2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32909

Implementation of Sustainable Integrated Aquaculture, Aquaponic, and Hydroponic Systems for Egypt's Western Desert Through Global Community Engaged Research

Lamyaa El-Gabry, Princeton University
Dr. Martina Sherin Jaskolski

Implementation of sustainable integrated aquaculture, aquaponic and hydroponic systems for Egypt's Western Desert through global community engaged research

Abstract

This paper presents an international student internship collaboration between Princeton University and the American University in Cairo. The participatory project addresses the need to design and test affordable renewable energy solutions for community based, circular farming models, enhancing food production while saving resources. Students partnered to study aquaponic and hydroponic growing systems and to construct a solar-powered, integrated aquaculture and vegetable greenhouse system for a real-life oasis community in Egypt's Western Desert. The greenhouse-based solution was tailored to match the capacity of a mechanical wind pump built and tested by a previous internship cohort in 2018 and further developed in a senior thesis project at Princeton University. Participating students worked with faculty internship supervisors, experts, and engineers in Egypt who implemented the system with local farmers. Students remained engaged in fieldwork through online meetings, updates from on-site, recorded interviews with local farmers and time lapse videos. In addition, students received solar-powered hydroponics and aquaponics kits, which they built and tested by growing plants of their choice. This home experiment gave students practical engineering experience and a perspective on the challenges of intensive, circular growing. An app was developed for recording data including water consumption, water quality, plant, and fish growth. Students met regularly during the internship via Zoom and participated in lectures, debates, group work, social games and cultural exchanges, in addition to supporting the installation in the Western Desert and getting their in-home kits working. Integrating online learning with hands-on experiential learning and real life, community-based engineering challenges facilitated international internship experiences without physical travel. Student experiences were evaluated through feedback forms and compared to the 2018 in-person version of the program. The impact on the community is evaluated qualitatively through interviews and quantitatively when data is available.

1.1 Background

This international engineering internship addressed fundamental engineering challenges linked to the sustainability of ecosystems, societies, and economies, and thus topics the global community should address through concerted action. Eliminating global hunger and ensuring food security, particular in low and medium-income countries, is a core objective of the Sustainable Development Goals. Feeding growing populations requires a substantial increase in global food production. As the bulk of global population growth occurs in developing countries, the enhancing of food production is often restricted by poverty, limited access to technology, or a lack of knowledge or capacity. Egypt's population of around 100 million [1] grows by a further million every 6-10 months, while the country is classified as vulnerable to food security, with challenges in food affordability, quality, and safety, as well as malnutrition and stunting [2]. Egypt is already the largest wheat importer in the world, as imports cover over 50% of the demand for wheat and other staple crops [3, 4]. The World Bank classifies Egypt as a lower middle-income country [5] with 32.5% of Egypt's population living below the poverty line in 2019 [1]. A vast majority of 95% of Egypt's population lives in the fertile stretch of the Nile River [6], with remote desert areas having much less access to public services, such as access to the electricity grid, water and sanitation services and suffering from higher transportation prices for goods and long distances to markets.

Boosting local food production in Egypt is limited by resource scarcity, particularly water scarcity and a lack of fertile, arable land, as 93% of the country is desert. Egypt's arid climate with close to no rainfall means that agriculture almost fully relies on irrigation. The majority of freshwater for irrigation comes from the Nile (over 95%), while in desert areas groundwater aquifers are an additional water source [7, 8]. In both cases, irrigation entails the use of pumps – either to pump water out of irrigation canals onto fields, or to pump water out of aquifers. Most irrigation pumps in Egypt are still powered by diesel – a practice that is becoming more expensive each year and Egypt is removing its fossil fuel subsidies. Some local farmers refrain from cultivating parts of their land, or have given up farming altogether, given the increased costs of diesel. Moreover, fossil fuel based pumping causes air, water and soil pollution and emits carbon dioxide, thus contributing to Egypt's carbon footprint. Put simply, Egypt needs to develop agricultural technologies and systems that significantly boost agricultural productivity and at the same time reduce the use of fossil fuels.

Over the past two decades, solar pumping has gained popularity across Egypt. This is partly because the imports of lower priced solar panels and parts from China has enabled access to these technologies for small and medium farmers. As Egypt is located in the world's sun belt, long sunshine hours throughout the year and high UV intensities make solar energy particularly attractive [9, 10]. In fact, Egypt, with the help of foreign investment, has implemented several mega solar energy projects over the past decade and is home to one of Africa's largest solar farms. As these mega projects are focused on generating electricity, farmers are more interested in the use of solar energy to power irrigation pumps. Although solar powered pumps require a high initial investment, rising costs in fossil fuels make this investment more and more attractive for small farmers. Most farmers do not invest in batteries, due to their high cost and short longevity, meaning that solar pumps usually only operate during the daily hours of sunshine, between 8 and 10 hours, depending on the season. Wind power also plays an increasingly important role in Egypt's energy mix, but almost exclusively for electricity generation. Using wind for pumping is an underexplored potential in Egypt, perhaps because it competes with solar pumping, which is much more cost effective as compared to its performance. In 2018, the first cohort of students that participated in the internship program built a mechanical wind pump that aimed at providing continuous day and night pumping, continuing operation even after solar pumps have shut down at sunset. Tests and calculations in 2018 showed that wind pumps have a much lower pumping capacity than solar PV pumps and are thus less attractive for agriculture, particularly where farmers engage in flood irrigation. However, the students identified small scale, protected growing situations, such as in greenhouses, as a potential niche for mechanical wind pumps.

In the farming communities of El Heiz, a small oasis of around 5,000 inhabitants living in 8 scattered villages in the heart of Egypt's Western Desert (Figure 1), most farmers still practice flood irrigation. Water is pumped up from depths of between 150 and 1,200m from the Nubian Sandstone Aquifer, a finite, fossil water source. The irrigation infrastructure for small local farms that produce mainly dates and watermelon as cash crops, as well as wheat, fodder crops and some fruit and vegetables for subsistence, is wasteful and inefficient. Most canals that transport water to fields by gravity are unlined, allowing for water loss of up to 50% before water reaches the fields, as some of the authors' previous experiments shows. The flooding of fields, combined with a decrease in water discharge from local wells, means that farmers often face water shortages, especially during the hot summer months. Longer-term water shortages are commonly met by drilling new wells, further increasing the pressure on the aquifer, while creating cones of depression that lead to wells taking water away from each other. Ironically, most vegetables eaten in El Heiz are transported there from Cairo, while large farms producing in the area market their own vegetables in Cairo. The challenge students who participated in the international internship were presented with was as follows: How can integrated, renewable energy powered farming systems increase food production in El Heiz, while significantly bringing down water, fertilizer, and fossil fuel consumption?

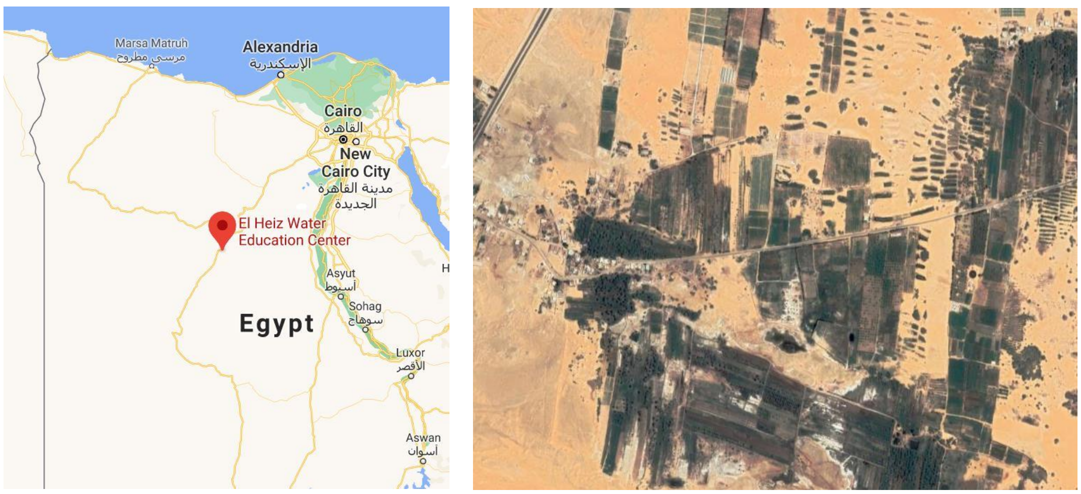

Figure 1: Location of El Heiz Oasis in Egypt's Western Desert (Google Maps and Google Earth).

