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A Qualitative Study to Assess the Learning Outcomes of a Civil Engineering Service Learning Project in Bolivia

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Abstract

To better understand the learning outcomes of engineering service learning projects carried out in an international setting, we performed an exploratory study to assess the learning outcomes of a student-led project involving the design and construction of a pedestrian bridge in a village in rural Bolivia. The students kept reflective journals during their four-week stay in Bolivia. We have analyzed the journals from a phenomenological framework. The data suggests that the design experience stretched the students' abilities to communicate effectively across cultural and linguistic barriers and also strengthened the students' abilities to work effectively as a team. There were multiple issues that arose in the field that required deviations from the original bridge design, forcing the students to make important engineering decisions in the field. The hands-on nature of the project gave students a newfound appreciation for scale as well as practical experience using surveying equipment, mixing and pouring concrete, working with power tools, and using safety harnesses. Additionally, students reported a fresh appreciation for civil infrastructure and a meaningful understanding of the ways in which civil engineering can be used to benefit society at a global scale. The paper presents a detailed analysis of the qualitative data and offers implications for others wishing to adapt our work.

1. Introduction

Several universities have recently implemented service learning programs in engineering to address shortcomings of traditional engineering classes[1]. By definition, service learning is a pedagogical practice that emphasizes experiential learning through structured community service[2]. Service learning produces a symbiotic relationship between the academic institution and the community by providing learning experiences for students while satisfying a real need within the community. Reflection is a key component of service learning because it instills a deeper understanding and awareness of the global and social context in which the project is carried out[1]. Thus, service learning naturally addresses an existing gap in traditional engineering pedagogies by requiring students to develop an awareness of the impact that engineering has on society and beyond. In addition, a well-formulated service learning project may also satisfy educational objectives related to technical competency, creativity, communication, and teamwork.

To better understand the learning outcomes of engineering service learning projects carried out in an international setting, we performed an exploratory study to assess the learning outcomes of a student-led project involving the design and construction of a suspended pedestrian bridge in a village in rural Bolivia. In 2013, a team of five university students traveled to Bolivia to complete the construction of the bridge. During their four-week stay in Bolivia, the students were asked to keep reflective journals that were guided by a series of weekly writing prompts. We considered the following research questions in the study:

- To what degree did the project advance the students' mastery of technical concepts?
- How did complexities (e.g., linguistics, local construction practices, diverse social and

cultural environment) related to the site affect students' perceptions of engineering design/construction, particularly within a global and social context?
- How did the experience affect the students' confidence in tackling unpredictable and ill-posed engineering problems?
- How did the project affect the students' abilities to function in multidisciplinary teams?
- What communication skills were strengthened as a result of the project?

2. Context for Learning

A Bridges to Prosperity student chapter designed and constructed a suspended pedestrian bridge in central Bolivia in 2013. The members of the student chapter designed the bridge according to the design manuals published by Bridges to Prosperity[3], and a team of five university students traveled to the site for a period of four weeks to oversee a major portion of the construction. The team of traveling students was comprised of four students from the Department of Civil and Environmental Engineering and one student from the College of Literature, Sciences, and Arts who was fluent in Spanish. One of the students was a graduate student, and the remaining students were upper-division undergraduate students (i.e., juniors and seniors). The students cited two primary reasons for participating in the project:

- Desire to participate in a real-world engineering project from conception to completion
- Desire to use professional skills and knowledge to address a significant infrastructure need in an underprivileged community

Staff members from Bridges to Prosperity assisted the students in identifying the bridge site, establishing the bridge construction contract with the community, coordinating labor contributions from the community, and procuring materials for the bridge. Staff members were periodically available on-site during construction to help the students resolve problems in the field and to oversee critical construction tasks. Additionally, an engineering professional (i.e., technical mentor) was onsite for approximately one week to assist with the most challenging construction tasks. However, the students assumed the role as the lead engineers for the project, and therefore were responsible for ensuring that the bridge was constructed properly and according to schedule.

