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A Methodology and Experience of Facilitating International Capstone Projects for Multidisciplinary Fields: Costa Rica Internet of Things (IoT) Case Study

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Introduction

This paper explores the opportunities, challenges, and pedagogy of a real-world, hands-on, international capstone project. We present a case study in which three faculty members from diverse disciplines, including engineering, computer science, and political science, guided a team of students from the Bachelors in ISAT (Integrated Science and Technology) program at James Madison University for a two-year capstone experience spanning the students' junior and senior years. The paper describes the overarching pedagogy and goals of the two-year ISAT capstone experience and describes how the ISAT "Holistic Problem Solving Habits of Mind" are integral to our teaching and mentoring approach in applied projects. The Habits of Mind are structured to facilitate student reflection on the technical, social, and ethical contexts of their work. We explain how the Habits of Mind structured our pedagogy from the problem identification phase through project completion. We describe the phases of the team's engagement with stakeholders at Punta Leona Hotel and Club Beach Resort, including: early problem identification regarding energy conservation and saving concerns; project development, in which students developed a solution centered around remote, app-based control of large energy consuming devices (e.g., air conditioning units) using Internet of Things (IoT); execution and implementation of the project over a three week period during a study abroad trip in Costa Rica; and remote follow up with stakeholders after project installation. One of the goals of the experience is for students to understand project management and interdisciplinary collaboration in a hands-on way, and to understand that stakeholder engagement is an integral part of the process. The goals, methodology, organizational structure, logistics, lessons learned, and the instructors' observations of the experience are also described in the paper.

Overview of Relevant Literature: STEM Study Abroad and Capstone Experiences

While employers increasingly seek "culturally aware" and globally engaged employees, engineering and STEM (Science, Technology, Engineering and Math) students who aspire to study abroad often struggle to find room in a curriculum that tends to be highly regimented and heavy on required courses [1]. Universities are under pressure to integrate additional technical content into engineering curricula, while simultaneously experiencing pressure to graduate students on time and to reduce the number of credits required for graduation [2]. In the year 2000, the Accreditation Board for Engineering and Technology (now ABET Inc.) put new standards in place. The new system shifted from one of counting credits and was superseded by an "outcomes-based process," in which educational institutions must demonstrate that graduates possess a breadth of abilities, such as the ability to work in teams and communicate across disciplines, as well as possess a technical depth of knowledge [3]. While previously study abroad had been viewed as a "perk" of being a liberal arts major, the outcomes-oriented ABET standards open new opportunities for integrating study abroad into the STEM undergraduate experience [4].

A key incentive for students is ensuring that the program does not interfere with curricular requirements [5]. Short-term study abroad opportunities that occur over winter or summer breaks, and enable STEM students to incorporate an international learning experience into an otherwise regimented curriculum, can provide such an opportunity [1]. Project-oriented study abroad programs, crafted for STEM students that take technical, scientific, and social contexts into account, provide one model for achieving ABET outcomes, and can additionally provide students with life-changing cultural, professional, and personal experiences [6].

Many companies hiring STEM students are multinational, "and all want graduates who can work in multidisciplinary, multinational teams that cross time, disciplinary, and geographical boundaries" [3]. Indeed, due to advances in telecommunications, companies have a *need* to "cooperate and work with people from other cultures and value systems in order to remain competitive" [7]. Project-based short-term programs provide an opportunity for STEM students to reflect on, and grapple with, "wicked problems" firsthand. Wicked problems are pressing issues that are global in scope, lack an easy answer, and transcend disciplines [8]. It is critical for students to be able to cultivate understanding and interact on a cultural and social level with their international team-members [9].

Recently, a study abroad framework has been proposed in which faculty develop "proactive learning interventions" wherein students are intentionally challenged and supported in engaging in, and reflecting on, cross-cultural experiences [10] (originally from Berg [11]). Demetry et al. [10] provide one example of such a framework, or "paradigm change," that shifts the pedagogical approach from one of *lassez-faire* to one that provides intentional interventions "intended to foster intercultural learning among engineering and science undergraduates." Demetry et al.'s [10] approach focused on developing two different types of project teams – mixed teams comprised of Worcester Polytechnic Institute (WPI) students and students from Chulalongkorn University in Thailand, and WPI-only teams. The study found that students in the mixed teams made stronger qualitative and quantitative gains in intercultural sensitivity, with mixed-team students identifying their CU project partners as "important sources of cultural learning." Demetry et al.'s [10] study identified the international project partners as "the most influential source of cultural learning for students."