Based on the work the previous cohort had started, the students came up with an integrated greenhouse-based system for fish and vegetable production, drawing water through the wind pump still installed in the oasis and powered by a solar PV system. The system would work on a closed loop, bringing extra irrigation water back from the greenhouse to the fishpond, and thus ensuring that no single drop of water was lost. The system idea was discussed with project engineers and farmers in the oasis, who also selected a suitable place for the system right next to the wind pump and discussed how a system could be operated to benefit several extended families. Other questions that were discussed by local farmers and then raised in class included whether fish feed could be produced locally, how the systems powering the integrated farming unit would have to be sized to perform under local conditions, what materials should be used to keep the solution simple, affordable, and replicable. To research additional, smaller-scale hydroponic and aquaponic systems that could be used by women inside extended house complexes to grow vegetables, or operated on urban rooftops, students built and tested smaller, solar powered home kits.

The real-life context of the challenge presented to students here, and the continuous online contact students had to local field engineers that communicated with farmers and implemented systems in El Heiz, increased the level of interest among students. Not only were they designing and engineering a solution that was going to be used, but they also witnessed the implementation of their solution for the duration of the internship. The participatory methodology engaged farmers, engineers, professors, and students that were physically located in three different countries and eight different cities. Presenting engineering students with real life sustainability challenges develops the types of creative problem-solving skills young engineers need to succeed in a world that faces fundamental sustainability dilemmas. The global community approach presented an additional skills layer of understanding different environments and cultures, developing empathy for different life situations, and maintaining openness to listen to approaches presented by young engineers, farmers, and exports from around the world.

1.2 Introduction to the Internship Program

International exchanges in Engineering are important and widely received as valuable [11, 12, 13]. Over the last decade or more, there has been a surge in global programs as co-curricular and extracurricular activities for students on campus [14]. The need for global minded engineers is evident as industries have seized on globalization opportunities and it is now the norm to have teams working across the globe. It is important for workforce development but also for human development that students learn to work on engineering project that are international and that engineering programs create intercultural engineers. Service Learning can have positive impact on skills such as teamwork and communication skills, global competency and develop socially responsible engineers [15, 16, 17]. It may also help attract a more diverse population into engineering [18, 19]. Sustainability taught through experiential learning contributes to students' understanding of ethics and their ethical obligation as engineers [20]; research shows a strong link between ethics and sustainability (environment) [21]. To study the long-term effect of participating in service learning opportunities, Canney et al. [22] surveyed alumni who were in their first job or subsequent jobs and found that participants with more service engagement were more likely to more strongly hold a desire to help others as a motivator in their job selection and that more service engagement as students correlates with expectations that helping others will be more integrated into one's career as an engineer.

Paterson et al [23] quantitatively assessed intercultural development using the Intercultural Development Inventory (IDI) to answer two questions: the first is whether service-oriented experiences attract engineering students with an intercultural mindset and the second is whether participation in service-oriented experiences leads to elevated intercultural proficiency for engineering students. The answer to the first question was a clear yes; students attracted to such programs scored significantly higher on the IDI which is somewhat to be expected. The more surprising answer was to the second question where there was no statistical significance between the IDI results of those who participated in service-oriented programs and those who did not in the long term (meaning over the 3-year duration of the study). There were however some students who showed very significant lasting shifts in their intercultural perspectives from participating in a community engagement experience. More research and analysis are needed to understand the motivating causes behind this finding. A secondary finding in response to the first question was that faculty who took the same IDI showed similar results to the students, basically a difference between the perceived orientation and developmental orientation meaning that participants perceive themselves to have higher intercultural competence than their actual scores. The authors suggest that this points to a challenge that engineering faculty may not be well equipped to facilitate the intercultural exchanges.

It is worth noting that the faculty facilitating the projects in Egypt are from different backgrounds: one is from Engineering and the other is from an Anthropology (Social Science). Furthermore, one of the faculty members has a very long-standing relationship and presence in the desert community that spans over a decade; she has lived within this isolated community and participated in social events (such as weddings and other non-technical activities) that really integrated her into the fabric of the community. These aspects are essential in ensuring suitable conditions for community engagement for the students. Furthermore, the project team consists of student in the US as well as students in Egypt that work together and also play together and socialize together outside of working hours. This intrinsically infused an intercultural appreciation that could not have been conjured simply through the joint engineering tasks.

The first edition of a joint research program between students at the American University in Cairo (AUC) and Princeton University was held in 2018. The program was a three-week intensive hands-on field experience in Egypt where students assembled, installed and tested a wind mill driven pump used for irrigation at the AUC campus; later the wind pump was transported to El Heiz, a desert oasis community in the Western Desert. Travel to the Western Desert was restricted by Egyptian authorities at the time which is why the wind pump was erected and tested at AUC and later transported to El Heiz. In addition to the wind pump project, the students travelled across Egypt to survey communities in the Delta and Red Sea coast to assess their water needs and develop potential solutions or proposals for future work in these areas. Nine students participated in the program; four from Princeton and 5 from AUC from diverse backgrounds in Mechanical and Aerospace Engineering, Civil and Environmental Engineering, Computer Engineering, and Operations Research and Financial Engineering equal numbers of male and female students were selected from AUC and Princeton. The wind pump was intended to serve as a test vehicle for use of wind energy in this community. It was moderately successful but because of its relative low flow rates, it did not have a huge impact on the community (unless the diesel engine was broken or out of fuel in which case it was better than nothing). While the wind pump could not produce sufficient water for flood irrigation, it can produce enough water for other low-water usage agricultural methods like small integrated protected systems or hydroponics.

For the second edition of the programmed planned for the Summer 2020, the team was to design an integrated aquaculture and hydroponic system for El Heiz that uses water drawn from the wind pump to fill a lined fish pond that contains tilapia. Fish provide nutrients needed for plan growth. The water from the fish pond is circulated to a greenhouse where crops are grown and then back to the fish pond. Pumps used for water circulation, as well as aeration of the fish pond, were powered using solar photovoltaics. The system design was the output of a senior thesis project at Princeton collaboration with research partners in Egypt and initial plans for the Summer 2020 were for another cohort of students to travel to Egypt to install and test the integrated aquaculture and hydroponic system in Egypt. The pandemic prohibited travel. The team debated postponing the work and ultimately decided to offer the program remotely to allow the community of El Heiz to benefit from the project as soon as possible. This paper describes how the program was shifted to an all-remote offering and how students were still able to do hands-on work though kits that were sent to students in the program as well as experience cultural exchange through games, videos, and other team building activities. In addition, the technical details of the wind pump and integrated aquaculture and hydroponic system are outlined along with results of the project to date.

