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Autonomous PV Systems for Developing Countries: Assessing Student Learning of Experiential Study Abroad Programs

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Abstract

Providing unique international educational opportunities is central to the holistic educational mission of the Sustainable Technology Program at Appalachian State University. Since the first experiential trip in 2006, the program has engaged students in unique international experiences with hands-on learning and technology transfer. This paper highlights study abroad programs to Costa Rica (2017 and 2018) and Peru (2018) that designed and implemented autonomous photovoltaic systems for lighting and cell phone charging for rural communities without access to electricity.

The technical components of designing a stand alone solar power system include: 1) load analysis, 2) battery and array sizing, 3) charge and load controller selection, 4) installation, and 5) cost analysis. Prior to departing, students participate in designing, prototyping and installing the system. These efforts have produced an open-source set of plans. The "Appalachian Street Lamp," is an inexpensive system that can be deployed to remote locales that can access a cellular network but do not have grid power.

These field courses emphasize key learning outcomes including: 1) use essential math and science skills to solve applied science problems, 2) formulate, design, or develop a system, process, or program to meet desired needs, 3) demonstrate the capacity to function in project teams, and 4) use the techniques, skills, and technical tools necessary for professional practice in the discipline.

A survey designed to assess program impact was sent to all 37 study abroad participants in September 2018. 22 responses were recorded that answered five questions related to technical proficiency and global competency. An average response of 4.90 was recorded across all questions using a Likert (1-5) scale. A final open-ended comment section revealed many testimonials stating the positive educational impact.

As educators, we see great value in getting students out of their comfort zones. Developing international courses with hands-on work projects can create unique transformational opportunities and become a platform for piquing student interest and motivation. This paper chronicles developing this program, the technical system, and the impact of learning technical skills in a study abroad context.

Introduction

Simple stand-alone PV systems are an excellent way to introduce students to solar power, energy storage, load analysis, and electrical design. Designing a system to provide the basic services of lighting and cell-phone charging in an off-grid developing world context is intriguing and noble. While many in the world still live without electricity, (estimated at 12% of global population) cell phone reception is often found in even the most remote corners of the planet [1]. Cell phones have become indispensable around the world and many people living off-grid literally walk many miles to charge their phones. The resultant design with 30-Watt PV module, charge controller, 12-volt battery, and loads is low-tech, low-cost, and safe for students to construct with minimal experience. This paper details the development of the "Appalachian Street Lamp," an off-grid renewable electricity kit, provides an evaluation of student learning outcomes, and a summary of survey responses. Our objective is to reflect on the value of incorporating hands-on learning during a study abroad program.

Global Competency

Global competency is of increasing importance in our complex and interconnected world. It inspires students to appreciate cultural value differences, learn new language, and better understand a global economic and cultural marketplace. It also fosters working effectively in diverse and multi-cultural environments while developing attitudes that cultivate global citizenship. For students in engineering fields, blending technical, professional, and global competency envelops the skills and attributes of a globally competent professional engineer [2,3]. For students, it shows maturity and helps them stand out to future employers.

Global learning has been the focus of the quality enhancement plan at Appalachian State since 2011 [4]. While this plan is linked to accreditation, Appalachian has invested significant resources to promote global learning opportunities. The Sustainable Technology program is directly engaged in these objectives by developing and offering short-term study abroad trips that are typically 2-3 weeks during summer or 10 days over spring break.

Appalachian Street Lamp

The inspiration for developing this system came from a workshop called "Solar Electricity for the Developing World" led by Ian Woofenden, off-grid enthusiast and senior editor for Home Power since 1998 [5]. His workshop was a crash course in all things solar and electricity intended for people without any background or prior training. The workshop culminated with installations of small PV systems on homes or shacks that did not have grid power in the rural mountains near Mastatal, Costa Rica. Students and Faculty participated in these workshops in spring of 2017 and 2018. During the summer of 2018, a condensed design was developed for a study abroad trip to Peru and installed at partner University, UNSAAC of Cusco, and in a rural community. The system is detailed below and it has become the basis for a series of lab activities in Photovolatics II, our new battery-based solar course.