The bridge to be constructed was a suspended pedestrian bridge that was approximately thirty meters in length and crossed a river. A photograph of the completed bridge is shown in Fig. 1. The construction process involved the following tasks: (1) excavation, (2) tier and tower construction, (3) anchor and cable installation, (4) cable sag set, (5) approach construction, and (6) fencing and decking installation. Prior to the students' arrival in Bolivia, the Bridges to Prosperity staff coordinated the excavation and tier and tower construction. The students were responsible for working with members of the community to complete the excavation, install the anchors and cable, set the sag of the cables, construct the approach, and install the fencing and decking. When the students arrived on site, the tier and tower construction was complete and the anchor holes had been excavated. However, the anchor holes were located five meters from their design locations. The students performed some calculations in the field and determined that the anchor holes had to be moved to ensure proper safety of the bridge. Additionally, the cables specified in the original bridge design did not arrive so the students had to revise the design to

Figure 1. Photographs of the Completed Bridge

use fewer cables and one of the cables had to be spliced to achieve the required length. Changes to the design that were made in the field were based on hand calculations and engineering judgment. Despite deviations from the original design and construction plans, the project was completed on schedule and the bridge was opened to the public.

3. Research Method

We asked the students to keep reflective journals over the course of their travel to Bolivia. Writing prompts were provided to elicit responses that would answer the research questions posed in Section 1. We devised the reflection questions to measure the expected learning outcomes, and we timed the questions to coincide with major milestones in the construction schedule, as shown in Table 1. The students were given the following guidance in keeping their reflective journals:

> Enclosed are a series of writing prompts to be completed over the course of your trip to Bolivia. There is no specified word limit (maximum or minimum) for each question. However, it is expected that typical responses will range from 250-500 words per question. When answering each question, reflect on your experiences, be as specific as possible in writing your response, and try to include examples (when possible) to illustrate a point.

Four out of the five students who participated in the project completed and submitted their reflective journals (i.e., $n = 4$). Handwritten journals were digitally transcribed prior to our analysis. We analyzed the writing prompts within a phenomenological framework[4], allowing common themes to be identified from the students' responses. The analysis involved (i) the identification of words, phrases, and anecdotes that corresponded to meaningful learning experiences (i.e., "individual natural units"), (ii) rereading each unit with "openness" and identifying of the central theme for the unit, (iii) evaluating the data systematically in regards to the research questions, and (iv) clustering the experiences into broader (i.e., "revelatory") themes[5,6]. The themes were then examined in the context of relevant literature and the findings supported by quotes from the participating students.

The themes presented here encompass what we believe to be the key learning outcomes of the international service learning experience in which the students participated. To ensure trustworthiness of the results, two of the authors independently performed thematic analysis of

Table 1. Reflection Questions Corresponding to Expected Learning Outcomes

Timing	Question	Expected Outcomes
Pre-trip	Why is this project important to you? What personal and professional goals have you set for yourself for this trip? What do you hope to get out of this experience? What are the greatest challenges that you foresee in carrying out the project?	Understanding motivation and preconceived notions about the project
Week 1 (orientation, site surveys)	Describe the apparent challenges that Bolivia faces in regards to the creation and maintenance of infrastructure (e.g., roads, buildings, power/water supply). You can frame your response in terms of construction techniques, the amount and type of resources available, the quality of construction, etc. What are your initial impressions of Bolivian culture and lifestyle, particularly in the communities that you are working closely with?	Engineering in a global context Overcoming social, cultural, communication barriers
Week 2 (anchor construction)	Describe your interactions with the community members, including positive and negative experiences. What challenges have you encountered in regards to communication and/or reaching consensus on important construction tasks, and how were these challenges overcome?	Overcoming social, cultural, communication barriers Engineering in a global context Teamwork
Week 3 (set cable, cross beams)	What have been the most challenging construction tasks so far? Were there any differences between how you planned the construction vs. how it was actually executed in the field?	Tackling unpredictable, ill-posed engineering problems Engineering in a global context
Week 4 (deck, fence)	Reflect on your initial impressions of Bolivian culture and lifestyle from your first week in the country. How have your impressions evolved over your time in Bolivia? Describe your greatest success (or successes) during the project's execution. How did it make you feel? How did your team react? How did the community members react?	Overcoming social, cultural, communication barriers Tackling unpredictable, ill-posed engineering problems Teamwork
Post-trip	Reflect on your responses to the pre-trip questions regarding the importance of the project, your personal and professional goals, and the challenging aspects of the project. Have your views changed from your prior responses (e.g., would you change any of your previous responses)? Summarize what you have learned from the experience of constructing a bridge in Bolivia. What new technical and interpersonal skills have you developed? What knowledge or understanding do you hope to retain in the future?	Personal and professional growth Supporting evidence for measured outcomes