2. Technical details of Integrated Aquaculture/Hydroponic System

2.1 System Description

The students were presented with several design challenges. First, they were asked to develop a design for an integrated, greenhouse-based fish and vegetable production system in a concrete location of El Heiz oasis using an existing wind pump and additional solar power systems to operate the necessary irrigation and oxygen pumps. For sizing calculations, they had access to performance data of the mechanical wind pump taken by the previous cohort in 2018, as well as some data taken in the field in El Heiz. The design should be based on a circular water management system meaning that water should be re-used, and no drop of water lost. Further, the system should be made of simple, locally available, and affordable materials to enable replicability and upscaling. The system should also be easy to operate by local farmers without specific technical knowledge and should be financially sustainable, meaning that farmers should be able to independently pay for its operation in the long run. Second, the students were asked to develop a local diet for fish and potentially freshwater shrimps based on crops that are locally produced or could theoretically be grown in El Heiz, while making particular use of agricultural waste products. Feedback from local farmers was particularly critical to access enough information to make sensible suggestions.

The design the students established with the inputs from the academic supervisors, the local engineers and specialists on integrated aquaculture is shown in Figure 2.

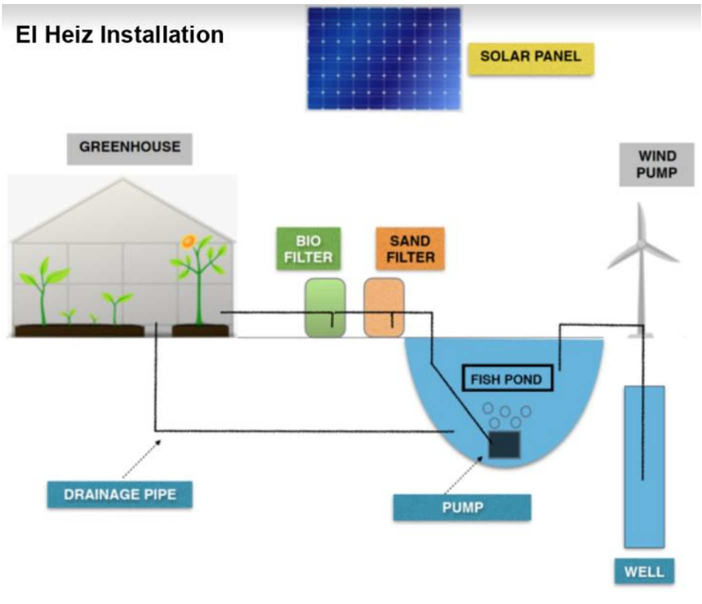

Figure 2: Schematic overview of the initial design of the renewable energy powered integrated fish and vegetable farming system in El Heiz.

Water is pumped up by means of a mechanical windmill from a local well from a static water level of around 2 meters and released into a fishpond. A pump for oxygen provision for the fish, initially planned as a submersible pump but eventually installed as an "shower" spraying water into the fishpond, is operated by a solar system. Water is then pumped out of the fishpond into drip irrigation lines inside a greenhouse to irrigate lines of vegetable plants. The sand filter and biofilter that were part of the initial design were replaced by plastic sheets placed underneath the plants itself, filled with local sand, acting as a natural and cheap filter system as excess irrigation water is led back to the fish tank via a drainage pipe creating a closed loop. Figure 3 displays the final installation of the system in El Heiz, which represents a design that was refined by the input from local farmers and integrated farming experts and that is simple, replicable by local farmers, affordable and does not require a change of filters.

Figure 3: Integrated system installed in El Heiz showing the fishpond with the oxygen shower (top right), the lines of vegetables the underlying plastic sheets and the drip irrigation lines (top center and right), installation of the sheets (bottom left), the weather station, solar panels, and wind pump (bottom center) and a view of the greenhouse from the fishpond (bottom right).

The installed system consists of two separate steel greenhouse structures covered with shading net (63% shading effect), keeping the inside cooler in the summer. In winter, the structures can be covered with an additional plastic sheet for creating warmth for fish and plants. The greenhouse for vegetable production has dimensions of 30x8 m, the greenhouse covering the fishpond 10x8m. The greenhouses are made of an easy-to-replicate steel structure of 2- and 1-inch pipes. The plants are planted inside growing sheets that catch the water and channel it back to the fishpond. The polyethylene sheets of 1 mm thickness are cut into pieces of 1 m width and 30 m length buried 40 cm beneath the soil surface with a slight inclination. The sheets are lined with 10 cm of gravel (2-3 mm diameter) on the bottom with 30 cm of sand covering the gravel, allowing for the cultivation of 800 plants. The irrigation system consists of 2 drip irrigation laterals for each of the 4 growing sheets, with laterals placed on top of the sand. The fishpond has dimensions of 4m width, 4 m length and 1.5 m depth, holding a total of 24 m^3 of water with a potential to accommodate up to

800 fish. The pond is also lined with a 1-mm polyethylene sheet. The 250W submersible pump has the capacity to lift 3 m^3 of water per hour at a 9 m head. A 1-inch irrigation pipe transports the water from the fishpond to the vegetable greenhouse for irrigation. An aeration system connected to the same pump releases water back into the pond like a shower, thus creating oxygen for the fish. The aeration is on a timer set for 15 mins of operation followed by 15 mins break. The pumps are powered by a 1-kW solar PV system connected to a 3-kW inverter and 2 12-V batteries operating at 200 Amp.

Measurements

Measurements are taken via a local weather station installed at the same height as the wind pump's turbine, a water counter on the pipe leading from the wind pump to the fishpond, handheld devices measuring pH, water temperature, oxygen, and salinity of the water in the fishpond on a regular basis (every 1-5 days), as well as a field spectrophotometer used to sporadically measure Ammonia, Phosphate, Nitrate, and Iron levels in the fishpond's water. At the time of writing, data collection is ongoing and what is presented here is merely a first batch of data that shows how a longer-term assessment of the system can indicate its local performance and feasibility. Measurements with the handheld devices and field spectrophotometer are made by the researchers during sporadic field visits. On top of this, a local farmer made measurements with handheld devices taken 24 times between 25 October 2020 and 9 January 2021, between 1 and 5 days apart. Taking these measurements helps the farmers understand the system and the connection between water quality and fish health. Especially the maintenance of sufficient oxygen levels is critical in a fishpond, making it critical for local farmers to be able to perform these tests on their own. A soil sample taken from inside the plastic sheets in the greenhouse in early November was analyzed by a professional agricultural laboratory.

2.2 Results

Between 25 October and 19 November 2020, the wind turbine pumped a daily average of 542.3 liters of water per day. Measurements of Electric Conductivity, which indicates salinity, were at an average of 3,645 μS (microSiemens), with recorded numbers ranging from 1,560 μS to 4,914 μS. Much higher-than-average salinity levels of 4,650 μS were recorded in the water extracted from the well on which the wind turbine is installed. For comparison, water salinity in the adjacent well feeding the large irrigation basin next to the greenhouse were measured at only 470 μS. The measured salinity level in the pond dropped significantly after a water top-up, which was usually done by adding water from the adjacent irrigation basin, which is filled with water from a different well. The average pH measured during the same timeframe was 7.5, ranging between 7.1 and 7.9. The optimum pH range in water for commercial aquaculture operations is between 6 and 8, making the pH measured in the pond perfectly within range. The average dissolved oxygen levels were at 7.7 mg/L over the entire time and 8.15 mg/L after November 7^{th}. Oxygen levels below 3 mg/L can cause stress to freshwater fish, while dissolved Oxygen levels below 1.5 mg/L can be lethal. Water tests taken with the field spectrophotometer showed Ammonia levels between 0.42 and 0.66 mg/L in the fishpond (critical level in Tilapia starts above 2 mg/L), Phosphate at 1.43 mg/L, Nitrate at 9.8 mg/L and Iron at 0.25 mg/L. Thresholds for these values in irrigation water are lower, but it should be kept in mind that in this system the fishpond represents the only source of fertilizer, and thus higher nutrition values in the irrigation water are wanted.