System Design

Loads: A 1-Watt LED light (Holly Solar) was chosen to run from dusk to dawn automatically (per charge controller setting which is up to 12 hours on June 21 in Peru) [6]. A 12 VDC powered USB port provides constant power for phone charging (2 amps x 5 V). These loads add up to 43.5 Watt-hours per day, or 3.6 Amp-hours/day for a 12 VDC system.

Load assessment

Design name: **Peru system**

Input the watts and quantity of the load (s)

How many hours will you run the light during the shortest day of the year?

Load	Watts	Quantity	Total Watts	Hours/ day	Average Wh/day
DC light	1	1	1	12	12
USB	10.5	1	10.5	3	31.5
			11.5		**43.5**

Choose a system voltage to calculate Amp-hours/day

Average Wh/day	DC System Voltage	**Average Load (Ah/day)**
43.5	12	**3.6**

Figure 1. Load Assessment Worksheet

Figure 2. USB port and Holly Block 1W 12VDC LED

Storage: A MightyMax 12 VDC, 18 Ah battery was chosen to store the PV energy and run the loads. It has a maximum depth of discharge at 50% with 2.5 days of autonomy.

Battery sizing

Average Load (Ah/day)	Battery Ambient Temp (F)	Batt Temp Multipier	Days of Autonomy	Discharge limit	**Total System Ah**	Battery Capacity Ah	Parallel strings	**Parallel strings**
3.6	70	1.04	2.5	0.5	**18.9**	18	1.0	**1**
	DC System Voltage	Battery Voltage	**Batts in series**	Batts in parallel	**Total Batteries**		Cost per battery	**Total batt cost**
	12	12	**1**	1	**1**		$ 35	**$ 35**

Figure 3. Battery sizing worksheet and 12V, 18Ah battery

Array Sizing: An array sizing calculator was developed based on average load, peak sun hours for Cusco, Peru. Estimated battery efficiency and array loss factors are included.

Array sizing

	in Amps				
	Average Load (Ah/day)	Peak Sun Hours	Batt Efficiency	Array Loss Estimate	PV array Imp required
	3.6	5.0	0.8	0.90	1.01
	PV array amps required	Module Imp	Modules in parallel	**Modules in parallel chosen**	
	1.01	1.65	0.61	1	
	DC System Voltage	Module Nominal Voltage	**# Modules in Series**		**Total # Modules**
	12	12	**1**		**1**
PV panel choice	Nominal module Watts		Cost per Module	**Total PV Cost**	**PV Array Watts**
AltE 30	30		$ 69	**$ 69**	30

Solar Resource

Location	Cusco, Peru	
PSH	5.0	kWh/m2-day

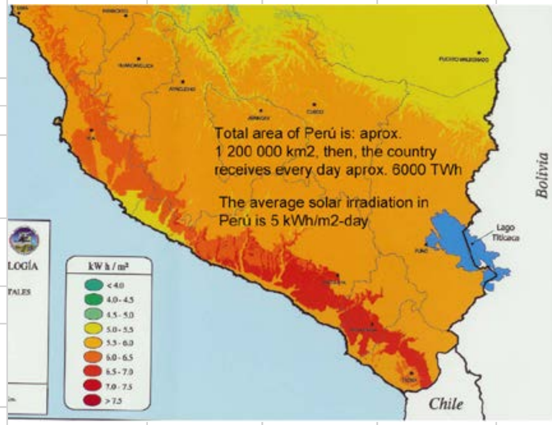

Figure 4. Array Sizing Worksheet with Solar Resource Map [7].

Recharge: Following a discharge to a maximum depth of discharge of 50%, the 30-Watt module runs the loads and recharges the battery in less than four sunny days.

Recharge Check

Array STC Imp	PSH	Batt Efficiency	Array Loss Estimate	**Ah/day produced**
1.65	5.0	0.8	0.90	5.9
Ah/day produced	Average Load (Ah/day)	Potential Suplus Ah/day		
5.9	3.6	**2.3**		
	Battery Bank Ah	18	Ah	
	DOD	0.5		
	Ah removed	9	Ah	
	Recharge time	**3.9**	**days**	

Figure 5. Recharge Check Worksheet, Charge Controller, and Pole Mounting detail [8].