the data and cross-checked their findings. The participants of the study were also asked to review the findings presented in this paper (i.e., member checking).

4. Measured Learning Outcomes

The learning outcomes were grouped into three major themes, namely:

1. Technical skills relevant to civil engineering
2. Global competency and cross-cultural communication skills
3. Teamwork and interpersonal communication skills

The broad themes are given in Table 2 along with constituent themes that stemmed directly from the individual natural unit analysis. We found that a wide range of field engineering and other technical skills were cultivated as a result of the service learning project and that these skills were highly valued by the students. The data provided significant evidence in support of global competency and cross-cultural communication skills as well as teamwork. Evidence of the learning outcomes for each of these themes is provided in the discussion that follows.

Table 2. Learning Outcomes from Thematic Analysis

Technical skills: Leadership/project management skills, quality control, safety, engineering tolerances, sense of scale, keeping to a schedule, decision-making skills, adapting to site conditions, understanding design philosophy and factors of safety, reading construction drawings, excavation/foundation construction, mixing/pouring concrete, building rebar cages, constructing a rock wall, using power tools, Abney levels, and safety harnesses
Global competency and cross-cultural communication skills: Global perspective regarding civil infrastructure, understanding of Bolivian culture, appreciation of and tolerance for life without modern conveniences, cross-cultural communication skills
Teamwork and interpersonal communication skills: Conflict resolution, interdependence

4.1 Technical Skills

Because of differences between the field conditions and the original bridge design, the project provided numerous opportunities for the students to learn about decision-making in the field and handling unpredictable, ill-posed problems. One example can be seen in the excavation of the anchor holes, which were located five meters from the design locations when the students arrived at the site. One student described the situation upon the team's arrival as follows:

> The construction plans had the exact position of the anchor holes laid out-approximately 13m from the rear face of the tier to the back of the hole. The placement of the anchors was critical to ensure that the load on the cables did not pull the anchors out of the ground. When we arrived at the bridge site, the holes were dug in the wrong place! Also, the manual stated that for a bridge spanning 30m to 60m there needed to be 3m of cover. The anchor was 1m tall, so that meant we needed a four meter deep hole…on both sides!! On day one we were struck with panic!

The students clearly recognized the deviation between the as-built and design locations for the anchor holes as well as the importance of proper anchor construction to the safety of the bridge. Another student elaborated on the team's course of action:

> We asked [a Bridges to Prosperity staff member] what we should do about it and her response was "you're the engineers; you can decide what to do." So, we ran a few calculations and decided that we needed the excavation to be where we originally intended it to be to achieve an acceptable margin of safety. So we had the community fill in the hole and dig a new hole 5 meters away (excavation for the anchor cage).

In the face of an unexpected problem in the field, the students initially "panicked" and sought advice from a Bridges to Prosperity staff member. However, the staff member gave the students an opportunity to learn from the experience by placing the decision in the students' hands. By checking the level of safety of the existing condition, the students demonstrated sound engineering judgment, even though their decision to dig new anchor holes required two additional weeks of labor and therefore delayed other construction tasks.