Oxygen levels in the pond dropped to critical and near critical levels twice since the implementation of the system. The farmers were initially not used to the fast changes in oxygen levels in a fishpond and waited too long before renewing the water. This led to algae blooms and oxygen levels dropping below 5 once and even below 2 another time. Low oxygen levels also led to the death of the first batch of fish early in the season. After this incident, farmers learned that they had to watch the water conditions more closely and ensure oxygen levels remained above 7 mg/L, changing or topping up water when quality values were decreasing. The water temperature in the fishpond ranged between a high of 25°C measured in October to a low of 19 °C measured in January, the coldest month in Egypt. However, it should be mentioned that by early January 2021, the cold winter temperatures had not yet set in. However, the temperature recordings show that the shading net provided sufficient protection to keep water temperatures warm enough for Nile Tilapia to survive in, even during the winter months, which lie outside the fish growing season in Egypt. By January 2021 the fish, which had been replaced once in early November, had grown considerably.

Overall, the growing conditions for fish in the designed system were measured as good, while the salinity levels in the water posed some limitations for the successful growth of plants. Local farmers explained the sudden rise in salinity in the water extracted from the well connected to the wind turbine with the fact that the solar system connected to the second well had recently been augmented, thus making it unnecessary for farmers to operate additional diesel pumps out of the well with the wind turbine (the system allows for parallel extraction). For that reason, the well was much less used and thus the water had become more saline, farmers explained. While Nile Tilapia can survive brackish water conditions and salinity levels of over 7,000 µS, high salinity levels in the water are having a negative impact on the growth of the vegetables in the greenhouse. Vegetables become unproductive at salinity rates over 2,000 µS. This is particularly the case as the sand taken for the plastic sheets in the greenhouse is sand that was not previously used for farming and thus has very high salinity levels as well. Only after a few seasons of cultivation will salinity levels in the soil drop due to the water leaching effect. For this reason, the first few seasons of vegetable cultivation are expected to produce limited results. However, should salinity levels in the well operated by the wind turbine remain so high, the wind turbine may have to be connected to an alternative water source, such as the large irrigation pond.

The soil sample from the greenhouse analyzed in November showed a high but not critical soil salinity ratio of 3.5, relatively high alkali levels (7.88) and a medium organic material percentage of 0.88%. The nutrient content was evaluated as good for most minerals (Mu, Mn, Zn, Fe), while the Potassium concentration was at the lower end of the spectrum. When farmers realized that high salinity levels in both soil and water were hindering plant growth, they replaced the first plantation of local peppers with more salt tolerant crops, including spinach and herbs (Figure 4). These plants can survive higher salinity levels until the land is not “hot” anymore, as local desert farmers would call it, and water has leached salt out of the soil. This, however, can only work if irrigation water is not salty as well, enforcing the argument that switching to another water source might be beneficial to boost plant production. While fish are currently fed with commercial feed, the plan is to consider the students’ recommendations for feeding mixes based on locally produced crops and byproducts to save money on operations in the long run.

Figure 4: Plant growth in the greenhouse. After peppers showed limited growth due to high water and soil salinity (left), the farmer planted spinach and herbs (center and right).

3. Details of Student experience

3.1 Learning outcomes

The engineering programs at AUC and Princeton are both ABET accredited. As such, we though to evaluate the program in terms of Learning Outcomes. ABET defines student outcomes as follows: "Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program." The service learning program, as with any course within the engineering program, will have student learning outcomes and meeting these outcomes will prepare graduates to attain the program educational objectives.

ABET has a list of student outcomes (a) through (k); they are listed below as defined by ABET:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

For this service program, the student learning outcomes are:

1. Formulate engineering problem and propose solution [ABET outcome (e)]

2. Understand constraints and work within given constraints to solve problems. [ABET outcome (c)]
3. Work in interdisciplinary, global and diverse teams. [ABET outcome (d)]
4. Benefit society and understand the societal impact of engineering and the greater social framework from which engineering projects serve. [ABET outcome (h)]
5. Communication skills: Learn to communicate technical and nontechnical information with people from different backgrounds (technical, socio-economic, language etc.). [ABET outcome (g)]

The learning outcomes are assessed after completion of the course through a survey and qualitatively by the course instructors.

3.2 Course structure

The service learning program was designed to have three key elements: a project that involves hands-on installation work, field visits, and lectures/group assignments. The first edition of the program in 2018 was an in-person experience in Egypt and will be described first, followed by a detailed description of the second edition in 2020 which was a remote experience.

In the summer 2018, the project was the construction of the wind pump and field visits were taken to villages across Egypt to assess water needs. The lectures provided background, skills, and information to tackle the project. The course met six days a week for three weeks in July 2018 in Egypt from morning till early evening. Week 1 was spent at the AUC campus attending introductory lectures and learning about the project. Week 1 lectures were held in the morning with practical lab activities/demos in the afternoon. Week 2 focused on the installation of the wind pump system and field visits near Cairo. Week 3 was a long-distance field visit along the Red Sea coast and additional testing of the wind pump on campus. Figure 5 shows the schedule for the three-week course.

The 2020 program included the following components: Project (at-site), Kits (at-home), and various lectures and group activities. Figure 6 shows the schedule for the 2020 program. Note the workweek in 2020 is Monday-Thursday to respect the weekend in each of the US and Egypt. Also, in 2020, Week 4 did not immediately follow Week 3 but was towards the end of summer allowing students more time to work; students were able to communicate updates via Slack and meet to work together on the assigned end of program deliverables at their convenience during that time.

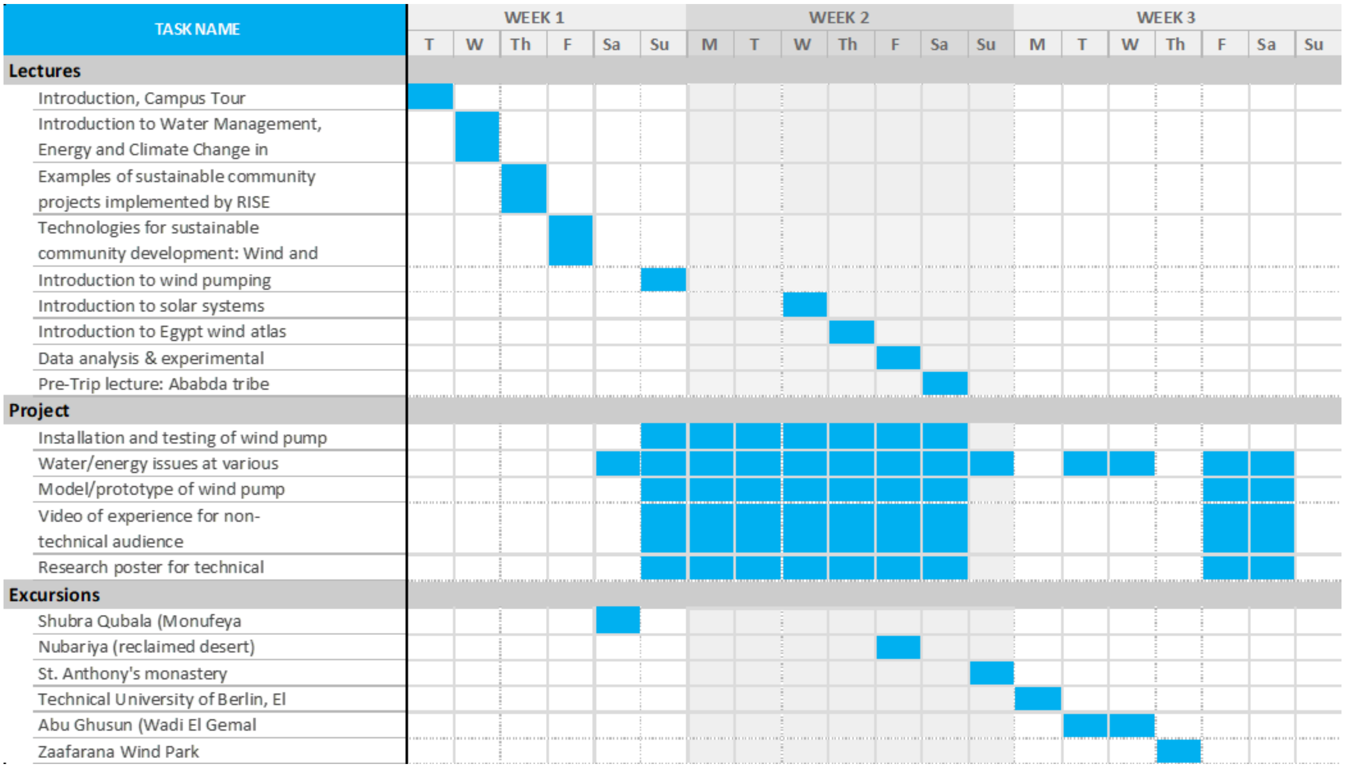

Figure 5 Summer 2018 Program Schedule (in Egypt, in-person)