The research of Spodek et al. [4] demonstrates that study abroad can offer tremendous professional development experiences for undergraduate STEM students:

> *"[They] return from study abroad feeling more confident, better able to express themselves, better able to communicate, more flexible and independent, more willing and able to view issues from multiple perspectives, with a better understanding of the world, and in summation, better able to think outside of the box."*

Additional accounts reinforce Spodek et al.'s [4] claims. For example, an account by Brigham Young University (BYU) faculty regarding the development of seven engineering study-abroad programs over the 2006-2007 school year highlights the cross-cultural skills and competencies developed by students working on humanitarian-oriented design projects [12]. The BYU programs center around different formats, including mentored travel, extended field-trip, service-learning, and international design. Indeed, small scale study abroad programs, with limited numbers of students, can provide dynamic and life-changing experiences and engender the development of critical skillsets for students. Darling [13] provides an account of a two-student study abroad bioengineering capstone experience in Ghana. As part of this problem-identifying and information-gathering experience, the students interacted with key stakeholders from the public and private sectors.

The different formats explored above demonstrate that STEM study-abroad can take many forms - it is not a "one-size-fits-all," and that the interests of faculty and needs of students can lead to a variety of engaging, tailored international experiences. One example of the changing study abroad paradigm for STEM students centers around facilitating international capstone experiences. Study abroad experiences that allow STEM students to also complete capstone requirements provides a unique opportunity for students to investigate a problem and develop technical depth in a dynamic international context [13]. This paper seeks to add to the body of literature on international capstone experiences by providing an example of a successful capstone experience working with clients in an international context.

Description of the 2-year capstone experience in ISAT

The two-year capstone experience in the ISAT Bachelor's degree seeks to inculcate students with set of holistic problem-solving habits of mind. These habits of mind include:

- Employ a holistic perspective by accounting for a broader system within which the problem exists
- Take a long-term view of the problem
- Know what kind of outside expertise is needed and when/where to get it
- Identify and engage relevant and diverse stakeholders
- Explicitly address the political/cultural contexts and dynamics that are relevant to the problem
- Employ sound scientific methodologies to understand and solve problems
- Assess technological, economic, cultural, social, and political merits of possible solutions
- Recognize the intellectual merit of their work and importance of their contribution to the existing body of knowledge, as well as how their effort plays into the larger system surrounding the problem.
- Evaluate the system-wide impact of possible solutions including potential unanticipated consequences
- Are self-reflective and self-critical of their analysis

Throughout the four year ISAT curriculum, students are exposed to foundational knowledge and cases that challenge them to apply the habits of mind. This culminates in the senior capstone experience, which challenges students to use their habits of mind and foundational knowledge in independently identifying a problem, assessing it, and proposing a solution. In the first two years of the ISAT curriculum, students are exposed to a breadth of knowledge, in courses focused on biotechnology, the environment, manufacturing systems, energy, telecommunications and network security, science policy, ethics, and others. In the second half of the curriculum, students are expected to begin developing a depth of expertise in one or more self-selected areas.

The two-year capstone experience empowers students to delve deeply into and to develop technical skills in a problem-area that interests them. In the junior year, students lay the groundwork for their project in a two course sequence. In the fall semester, the students focus on problem identification and being matched with an appropriate faculty advisor. In the spring semester, students work with their advisor to develop a project proposal, which is to be executed during their senior year. The capstone project detailed in this paper is somewhat unique in this regard, because it does not follow the traditional capstone timeline. Since the study abroad experience took place during the summer, the students completed most of their capstone requirements over the summer of their junior year, with their senior year then focusing mainly on client follow-up and monitoring.