The challenging site conditions gave students an opportunity to learn about the factors of safety that are built into the design manuals and that field conditions and other constraints often require deviations from the original design. For example, the students were only able to dig the anchor holes two meters deep in a two week period despite the fact that the design manuals called for anchor holes that were four meters deep for the given bridge span. When the Bridges to Prosperity staff member appeared on site, she said that the two meter holes were adequate, which seemed to surprise the students. After some discussion, the students learned that the specifications in the design manuals were overly conservative. In response, one student noted, "The B2P design guidelines for dirt coverage were not hard and fast at 3 meters. So even if our bridge was 40m long, a 2.5m hole would have most likely been okay." Regarding the adequacy of the 2m anchor holes, another student stated,

> I think the problem lies in the accounting of people standing shoulder to shoulder in regards to the load the bridge must withstand. There must be factors of safety built in, but people will not STAND shoulder [to shoulder] on the bridge. It is a bridge used for passage and I think the most amount of people we have seen on the current bridge at one time is 5. … [The Bridges to Prosperity staff member] suggested we redo our calculations in our meetings back home and calculate the horizontal and vertical forces of the holes being 2m (excluding anchor space) and make sure we see the safety of it.

Rather than doing the calculations upon their return to the U.S., the students calculated the new forces in the cables and verified the safety of the modified design while in the field. Thus, the students learned about the sources of conservatism in the design manuals and were able to adapt the design to the site conditions, which did not allow for excavation to the design depth of four meters due to the soil conditions and available tools (i.e., shovels and picks). Rather than employ a less conservative design, the students were able to increase the safety of the shallow anchor holes by extending the approach walls to cover the anchors, as described by one student:

> The holes were not dug to our original specifications, either. We strengthened the horizontal resisting force against the anchors by building the approach walls to up to the concrete anchors. This way, if the anchor wanted to pull out, it would have to move the massive rock wall that we so expertly hand crafted!! This will never happen! The cables were at an angle such that the anchors would not be able to pull out in the vertical direction with the amount of soil that was on top of the anchors.

Difficult construction tasks also gave students an opportunity to demonstrate creativity to improve the efficiency of the construction process. For example, one student described a system that was devised to lift dirt out of the anchor holes at greater depths:

> …digging at that depth became difficult because it was a great distance to lift a shovel. We eventually developed a system in which we used buckets to haul the dirt out – we had 2 people in the hole digging/pick axing and filling buckets with the dirt/soil and 2 people at the top of the excavation pulling the buckets out of the excavation and depositing them onto a dirt pile.

Another student mentioned similar innovations in the construction process such as "jumping on cross beams to weight them down" during the decking installation. Teamwork appeared to be an integral component of the innovations in the field, as described in Section 4.3.

It is important to note that the students acknowledged that the process of physically constructing a bridge addressed significant learning outcomes that had not been covered in the classroom. The challenging site conditions and unforeseeable complications in the field gave students an opportunity to learn about construction delays and adapting the design to specific site conditions. One student explained the learning experience as follows:

> There is so much of the bridge building process that you can't prepare for in the classroom, so you just get out there and do the best you can. I think I learned that 90% of what we did we just learned on the fly from [the Mason], [the Bridges to Prosperity staff], and even each other. Each bridge is different and each site has its own challenges, so the only thing to do is to be constantly thinking of what the task at hand is and if there is any way to improve it. The work we did required about 30% classroom knowledge and 70% just common sense and physics laws. Each are important and it was a good mix.

The hands-on nature of the project also allowed the students to gain practical experience in construction that is not commonly addressed in the civil engineering curriculum. When asked to summarize what they had learned from the experience of constructing a bridge in Bolivia, the students reported that they learned "how to mix concrete in large quantities, how to build a rock wall, how to build a foundation, how to use an Abney level, how to level the bridge cables, how to build rebar cages, how to work with power tools to build the deck of the bridge, working with a harness suspended up in the air," as well as how to "read construction drawings and design specifications," and "proper construction and purpose of a rock wall."