Controller: A Midnite Brat (30 A, Pulse-width modulation) was selected for the charge controller. It serves as both a PV charge controller and load controller, and operates the light automatically using a built-in solar clock that uses the module as a photocell to learn changes in dusk and dawn.

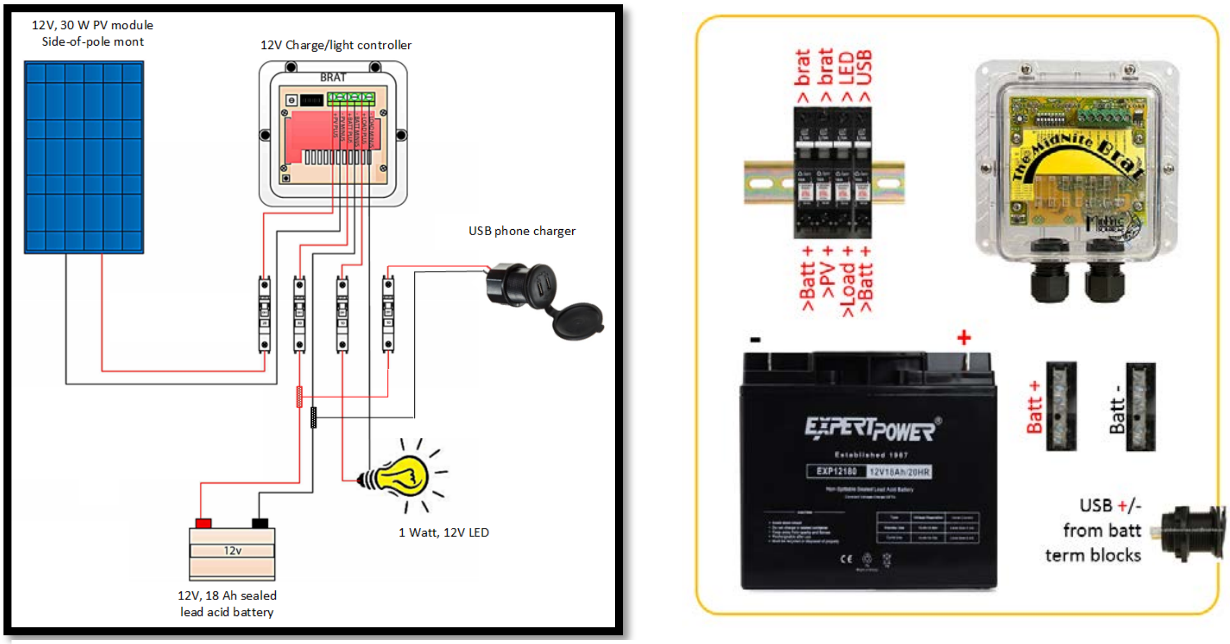

Figure 6. Schematic and Box Layout (17"x14"x6" deep)

Mounting: The 30 Watt module mounts using a 14" Tamarack side-of-pole mount. The LED light mounts under the module and to provide light automatically at night. The balance of system components and the USB charger attach to a pole-mounted enclosure.

Table 1. Appalachian Street Lamp Total System Cost

Component	Cost	
Battery (12V, 18Ah)	$	35.00
30 W Module	$	69.00
Controller (Midnite Brat)	$	76.00
Enclosure	$	60.00
Din Rail	$	9.00
Breakers	$	31.00
Wire	$	10.00
Pole Mount hardware	$	37.00
Connectors	$	5.00
LED	$	36.00
USB charger	$	18.00
GRAND TOTAL	**$**	**386.00**

Learning Objectives

Students take two courses at the junior or graduate level as part of the study abroad program, earning up to 6 credit hours. While study abroads are not required, these field courses satisfy key learning outcomes of the our program at the “emphasize” level using the common coding scheme of introduce, reinforce, emphasize.