The Program in Costa Rica

International Partner

Punta Leona Hotel and Club Beach Resort is a coastal resort located in the province of Puntarenas, Costa Rica which opened in 1975. The resort's accommodations for national and international guests include 108 standard rooms and 97 fully equipped apartments and bungalows. The resort estates span over 114 acres. It has two mini supermarkets, three swimming pools, and four restaurants. The resort has two beaches and one of them is considered one of the prettiest in the country and has many awards with the Costa Rica Blue Flag program. Punta Leona Hotel and Club Beach Resort employs approximately 335 people, and its owner and management are committed to being a leader in sustainability. The resort strives to achieve a high sense of social responsibility by being a quality employer, strengthening ties with the members and community, providing a high quality of service, and creating a culture of continuous improvement of policies, goals, and values. The overarching goal of this relationship is to create a more knowledgeable and sustainable community for the resort employees, guests, and surrounding community.

The program

This program is one of JMU's international programs that are offered in more than 75 countries. It started in 2006 as a course-based program with the University of Costa Rica (UCR) and involved an energy course along with a cultural component. The program used the mixed method with seven students from JMU and seven from UCR [14]. The program evolved from course-based to project-based when a relationship with the resort started in 2011 during a meeting between a JMU faculty member and the general manager of the resort. The resort wanted to reduce its electricity bill along with its overall energy consumption. The first project was to conduct an electricity and energy audit in order to provide management with information on the resort's buildings and electricity consuming devices and to provide the management with options to reduce energy consumption. The first group incorporated the mixed team approach: three students from JMU and three from the Mechanical Engineering program at the UCR. While at the resort, a relationship developed between JMU faculty and the resort owner, management, and employees which resulted in a better understanding of the issues. Over the following years, JMU conducted 23 small projects that included: photovoltaic stations for lights and backup systems; an insolation study to identify optimum locations for solar energy system installation; a development of a wind monitoring station; development of a solar powered ventilation system for the reception area; the construction of an electric bicycle, tricycles and cargo bikes; the construction of an educational solar thermal heater; the construction of an energy efficient dehumidifier for restaurant salt; an energy audit using infrared imaging; the construction of educational sustainability materials and the development of social responsibility program; etc. Throughout the academic year, JMU and the Punta Leona Hotel and Club Beach Resort's management discuss possible student projects. By the end of each summer program, we conclude with a brainstorming session to identify possible projects for the next year that are based on the needs of the resort and that are achievable by our undergraduate students; the resort must budget for the projects and its employees. Last year, we started to offer projects which were more involved in their scope, timeline, and budget than those which had been pursued previously. The two capstone projects which were completed were the development of an aquaponics/hydroponics system and a project utilizing the Internet of Things (IoT) in order to promote energy savings and awareness. This paper will focus on the later project.

Once projects are identified, the JMU faculty submit a summer program application to the Center for Global Engagement (CGE). JMU faculty will advertise the projects in the junior capstone preparation class (ISAT 490) and upper-level classes. Once the program gets approved, the students may apply online. Besides the traditional application information (name, major, etc.), this program requires a recommendation letter, a minimum GPA, an interview, and an essay indicating why the student wants to participate, what her/his expectations are, and what strengths and contribution the student will bring to this experience. Once the application is complete, JMU faculty interview the students and gage their qualification and readiness. This qualification evaluation includes consideration of previous travel, the student's acceptance and tolerance of other cultures, the student's adaptability to adjust to a new country, food, housing, and environment, his/her ability to work in groups, and, most importantly, a determination as to whether or not the program is right for that student and his/her interests.

Assessment of Deliverables

Students will develop and document deliverables as specified in their Project Proposal. Deliverables are assessed by JMU faculty and two managers of the resort with the grade input split equally (50% faculty, 50% managers)**.**

Course grades were based on:

- 30%..... Professional management of the project and effective communication with all parties
- 30%..... Quality of deliverables / Written project report
- 15%..... Timely achievement of project milestones and deliverables
- 15%..... Professional behavior
- 10%..... Energy Challenge: Each student is required to come up with energy savings ideas (a minimum of $500 per year savings is the minimum which is acceptable for the resort manager)

Students are required to attend and participate in all group project sessions. JMU faculty consider attendance and group participation in assigning the course grade. Fellow student evaluations (peer evaluation) are taken into consideration in evaluating individual students' performance.