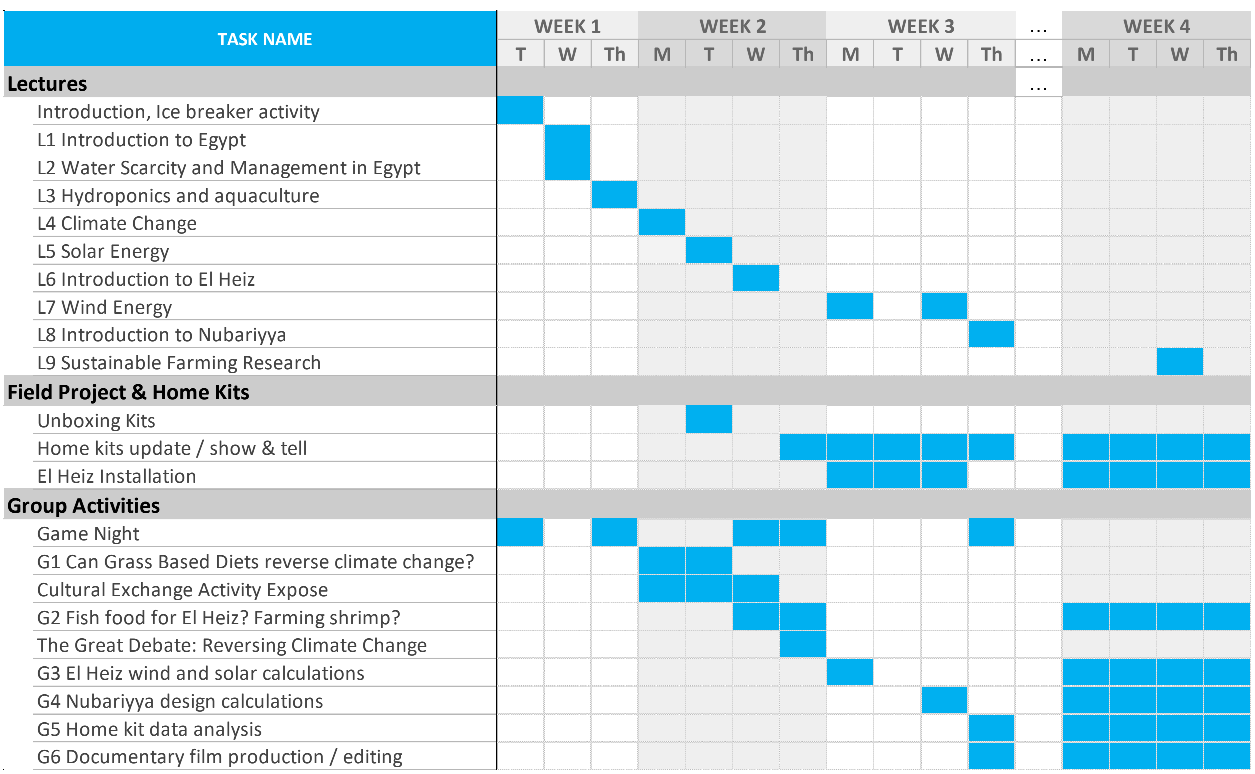

Figure 6 Summer 2020 Program Schedule (remote)

The project for 2020 is the installation of the integrated aquaculture and hydroponic system in El Heiz. Neither US or Egyptian students were able to be there for the installation due to stay at home orders because of the pandemic. However, they were able to support the field work through calculations, data analysis of the wind pump performance to see how field data compared to on-campus tests in 2018, research on fish feed and other decisions that were needed on site. The team received daily updates from the site via photos and video conferences with the engineer. A time lapse camera was installed at the start of construction to show the progress. The construction and installation were carried out by the lead engineer on the team aided by local farmers from El Heiz. Whenever possible, materials were sourced from the nearest available location to El Heiz to ensure sustainability of the project once the team has left.

3.3 Kits

There were two motives for including kits as part of the remote program. The first to offer students a hands-on experience in lieu of participating in the physical construction in El Heiz that they would have had in an in-person experience. The second is to evaluate the feasibility of small-scale aquaponics kits for the inexperienced home user and see if they work and what issues were encountered. The kits were small-scale solar-powered aquaponic and hydroponic systems that students assembled and tested. Measurements of water consumption, water quality and plant growth were recorded using an app developed by two of the students on the team. Updates were provided during the Zoom meetings by the students along with a show and tell of their kits and any issues they're having so we can resolve them. Trouble shooting was a major part of the process; students would use their camera phone to relay live footage and the engineer or one of the peers who came across a similar problem would suggest a fix. Ultimately everyone was able to get their system up and running. Figure 7 shows a schematic of the solar powered aquaponics kit and Figure 8 shows photographs of the kit including plants and fish. Figure 9 shows photos of the hydroponics kit. Locally sourced materials were used so there are some differences between the Egypt and US kits based on availability of parts. One difference is the US system uses a DC pump to aerate the tank whereas the kits in Egypt use an AC pump and thus requires an inverter. The solar panel is highly oversized for the Egypt system (and the US system as well) because it was what was readily available on the local market.

When asked in a survey at the end of the program what surprised you about your system (aquaponics/hydroponics), the responses were: it was very simple to manage once everything was set up, the interest my community had for it, the fact that it is simple yet very effective. One student said "In hydroponics system, I [was] surprised that we can grow plants without a soil. In [the] aquaponics system, I surprised [by] how much the increasing rate of plants' height was and how much green the leaves were." Others commented on how responsive and delicate plants can be, and how quickly they react to changes.

When asked "What do you think worked in the kit?" students answered that the scale was very manageable and the setup was flexible; they liked the flexibility they had in the choice of plants to grow and how we wanted to modify it in order to make it more efficient. Another commented that the tanks or plastic containers were apt for this scale of experiment; especially for the plants. "I'm not sure what will happen when the fishes grow larger, say 100g each, seeing how hyperactive they can be. I think the solar energy and storage systems were working well throughout the whole internship program. They were pretty easy to set up, and maintain. They kind of ran themselves."

In response to the question "What do you think needs to be fixed in the kits?", students said more clarity was needed when initially setting it up. The U.S. students were shipped parts to assemble whereas the AUC students received completed kits that were delivered by the engineer in Egypt to their homes. Princeton students commented that they didn't have all the necessary parts and needed to get some additional things to complete the kit. "The pH meter took a long time to read the pH value and we need a better pump." Both students in Egypt and the US complained about the pump even though they were different pumps and models.

An app was developed for students to enter data on water quality and plant growth and the amount of water added to the system. This app was developed by two of the students during the internship. Students were asked to rate the app on a scale from 1 to 5 where 5 is the highest score; most gave the app a 4/5 and only 1 student gave it a 3/5 and that was the lowest score.