Table 2. Student Learning Outcomes from the Study Abroad Experience

Student Learning Outcome	***Category***	***Evidence***
Use of essential math and science skills to solve applied science problems	Emphasize	Calculating loads, battery and array sizing. Understanding power and energy related to the solar resource.
Formulation, design, or development of a system, process, or program to meet desired needs	Emphasize	Design and construction of an off-grid system with specified critera.
Demonstrating the capacity to function in project teams	Emphasize	Team work carried out in meaningful real-world exercise. Working with fellow students from host university.
Use of techniques, skills, and technical tools necessary for professional practice in the discipline	Emphasize	Design, implementation, commissioning, trouble-shooting, and explaining the system.

Survey Results

A survey was sent out to all participants of the three study abroad courses involved in developing the autonomous PV system. The survey was designed to assess program impact related to technical proficiency and global competency. 22 responses were recorded out of 37 total participants. Each question used a 1-5 Likert scale where 1=strongly disagree and 5=strongly agree. The average response across all five questions was 4.90. The overwhelming positive feedback is an affirmation to the value to these types of experiences.

Table 3. Survey Results from student participants

Question:	**Average Score**
1) This course increased my understanding of energy needs in developing countries.	4.86
2) This course increased my understanding of small-scale stand-alone solar PV systems.	4.86
3) This course has increased my confidence in participating in renewable energy projects in developing countries.	4.91
4) After completing the course, I am more likely to travel and/or work abroad.	4.91
5) This course increased my understanding of infrastructure and energy challenges in the developing world.	4.95

A final open-ended question asked for comments on how the study abroad course affected your college expereince.

Table 4. Responses to "How this study abroad program affected your time at AppState?"

Very practical and hands-on.
This course impacted my life more than any other class or travel I've had yet.
It was one of the most memorable parts of graduate school for me.
This course gave me the time and opportunity to see what living in another country to help others would be like.
This helped to reinforce my desire to enter into a field in which I am contributing to the energy security of the future in a sustainable manner.
This opportunity is such an amazing life experience. I encourage anyone who is able to take a trip such as this.
Best choice I've ever made in college and highlight of my time at the University.
Helped my understanding of how culture effects sustainability abroad

Conclusion and Future Plans

Developing a study abroad program with a technical project can be meaningful endeavor. Allowing students to participate in real-world problem solving leads to a sense of accomplishment and feeling of worth. This further promotes the appreciation of culture, language, and the context of how other people around the world live. We found that the technical project was a valuable medium for our students to interact with our host-country university students. At one point, we realized that we had brought a 24 V light and needed another 12 V light. We were able source an automotive light and continue with the installation. Improvising in this environment spurs ingenuity and becomes a valuable lesson. All of these factors contributed to a high level of student satisfaction and positive feedback. We are encouraged by this to further develop these rich experiences.

Future plans include adding a battery capacity meter to the system to allow monitoring battery state of charge. We are also interested in assessing how adding Wifi Hotspot capabilities would impact system design and performance. A final idea is to consider developing and installing an off-grid data acquisition system for collecting solar, wind, temperature and other environmental data using this system as a platform.

References

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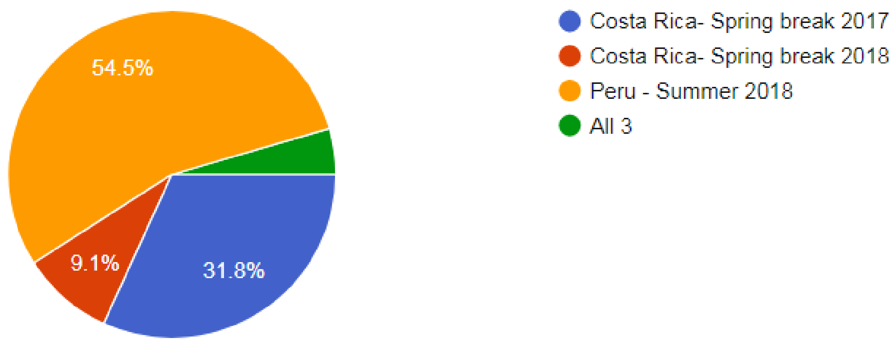
Appendix