Internet of Things (IoT) Project

The rapid increase and use of mobile technologies and wireless communications has opened the door for many smart home applications that monitor and control energy consumption. The Internet of Things (IoT) has researchers investigating controlling appliances remotely in smart homes. By utilizing the technology of IoT [15], the capstone team analyzed the main parameters that should be taken into consideration when building an energy management system. Our partner, as a facility, is relatively large and presents unique challenges. The capstone team drew on previous work in this domain [16], in which innovators designed an intelligent power management device which adopts users' locations, motion detection, and living patterns as its parameters to reduce the energy consumed by some appliances, such as lights and humidifiers.

Eight students participated in the program, with three on the IoT project. The project timeline was divided into three phases: 1. Design and build, 2. Implementation, and 3. Project improvements, monitoring, and analysis. Phase one was conducted in the spring of 2017; Phase two in the summer; and Phase three in the fall of 2017 and spring 2018.

Interactions and communications between JMU faculty and students and the resort management started almost immediately once students had been accepted into the program and a project proposal had been agreed on. These communications ironed out details such as: resort budget for the projects, what electricity consuming devices the resort wanted to monitor and control, and how many units needed to be installed along with their locations. Communications were handled via e-mail, Skype, WhatsApp, and a visit to JMU by two resort managers.

Once an agreement was reached on the details of the project, parts were ordered, assembled, and tested before the team's departure to Costa Rica. A Gantt chart was created by the students and shared with the management at Punta Leona Hotel and Club Beach Resort to allocate resources, manpower, and to coordinate logistics during the program. Students worked closely with employees and management at the resort, as well as professionals and entities from outside the resort, to complete the projects.

Timeline, Progress, and Expectations

In our project, the system is not only required to monitor, but also to control, a selected number of AC units, lights, and power consumption devices around the resort. The idea was introduced in fall 2016 and a call for student(s) who might be interested was announced. Students were interviewed and selected by the end of fall 2016. Students were encouraged to start the proof of concept during the spring of 2017 using the methodology developed by Salib et al. [17]. A group of students worked on the concept of monitoring and controlling an electric unit from a smartphone application. The idea was successful and prepared the students to scale up for the summer 2017 as shown in Figure 1.

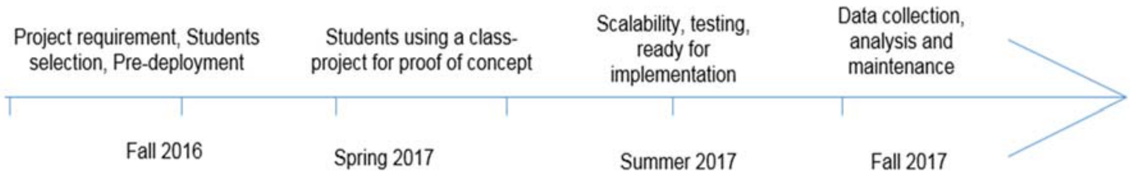

Figure 1. Timeline for the project

The pre-deployment phase was focused on components that would serve the needs of the external clients for this project. IoT technology that was explored during this phase of the project included the use of: Raspberry Pi, Arduino, current sensing/reading devices, solid state relays vs. mechanical relays, analog-to-digital conversion devices, and various additional components. Additionally, during this time, various data capture and cloud storage options were explored to prepare for future data analysis needs.

The Main Idea: Monitoring and Controlling of Devices via Smartphone Application

The strength of the project was having *both* monitoring *and* controlling capabilities for several electric units handled by one smartphone application. The project is divided into three parts: a backend, a center, and a frontend. The backend consists of the hardware sensing and controlling items such as CT (Current Transformer) Clamps, a computing unit (Raspberry Pi), an analog-to-digital converter, and a relay. The center consists of the handling the data using a database which is stored in the cloud and fulfills the security requirements. The frontend consists of the application running on an iOS platform (e.g., iPhone 7) as shown in Figure 2.