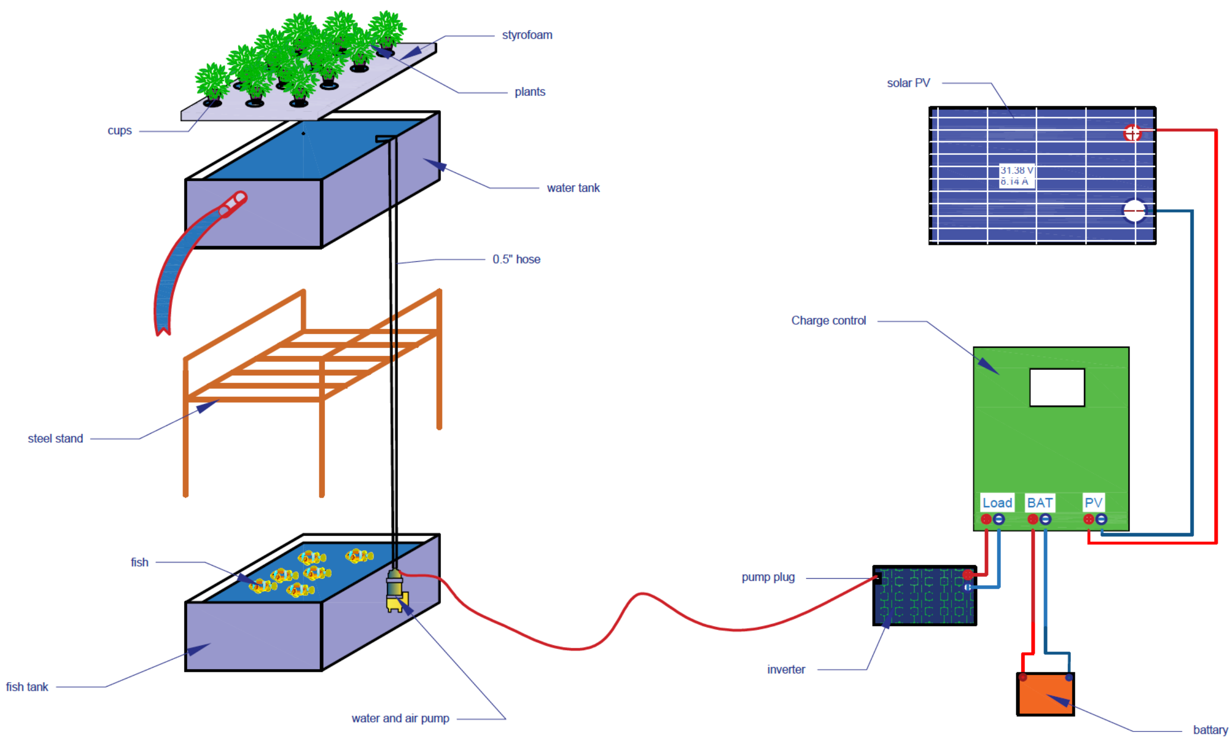

Figure 7 Schematic of solar powered aquaponics kit

Figure 8 Aquaponic system kit: Configuration, Fish, Plants (peppers) by end of summer

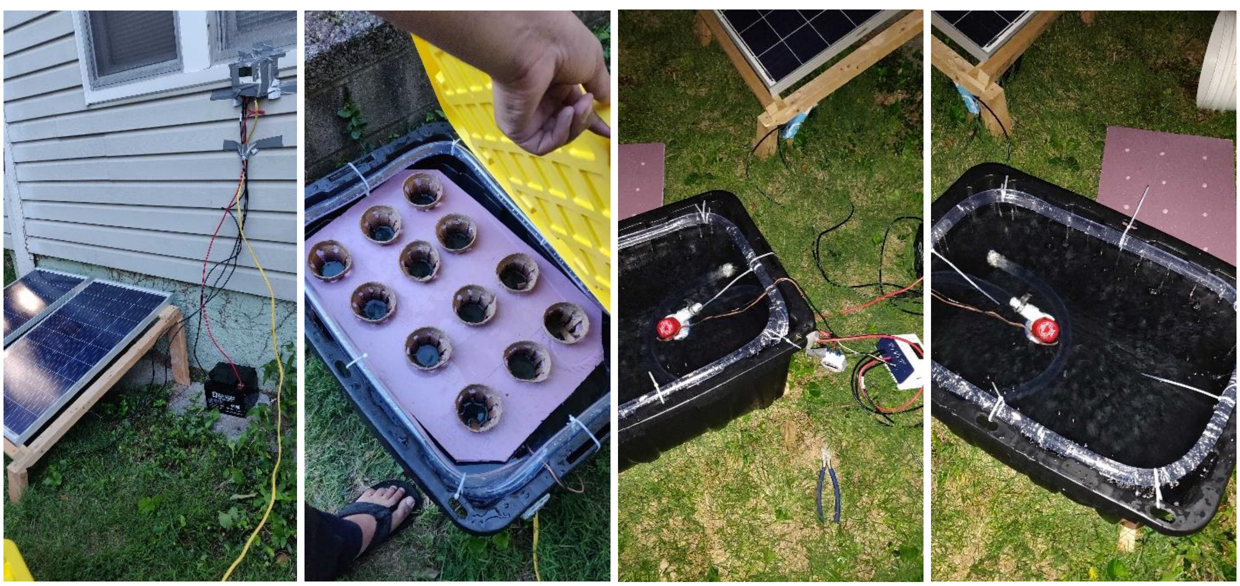

Figure 9 Hydroponics kit setup: Solar panel and battery, floating tray, pump connected to timer, pump/hose assembly

3.4 Lectures/Group Work

Lectures and group activities are the final component of the program; they are listed in Figures 1 and 2 for the in-person and remote experience, respectively. For the remote program, weeks 1-3 were 3-hr Zoom lectures and facilitated group work in breakout rooms. Care was taken to ensure that groups were made up of AUC and Princeton students. Everyone worked on some aspect of the group activities during these three weeks. Then for the remainder of the summer (about one month), each group activity was assigned a student leader and one to two team members to support the lead in wrapping up the activity and preparing the documentation. Table 1 shows the action items. Slack channels were used to facilitate discussions and are shown following the hashtag. For each action item, a faculty point of contact was designated; the coauthors plus the engineer were the points of contact but this phase was student led, rather than faculty led.

Table 1 Group work student deliverables

Action Item
Fish food #fish
Home kit data analysis #kits
Wind pump performance #wind pump
Nubariya design #nubariya
Film/documentary #film
El Heiz Walk-through #elheiz
End of Internship Survey #survey
Home kit data entry #kits

The first action item #fish was to develop fish food from locally sourced materials in El Heiz; the recipes were reviewed by a consultant who operates an aquaculture farm. The goal was to enable the community to be self-sufficient by providing a fish food diet that did not require purchasing commercial feed. The second action item #kits focused on analyzing the data that was collected throughout the summer. The next, #wind pump analyzed wind pump field data and compared it with measurements (wind speed, water meter readings) that student in the previous cohort made on campus to answer questions such as: did the wind pump perform in the field as it had on campus, how does wind pump performance vary year-round? There is another possible site for a future cohort to work on and that is a farm in the reclaimed desert area of Nubariya; this group's project was to develop a proposal to implement a solar-powered integrated aquaculture system that would replace traditional fertilizers and the diesel engine used for irrigation. Another task was to develop a short film to document the project that could be shared with the public and also used for recruiting future participants. The walk-through of the project was also for educational purposes to show how the system works. The students also put together the end of program survey whose results are shown in the next session 3.5. In addition, all students with kits were tasked with uploading data on the water quality and plant growth for the duration of the summer.

