest mass migration in human history. This migration has been accompanied by a dramatic increase in the average income of individuals -- the "flattening" of the world. It is estimated that over a thousand vehicles are being added each day to Beijing[2]. The average residential floor space in China will increase 50% from 2003 to 2020, and the average Chinese energy demand will grow 4.4% annually[2]. It is not an exaggeration to say: As goes China, so goes planet earth. In his new book, *Hot, Flat, and Crowded*[2], Thomas L. Friedman writes, "For me, the crucial question of this book is actually two questions: 'Can America really lead a real green revolution?' and 'Can China really follow?' Everything else is just commentary". In just two decades, China has changed from a repressive socialist economy to an individualistic free-market economy. The change is staggering.

The only way to understand what is going on in China is to be there and experience it. The China Mega-Structures students ate their food, participated in their economy (shopping), heard their stories, learned a little bit of their language, listened to them sing, and watched them work and play. In the winter semester prior to the study abroad program, students participated in a 1/2 credit hour prep class where they listened to lectures from professors who specialize in China politics, China economics, and China culture, and they discussed books on these same subjects. This program objective contributes to ABET outcome (H) the broad education necessary to understand the impact of engineering solutions in a global and societal context. Here are some of their comments at the end of the program:

> “Wow. It’s was awesome seeing how the people live and do things, visiting historic sites, and feeling their culture.”
>
> “As neat as some of the ancient Chinese sites were, the real treat for me was the chance to see China now, because I believe years from now this era is going to be an important one in Chinese history.”

College Emphasis: cHaracter development
Program Objective #5: Develop moral responsibility towards people and the environment.

This was accomplished by witnessing the human and environmental impact of civil engineering projects. For example, the students not only observed the Three Gorges Dam, but they traveled by boat to view the beauty of the Three Gorges that were impacted by the dam, and they talked with some of the million plus people that have been relocated since the dam was built. The economic benefits of the dam were discussed such as the hydroelectric power, the flood control, and the increased shipping accessibility. Students considered the sad extinction of two large species from the Yangtze river: the Yangtze river dolphin, which could grow to 8 feet long and weigh up to a quarter ton, and the Yangtze giant soft-shell turtle, believed to be the largest freshwater turtle in the world. In 2009, they will visit the Research Institute of Chinese Sturgeon where Chinese scientists are fighting to help this large Yangtze river fish survive.

Many of the mega-structures have interesting green design characteristics. For example, the Pearl River Tower in Guangzhou harvests wind energy as it passes through two large openings in the tower. The Linked Hybrid in Beijing harvests geothermal energy from 660 wells that are each 100m deep. The Parkview Green in Beijing encases skyscrapers in a shield that provides thermal insulation from the cold winters and hot summers.

This program objective contributes to ABET outcome (F) an understanding of professional and ethical responsibility, and ABET outcome (J) a knowledge of contemporary issues. All of this is designed to develop a sense of compassion for the people and the environment affected by civil engineering projects. Here are some of the student comments at the end of the program:

> "I was able to interact with the people, and begin to understand the impact of these projects on their lives."

> "Civil engineering is a very real skill that impacts the daily lives of normal people, and now I know that, not only as a fact I've been taught, but as a person who has experienced it."

CONCLUSIONS

The study-abroad program described in this paper achieved the goal of providing an opportunity for students to learn by experience. The students experienced China, they experienced in-depth case study, they experienced professional interaction, they experienced exposure to numerous innovative designs, and they experienced the human and environmental impact of large engineering projects. These experiences made them excited to be structural engineers, and contributed to ABET outcome (I) a recognition of the need for, and an ability to engage in, life-long learning. Here are some of their comments at the end of the program:

> "I loved this course. This course has been a culminating experience for me."

> "This course was easily the highlight of my studies at BYU."

> "How do you write a paragraph on an experience that has altered your life?"

> "Mark Twain said: Don't let schooling interfere with your education. Our trip to China didn't just school us; it educated us."

Bibliography

1. *Solutions for a Modern City: Arup in Beijing*, Black Dog Publishing, London, UK, 2008

2. T.L.Friedman, *Hot, Flat, and Crowded -- why we need a green revolution and how it can renew America*, Farrar, Straus, and Giroux Publishers, New York, USA, 2008