Survey Results

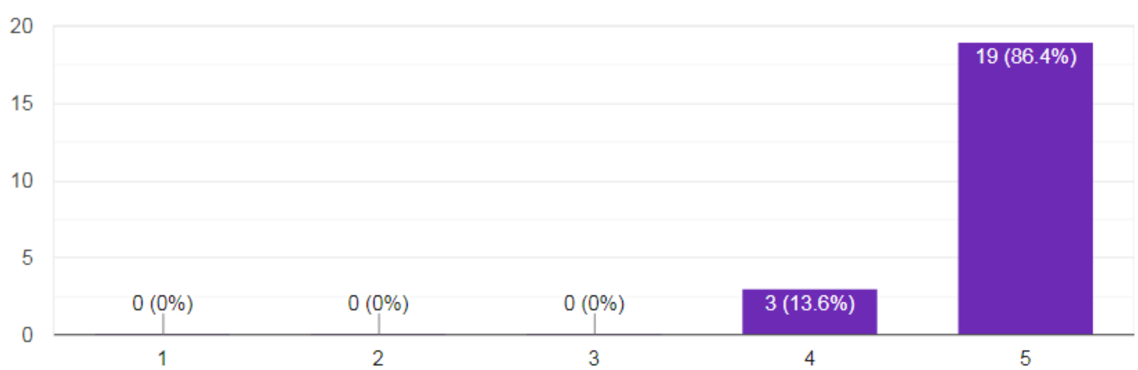
Which international trip did you attend?

22 responses



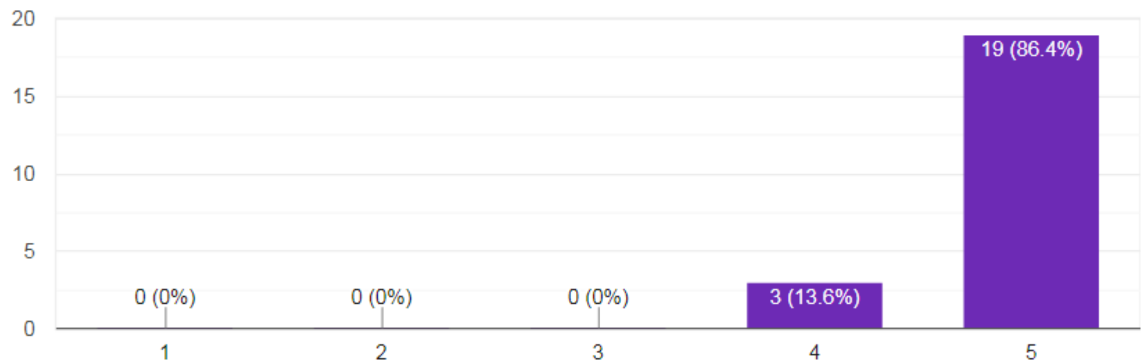
This course increased my understanding of energy needs in developing countries.

22 responses



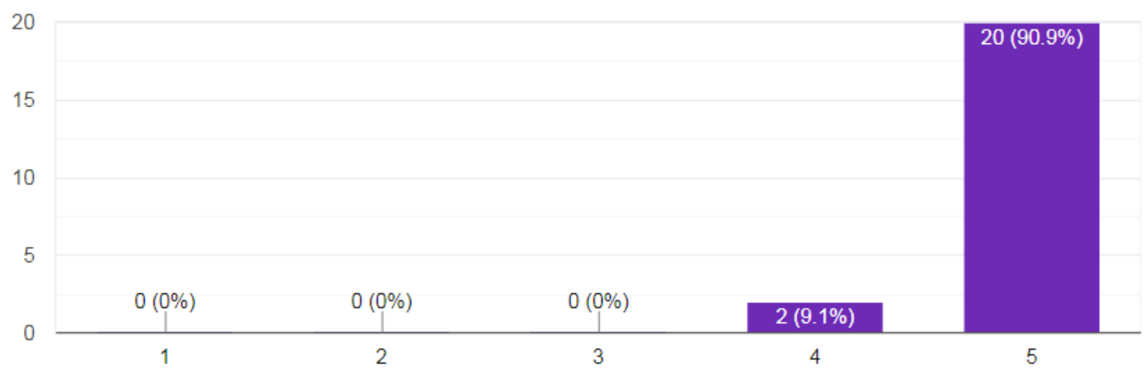
This course increased my understanding of small-scale stand alone solar PV systems.