While these tangible skills are to be expected, we believe that the hands-on nature of the project allowed the students to develop an appreciation for scale and engineering tolerances that had not been previously developed in the classroom. This was particularly evident in the excavation of the foundations of the bridge, which had to be dug by hand due to the lack of excavation equipment. One student stated, "In the classroom it is easy to say 'dig a 5m hole,' but with a finite amount of time, people, and only shovels, this is easier said than done." As described by another student,

> I also had a wakeup call with how deep holes really are. All through college I would design something and call out a certain depth; now I know the effort that goes into digging something that deep! A 2m deep hole is enormous when you dig by hand! Before, it seemed like such a small amount.

Regarding engineering tolerances, one student stated that the act of building a rebar cage by hand taught him "that it is very difficult to get everything to the correct dimensions!"

4.2 Global Competency and Cross-Cultural Communication Skills

The project contained elements that allowed the students to develop global competency, particularly because the project was carried out in an international setting and required the students to work closely with members of the community. In relation to global competency, we found that language barriers and cultural differences provided important learning experiences for the students in regards to cross-cultural communication skills. Global competency in engineering is defined by Downey et al.[7] as the attainment of "knowledge, ability, and predisposition to work effectively with people who define problems differently." At a minimum, global competency requires students to have an understanding of the similarities and differences of people from different countries, the ability to analyze how the value of engineering by people from different countries is affected by their lives and experiences, and a predisposition to appreciate and respect the different knowledge, skills, and perspectives that people from different countries can bring to an engineering project[7].

The juxtaposition of resources and lifestyles between Bolivia and the U.S. provided a rich opportunity for cultivating global competency in the context of engineering. The students' responses to the reflection questions provided significant data for the assessment of global competency. For example, in the Week 1 questions, several students acknowledged the differences between U.S. and Bolivian infrastructure but also reflected on the geographical, political, and resource limitations that led to the state of the infrastructure, indicating a deeper level of understanding. The students were also able to recognize perspectives that were different from their own and realized that engineering work (i.e., infrastructure) holds different value and significance to people living within different circumstances. As one student stated, "I also was able to gain a more global perspective on the needs for infrastructure development. Before, I think it was just something I had read about and knew there was a need for it, but it became more real to me during this trip." Another student remarked, "I will never take infrastructure here, or anywhere, for granted because a lot of work, planning, and effort is required."

4.3 Teamwork and Interpersonal Communication Skills

Borrego et al.[8] discussed several constructs of importance to teamwork in engineering, namely, shared mental models, interdependence, trust, conflict, and social loafing. For the project being studied, shared mental models were fostered prior to travel through a series of pre-trip meetings between the students, the faculty advisor of the student chapter, and the Bridges to Prosperity staff. Through these meetings, the students developed a shared set of goals to be accomplished during the trip, created a detailed construction schedule, designated task leaders for each construction task, and discussed and planned for various scenarios that might be encountered in the field. Interdependence was high due to the complex and high-stakes nature of the project. For example, quality control naturally required certain team members to check the work of others, which was described by one student as follows:

> [B]efore we could back fill you must be 100% sure of your anchors work because if you aren't there is no going back. Our group responded well to ensuring the small details that would ensure the safety of the bridge. Some examples are well-placed and well-rodded concrete around anchors, all clamps tightened to at least 25% reduction, and backfilling with all different size rocks and particles. We relied on each other to double check each others work throughout these steps. For example, [one student] and I would set the clamps at their appropriate distances and then have [two other students] check to make sure they looked straight and even and then we would tighten them.

Additionally, challenging construction tasks provided significant opportunities for group-level creativity. In particular, the students utilized a team-based approach to innovate various construction processes so as to improve efficiency, as mentioned in Section 4.1. One student described the team's approach as follows:

> We were constantly offering ideas we thought would make this process more efficient. Some ideas were accepted by the group as feasible, others not so much. That's how the group worked, offer new ideas of how to do every task from lifting dirt out with buckets to jumping on cross beams to weight them down, and then some would be accepted, others not. Nothing was personal, but we were given large challenges and so any idea on how to make something easier/more efficiently should be heard.