3.5 Student Feedback

Student feedback was gathered using an online survey student. The survey contained both closed and open-ended questions and generated quantitative and qualitative data about students' program experiences and evaluation. Table 2 shows the demographics and other data about the participants in 2018 and the same information for the 2020 participants.

Table 2 Participant Demographics

	2018 In-Person Program	**2020 Remote Program**
University	4 Princeton	3 Princeton
	5 AUC	4 AUC
Gender	4 Female	3 Female
	5 Male	4 Male
Response rate	66% (6 out of 9 participants)	57% (4 out of 7 participants)
Majors	1 Civil and Environmental Engineering	1 Environmental Engineering
	1 Computer Engineering	1 Sustainable Development
	1 Mechanical Engineering	1 Petroleum and Energy Engineering
	2 Mechanical and Aerospace Engineering	1 Mechanical Engineering
	1 Operations Research and Financial Engineering	
Class	1 Sophomore	0 Sophomores
	3 Juniors	3 Juniors
	2 Seniors	1 Senior
How did you learn about the program?	5 learned about the program in their university department 1 learned about it from university Facebook page	3 learned about the program from the professor 1 learned about the program from National Society of Black Engineers

Students were asked what motivated them to apply to the program. Reasons mentioned include a passion for promoting sustainable development and renewable energy, community outreach, skills and expertise development, and that the program sounded fund and meeting students from other countries made it even more appealing.

On a scale from 1 to 5 where 5 is best, 75% of survey respondents rated the overall program as 5 and 25% rated it as a 4. The respondents were unanimous in that the program's time commitment and effort were adequate (not too demanding and not demanding enough). 75% said that the program related to their academic studies and 25% had previous experience in hydroponics / aquaponics. When asked what new skills/techniques/knowledge were gained during the internship, students responded with the following: setting up solar panel system, the applications and benefits of aquaponics systems, the practicality of actually planning and implementing the system from the scratch, problem-solving and technical skills dealing with the kit by my hands, communication and teamwork skills through online discussions and group works, data analysis skills through gathering data of the plants and fish in the system and share some findings with the team, research skills and attention to detail has significantly improved because the whole internship program.

Learning to scale projects and calculating economic incentive were also cited as skills gained during the internship.

Figure 6 shows how students rated each of the lectures. The most popular lectures were Lectures 3, 6, and 9; lecture 3 was a guest lecture on commercial hydroponics and aquaculture given by someone who operates commercial Integrated Aquaculture and Hydroponics farms in the United States. Lecture 6 was an introduction to El Heiz community and water problems and Lecture 9 was another guest lecture by a researcher at Princeton University who described ongoing research on sustainable farming on campus and it was a good opportunity for students to compare the work being done in communities in Egypt with research at Princeton.

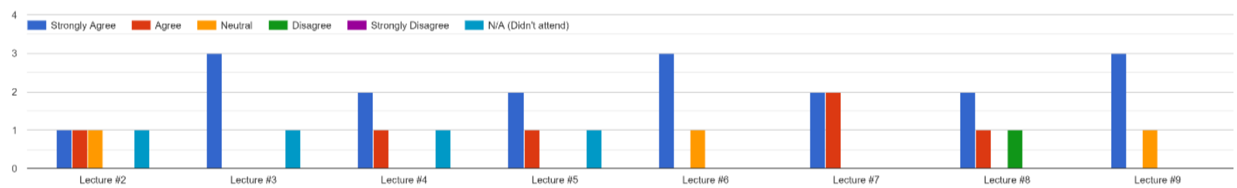

Figure 1 Rating of effectiveness of each lecture: #2 Intro to water scarcity and management, #3 Commercial Hydroponics and Aquaponics, #4 Greenhouse effect and Climate Change, #5: Intro to Solar Energy, #6 Intro to El Heiz community and water problems, #7 Into to Wind Energy, #8 Intro to Nubariya, #9 Sustainable Farming Research

Figure 10 shows how students rated each of the activities that followed the lectures. The most popular activities were the Fish Food activity where students worked in teams to research possible fish food for El Heiz and the Solar Power Cost calculation of a solar PV installation at Princeton University that followed the solar energy lecture.

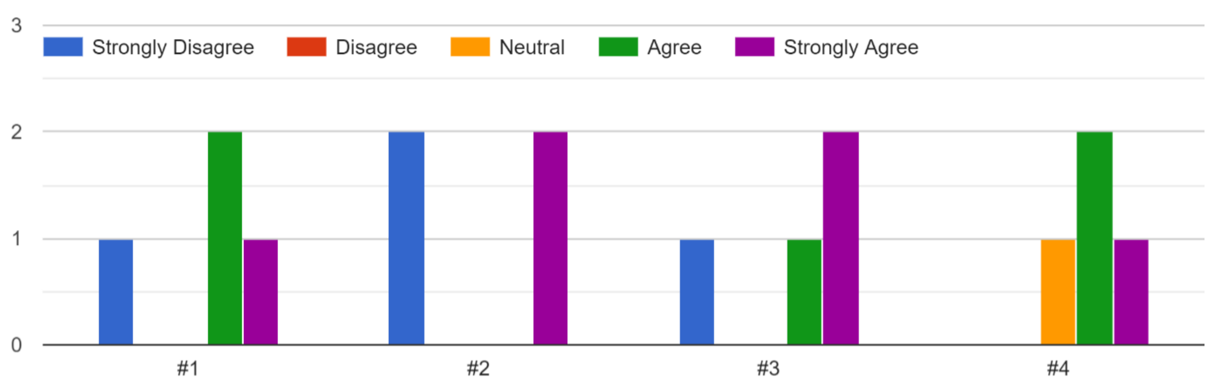

Figure 10 Rating of activities: #1 Great Debate: Can Grass Based Diets reverse climate change? #2 Fish Food: What can we feed the fish? #3 Solar Power Cost: Calculate the cost per kWh of solar energy, #4 Wind Pump Performance

Figure 11 shows how students rated the various activities and tasks throughout the internship. The most popular activities were the kits and the fish food activities. The games rated favorably, the most popular was Skribbl. Each pair of students hosted a game night where they chose whatever game they wanted us to play and ran the game night.

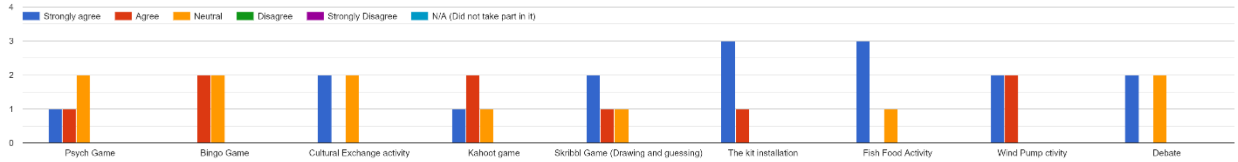

Figure 11 Evaluation of all internship activities

In the remote offering, it was especially important that students felt comfortable asking questions and interacting with one another and so we used the breakout rooms for activities during lectures and after lectures and played online games and students also made videos of drives or walks through their home town and showed those videos. The intent was to break the ice and bring travel to students when we couldn't travel. The instructors also shared videos of their locations. Across the group, the team members were in different parts of New Jersey and California, Cairo, Alexandria, and the Delta in Egypt as well as Germany so there was a lot of diversity in where "home" was that summer. The survey asked questions about how successful these efforts to build connections were. On a scale from 1 to 5 where 5 is highest, 50% of participants rated the efforts 2/5 and the other 50% rated it a 3/5. So unfortunately, it wasn't enough and building connections was moderately or less than moderately successful. Students did feel comfortable asking questions, 50% rated their comfort level at 5/5 and other 50% a 4/5. The survey asked about the effectiveness of the online communication tools, Zoom and Slack. 100% of participants found slack to be effective and 75% found breakout rooms in Zoom to be effective. Students were asked in the survey to offer suggestions to improve remote team building and there was a suggestion to create a schedule system, so that everyone can have like an individual "coffee chat" with each person throughout the internship to get to know each other better. Another suggested more icebreaker games during the lectures.