22 responses



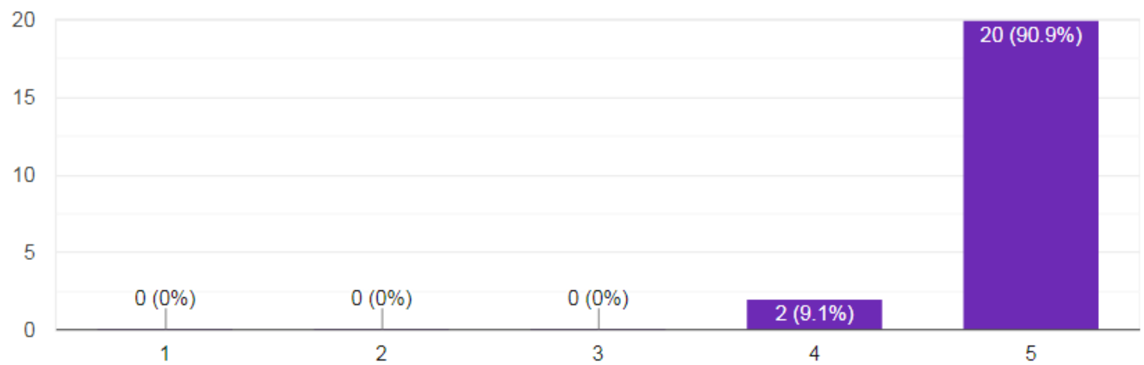
This course has increased my confidence in participating in renewable energy projects in developing countries.

22 responses



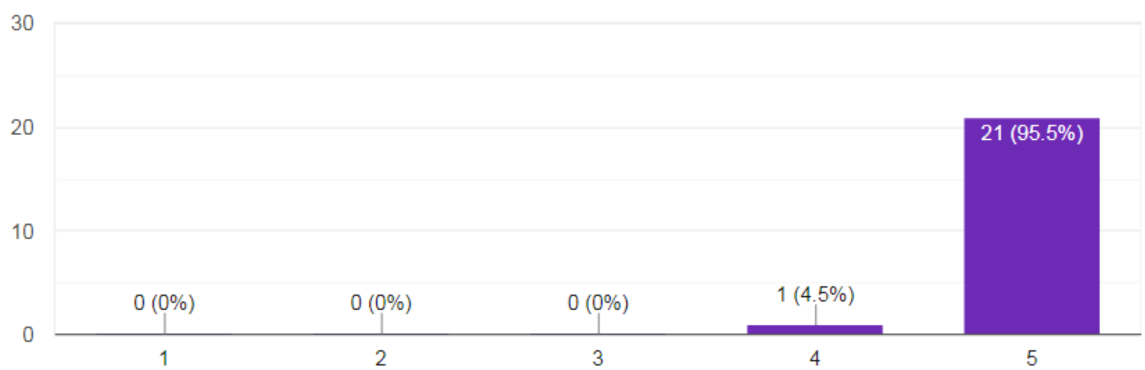
After completing the course, I am more likely to travel and/or work abroad.

22 responses



This course increased my understanding of infrastructure and energy challenges in the developing world.

22 responses



Photos:

PVII class building Appalachian Street Lamps as a lab activity

Street Lamps deployed for testing

Appalachian Street Lamp operating in a remote village in Peru (with Yosef)

Inspiration for the Appalachian Street Lamp in Costa Rica

Students installing the Appalachian Street Lamp in a remote village in Peru