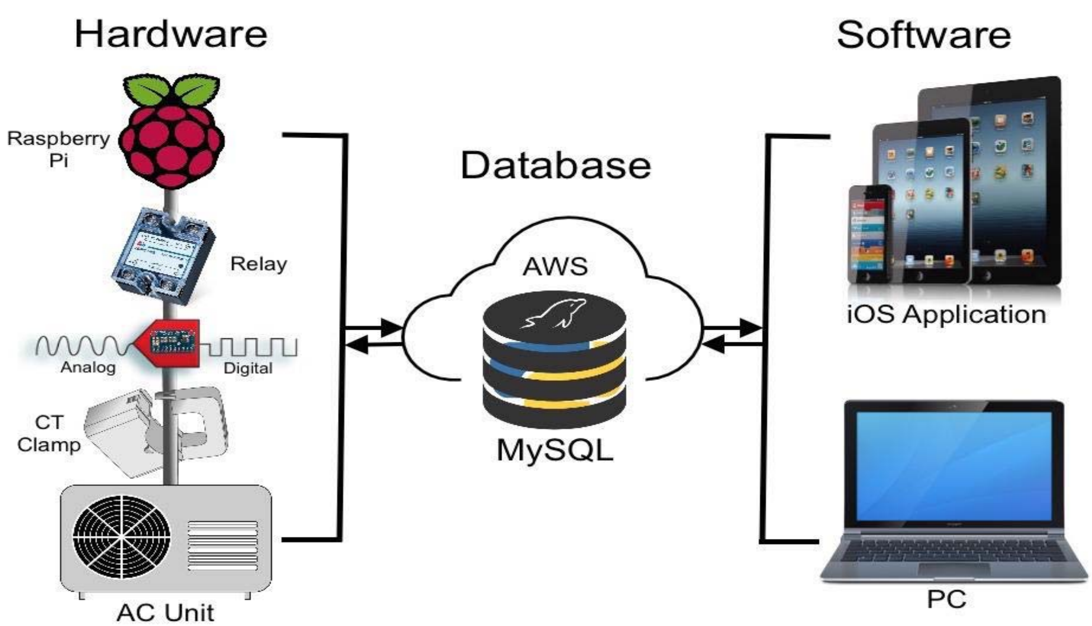

Figure 2. An architecture diagram of the project

Testing and Getting Ready for the Deliverables

To get ready for testing, the team of students emulated the project in the university lab in preparation for the on-site installation. The team gathered information about the Wi-Fi reliability, installation locations, and equipment/materials necessary for the installation. After testing a couple of the units in the lab at JMU, the team purchased extra hardware components required for the on-site deployment and spoke with the electrician on-site over Skype about some of the unit specifications, and the team also spoke with the Information Technology staff about the networking configuration on-site.

The target implementation consisted of controlling 18 units, which included 8 AC units with energy monitoring capabilities, four lighting units that did not include energy monitoring capabilities, and six back up units in the event of malfunction or damage to a node. All units were switchable through an iOS application accessible by the end-user from any place in the world which is connected to the internet. For security reasons [18, 19], the application can limit access to a certain area (using IP addresses) or a specific city, but for testing purposes, the team decided to rely on the encryption of the username and password given to users and stored securely in the cloud database [20].

The team considered differences between the US-energy power and the target AC units' physical specifications. The plan was to start the installation of one unit to ensure the procedure could be replicated with additional AC units. The team prepared a wiring diagram that could be carried over to the other units. With this approach, the team was able to perform a successful installation of the AC units. Also, the lighting units' installation followed a similar process, with a deviation in source voltage. The lighting units provided a source voltage of 120V vs 220V and required the use of a 30A solid state relay, a 120V bypass, and unit switches. Although data was not collected from the lighting units, the CT clamps were still used in the configuration for error detection and control assurance. The monitoring and energy consumption on the Raspberry Pi was done using scripts written in the Python coding language. These scripts were written and tested before deployment and pre-installed on all Raspberry Pi units.