According to Sears and Baba's multistage, multilevel theory of innovation[9], the group-level innovation was the product of the team's motivation to innovate (as evidenced in this case by the team climate and group norms), resources in the task domain (as evidenced in this case by team-member exchange and possibly the team size and diversity), and innovation management skills (including leader commitment/support and constructive conflict). Interestingly, these qualities were cultivated naturally within the team without formal leadership training or organizational structure. The quote above also illustrates a high degree of trust amongst the team members, with participation from all members being accepted without judgment. For example, one student expressed, "Ideas to make tasks more efficient can always be shared, no matter how crazy because engineers are meant to think outside of the box."

Some conflict arose within the team. The students had to exercise conflict resolution skills, such as effective communication and patience, in order to achieve consensus in a number of instances. As one student described,

> We had to make decisions as a group and at some times, it was easy to lose patience with team members. Sometimes I wanted the group to follow my way of doing something versus another way of doing something. Communication is key, and a good leader keeps his cool in stressful situations. Tempers were not an issue for our group, but I can see where a less cohesive group could get into a lot of trouble when people have differing opinions.

There was no evidence in the students' journals of social loafing, which is defined as the inclination of certain individuals to exert less effort in a team setting than they would otherwise exert individually. This is most likely due to the fact that the students had a vested interest in the project's success, i.e., the students had committed significant personal resources and were motivated by the purpose of the bridge, as indicated in the responses to the pre-trip questions.

5. Implications for Engineering Education

The civil engineering service learning project provided a unique opportunity for the students to develop a range of technical and non-technical skills that are not fully addressed in traditional civil engineering curricula. Our findings support the notions that international experiences strengthen global competency and communication, real-world engineering projects improve mastery of technical skills as well as interpersonal communication skills, and service learning instills a greater understanding of the social context of engineering work.

The bridge construction project is particularly significant for civil engineering education due to the breadth of technical skills that were cultivated, as described in Section 4.1. Infrastructure projects encountered in civil engineering are often so vast in size and scope that it is unfeasible to replicate the real-world engineering experience in a classroom. Consequently, students spend most of their time designing and analyzing *components* of a system and rarely see a project through to completion. Our findings suggest that comprehensive service-learning projects in civil engineering may be useful for teaching students important skills (e.g., handling unexpected and challenging site conditions) that are not being addressed in the classroom. The students who participated in this study indicated that seeing a project through to completion was one of the greatest motivators for participating in the project, and they noted that the field engineering skills were some of the most important learning outcomes of the experience. The extent of learning was aided by the fact that the students assumed the primary responsibility for the bridge and were allowed to make mistakes in the field with, of course, the supervision of a trained engineer.

Our data also suggests that hands-on construction experiences are important for giving students a "feel" for scale, tolerances, and construction sequencing.

The degree of learning is believed to be considerable in the project considered here due to the intersections between the international, real-world problem-based, and service learning experiences. In this paper, we have focused primarily on the technical skills that were cultivated from the design-build experience, although global competency, communication, and teamwork played equally important roles in the learning outcomes of the project. Our findings cannot be generalized at this point in time due to the small sample size (n = 4) and the limited data that was collected in our study. However, our study justifies further research to better understand the learning outcomes in similar types of projects.

6. Conclusions

We have performed a qualitative study of a civil engineering service learning project in which a team of students traveled to Bolivia to oversee the construction of a suspended pedestrian bridge. We found that the students learned technical skills as well as strengthened their global competency, teamwork, and communication skills. Unexpected complications in the field gave the students an opportunity to learn how to manage unpredictable and ill-posed engineering problems and to make important decisions on the fly. The hands-on nature and comprehensive scope of the project allowed the students to develop a range of technical skills of relevance to civil engineering. By working closely with members of the community, the students were able to gain an appreciation for Bolivian culture, strengthen their global competency, and improve their cross-cultural communication skills. The desire to complete a tangible construction project fostered interdependence, which supported the effectiveness of the team and led to innovation. The study is a preliminary study to understand the learning outcomes of engineering service learning projects carried out in an international setting.

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