On-Site Challenges and Performance

Despite the fact that JMU faculty and students undertook a great deal of preparation and thought about many program factors, planned out logistics, and coordinated with the client on deliverables to ensure a smooth and memorable program, there were some challenges. Below is a list of some of these challenges that need to be considered as faculty plan a capstone project abroad:

Group Dynamics: It is crucial to consider group dynamics and the development of positive team relationships. Faculty need to consider that some students are already friends and may exclude others. Sometimes, emotions can run high because they are in a different environment, outside their comfort zone and culture, and are participating in ever-evolving group dynamics.

Supplies: Supplies were limited at many points in time. Students worried about not being able to install all of the units due to supply constraints. The resort is over half an hour from the closest city. If the students needed a certain part that was not available at the resort (or students did not think about it in advance), it would often take half a day to a full day to acquire the unanticipated parts and supplies. On one occasion, the resort ordered a few parts which were not the ones specified by the students - perhaps because the specific parts were not available or possibly in an attempt to save project funds.

Wi-Fi Connectivity: Many of the units faced issues related to Wi-Fi strength, reliability, bandwidth, and/or security. Wi-Fi reliability is an issue that the resort is working on, but this needs to be considered as a potential barrier.

Allocation of Employee Time and Resources: The resort electrician, for example, was often unavailable to the students and their needs due to his need to take care of issues at the resort. Resort employees have full time jobs, and their first priority, by default, will be resort services. While the resort did its best to fulfill the team's requests, there were a few emergencies that came up. Students need to be aware that the resort's employees have competing priorities.

Different Electrical Wiring Systems: Students worked on 8 AC units. Two were 120V and 6 were 240V. They tested the 120V system in the U.S.A. and did not prepare for the 240V systems. Another challenge was that not all of the AC units had the same wiring system. The students were determined to resolve the issue and worked on the first unit from sunrise to sundown as they were so focused on solving the problem.

Alcohol: As with any study abroad experience, it is important to consider that students are away from home, and suddenly may be of legal drinking age in a foreign country. Prior to, and during, the trip, it is important to educate students on safety in general, but also to educate them on responsible behavior regarding alcohol consumption. In this study abroad program, students are provided with all-inclusive wristbands that allow them access to the resort restaurants. The students wanted alcohol as part of their meals package, but university policy cannot pay for alcohol, therefore we worked with the resort management to ensure that the students had unique wristbands that would allow them access to restaurant food items, but not alcohol.

Being at a Resort: Especially during the first few days, students feel like they are vacationing in a resort and want to take advantage of all of the amenities - faculty need to be stern in reminding students that they are there for a project. Daily check-ins, faculty presence, and structured team meetings help with keeping students on task.

Project Follow up Plans and Challenges

Despite the fact that the team is very proud of the project, being seniors graduating in May 2018 presents several challenges for them. Firstly, with busy senior schedules, there is no time to track the units, to determine which units are running correctly and which have stopped for any reason. The solution to this challenge was to write a script that informs one (or more) of the team of the daily units' status. Secondly, students are traveling for on-site job interviews. Usually, not all the team will be traveling at the same time, but in case this happens, a follow-up team meeting is needed after returning to check if all units are working and the data collection is done correctly. Thirdly, the continuity of the project is a challenge. The team is graduating in May 2018, which requires handing off everything to the resort or another team of students to continue data analysis and to answer any maintenance questions. In order to assist with the hand-off of the project, the team prepared a detailed report and tutorials to help whoever will continue the project understand the technical and non-technical details.

Recommendations and Lessons Learned

Judgment of Student and Group Dynamics: During the pre-trip phase, faculty need to take a close look at students' abilities. Students who might be good in coursework, writing papers, and designing might not be equipped to build and execute a hands-on project. Another factor is their attitudes and behavior during the application phase may not be the same as a group during the program. Investing time in interviewing and observing students in and out of class is well worth the effort in order to construct an optimal team.

Know Your Partner Well: We learned that it is crucial to know the managers and employees well, and how the system works – both on a technical, business, and social level. A good working relationship with partners is key – for both faculty and students. Faculty and students need to know who has authority to approve work and purchase orders in order to save time and efficiently collaborate with the resort partner.

Communications and Understanding: Good communications and understanding between faculty and resort management were essential in managing expectations of students. Students were educated on how the resort operates, and on how they should communicate before, during, and after the program. Faculty gave the students concrete examples regarding the ordering of parts, logistics, etc. Prior to the trip, faculty need to work with the management and the students to make sure parts will be available on site, specifically if parts are coming from the U.S. - customs, costs, and delays are all factors which can affect completion of the project. Students need to understand that they cannot just "Amazon Prime" an item like they would at home.

Language: Having a bilingual speaker in the group is a plus. This past year, the presence of a bilingual student helped the team better communicate and progress with the resort employees as compared to previous years.

Project: Students had no to little experience in the technical area prior to the project. Selecting students with the right expertise in different areas (database, cloud computing, iOS system, hardware), was essential in this project. When dealing with a bigger project, faculty learned to break it into smaller parts/sub-teams and assign various aspects of the project over the pre-trip semesters in order to be ready for implementation during the summer.

Parts and Supplies: More preparation is needed when geography is a challenge. We learned that it is important to make sure that the project will have most of the items which will be needed, prior to team arrival on-site, including small details such as screws, otherwise, as we learned the so-called "hard way", it may end up taking half a day to drive to a major city just to get small parts.

Timeline: Buffer time should always be integrated into the project plan. The students learned to allocate extra time for the project. We encouraged them to think about possible delays due to blackouts, local weather (sometimes there can be torrential rain in the afternoon), and internet dependability.

Point Person: Have one point faculty, manager, and student per project - this will avoid "he said/she said" situations, for both faculty, management, and students. This project involved two managers along with three faculty members; sometimes students did not know who to consult.

Students: Faculty need to remind themselves that they are dealing with 20-year-olds; there is an inevitable parenting component that is very different from regular academic-year interactions with students. On the study abroad, faculty are living with students. There is not the separation between faculty and students that faculty are used to - the faculty's responsibility goes beyond making sure that the project is completed and also must include insuring the health, safety, and safe return of students back home.

Faculty Commitment: Including a capstone component into a study abroad required more faculty and time as compared to previous study abroad years, in which the projects were more contained. These capstone projects included the design, implementation, troubleshooting, and maintenance of some rather complex systems. Troubleshooting is required throughout the year. Every week, an issue came up that the team had to be in touch with the resort about. Faculty need to be aware that in addition to participating in the summer study abroad component, committing to a capstone project is a two-year commitment and requires weekly, if not daily, time commitment by both students and faculty.

Multidisciplinary Faculty: In the months after the trip, the students reflected on all that they were able to accomplish, noting that: "With the support and guidance of our capstone advisors and the [pre-trip] course, we were able to achieve so much that looking back now amazes us." The students also emphasized the benefits of having an interdisciplinary team of faculty advisors for the project, reflecting that the different disciplinary perspectives allowed them to better design and execute the project:

> *"Having 3 Professors with Doctorates in three different areas of expertise advise our project allowed us to see views and thoughts from people in other mindsets than our own. Having a Telecommunications, Networking, and Security doctorate professor to help us develop our prototypes and product from application development to our raspberry pi based hardware. Having a social context doctorate professor prior to leaving allowed us to think about the impacts on the staff of using our product and the learning curve the workers might face due to aspects such as the language barrier we faced and the technical deficit between the employees and ourselves. Lastly, having a doctorate professor focusing in sustainable energy working with us helped us define and analys[e] data received properly."*

Conclusion

Throughout this capstone/study abroad experience, faculty gained a number of insights into how such an experience can be an impactful and beneficial experience for STEM students. The insights we gained from the students' reflections on the experience, as well as consulting with the resort management and with each other, has enabled us to develop an evolving framework for an engaged, international capstone experience where faculty from different disciplines effectively collaborate and learn from one another. This experience also facilitated STEM students developing technical depth as well as professional and cultural competencies, in addition to memories that will last a lifetime.

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