In terms of ABET learning outcomes, there doesn't appear to be a significant difference between student assessment of outcomes in the in-person program in 2018 shown in Table 3 and the assessment for the remote program in 2020 shown in Table 4. Maybe there was a slight increase in communication skills for the remote program but with the small number of responses, there aren't really any significant changes. This may be good news in that it is possible to learn problem solving and work in global teams and benefit society without having to go abroad. Clearly there are losses and the feedback given was that despite these efforts, students were not able to connect. In contrast, in 2018, the overwhelming response was the interpersonal connections formed between the participants that transcended the program.

Table 3 Student assessment of outcomes for 2018

Outcome	**SA**	**A**	**N**	**D**	**SD**
#1 (ABET outcome e)	50%	50%	0%	0%	0%
#2 (ABET outcome c)	50%	50%	0%	0%	0%
#3 (ABET outcome d)	83%	17%	0%	0%	0%
#4 (ABET outcome h)	83%	0%	17%	0%	0%
#5 (ABET outcome g)	17%	67%	17%	0%	0%

Table 4 Student assessment of outcomes for 2020

Outcome	SA	A	N	D	SD
#1 (ABET outcome e)	50%	50%	0%	0%	0%
#2 (ABET outcome c)	50%	25%	25%	0%	0%
#3 (ABET outcome d)	50%	50%	0%	0%	0%
#4 (ABET outcome h)	75%	25%	0%	0%	0%
#5 (ABET outcome g)	50%	50%	0%	0%	0%

#1 Formulate engineering problem and propose solution, #2 Understand constraints and work within given constraints to solve problem, #3 Work in interdisciplinary, global, diverse teams, #4 Benefit society and understand the societal impact of engineering and the greater social framework from which engineering projects serve, #5 Communication skills: Learn to communicate technical and nontechnical information with people from different background (technical, socio-economic, language etc.)

Students were asked "How do you think this project should move forward for the next summer?" and responded that additional data collection, more in depth analysis, and a focus on specific plants to grow; students were free to choose what they wanted to grow. Students wanted more direct contact with the people living in El Heiz; their contact was with the engineer on the project and not the local farmers; on site there is no phone/internet so communication was with the engineer when he was able to find connectivity a little distance from the site. Community members were interviewed (in Arabic) and their video shared with the students but it was not interactive.

4. Social / Community Impact

Integrated farming systems have an immense potential to boost resource efficient food production in the MENA region [24]. This internship tackled the design of affordable systems for small desert communities that are easy to install, operate, maintain, and replicate. Installing such models is of crucial importance, as farmers learn and innovate by watching their neighbors. In El Heiz, there is an urgent need to transform the local irrigation and growing systems by developing and testing more resource and production intensive, circular solutions. As water availability is a sustainability factor, given the finite groundwater source, production systems based on a "more crop per drop" approach can help sustain local water resources for longer, while also increasing the local availability of food, especially locally grown vegetables, and fish.

Local farmers in El Heiz have shown a keen interest in the integrated farming concept and have shown a steep learning curve when it comes to fishpond management over the past few months. Fish cultivation is not common in El Heiz, with only one commercial fish farm and one or two smaller farmer-run ponds. There is no integrated, renewable energy powered system in the oasis that also reuses irrigation water. As farmers are starting to pay higher prices for diesel and are becoming aware of water shortages, systems that increase production and save resources are starting to attract local interest. Due to a lack of local fish productions, fish consumption is rarer than meat or poultry consumption in the daily diet. Community members usually buy fish from traders that go around the oasis by truck, selling fish from the Nile Delta or frozen products imported from Northern Europe. This fish is usually rather expensive and not always fresh. Boosting local fish production through integrated farming systems that raise the output per m^3 of water extracted from the finite aquifer would also mean an improvement of local diets and easier access to healthy, fresh, and locally grown fish. Therefore, more productive local farming systems could play an important role in advancing SDGs 2 (zero hunger), 3 (good health and wellbeing) and 10 (reduced inequalities).

The full impact of the installed system remains to be seen, and full data sets of agricultural and fish productivity will be required to assess the overall performance and productivity of the system. The data sets collected over the past few months indicate that the system is feasible, and that results are promising. While it may be too early to assess the system's outputs, there are considerable savings for farmers regarding the system's inputs. A conventional flood irrigation system for growing vegetables in a sandy soil plot of the same area as the greenhouse without fish would require an hour of irrigation every day of the year, using roughly 365 liters of diesel fuel for pumping, as well as 450 kg of fertilizers, costing a farmer around 360 USD per year. A conventional, diesel-powered greenhouse irrigated with a drip system would require 90 liters of diesel per year for pumping, as well as 230 kg of fertilizers, costing farmers around 160 USD per year. Installing an additional water meter to measure the water input of the entire system (including top up water) will allow for a full calculations of water savings by the system. This meter has already been purchased and will be installed soon. A full evaluation of data from the weather station and a calculation of CO_2 emission savings are also planned. The operation and maintenance of the system has already attracted a significant level of attention from local farmers, thus raising awareness, knowledge and developing local capacity. Moreover, the farmers are already looking forward to grilling the first self-produced fish in a few months.

5. Conclusions & Future Developments

The remote international service experience proved to be educational and as effective in achieving learning outcomes as the in-person experience; however, students still expressed a lack of human connection to the peers and the community. The hands-on home kits were important in giving students experience in solar energy and aquaponics and hydroponics. There were challenges with the kits particularly starting up but the students enjoyed getting their systems up and running and seeing the fruits of their labor. The field project had some technical difficulties as well and iterations in the operating conditions proved necessary to achieve a functioning system where fish and plants are both healthy. The community has been enthusiastically involved in the operation of the integrated aquaculture and hydroponics system and have continued to operate the system and collect field data for the project team. Technology such as Zoom and Slack certainly made it possible to have an experience that was truly educational and fun but there is still room for improvement if we are to continue with a remote field experience such as this in the future. It proved to be doable; though of course in person travel has its own delights, it's not impossible to do this. In fact, there may be times when this is the better route as we were able to divert funds from travel expenses to materials and equipment that benefit the community and the students. It was also possible to extend the duration of the project since no additional housing expenses were needed. This may also reach participants for whom travel is not an option, there is clearly now an alternative to experiencing an international project without leaving your home.

In terms of future work, there is an indefinite hold on travel at the co-authors' respective institutions. The team hopes to implement an integrated aquaculture and hydroponics project in Nubariya in reclaimed desert lands and is in the process of seeking funding for the project. On campus, there are two projects that have spun off from this work. One looks at automating data collection and circulation for the aquaponics kits and the other is implementing a small-scale integrated aquaculture and hydroponics community garden in one of the residential colleges as part of a Campus as Lab initiative.

Acknowledgements

The authors would like to acknowledge the financial support provided by the Bartlett Family Fund administered through Princeton University. We would also like to acknowledge the research and technical expertise of Hassan El Husseini (Lead Engineer), Michael Vocaturo (Princeton University), and John Reid (Waterfield Farms) which was critical to the mission and accomplishments of the project. Finally, we would like to acknowledge the students who took part in the project whose passion, commitment and flexibility made the project a success; they are: Marie Elia, Andy Khalaf, Mohamed Hassan, Nour Boulgamh, Ozoh Chukwuebuka, Leo Espinoza, Yousuf Tariq-Shuaib, and Nadia Ralston.

References

[1] Central Agency for Public Mobilization and Statistics, “Home Page”, https://www.capmas.gov.eg/HomePage.aspx

[2] World Food Program, 2021, “Egypt”, https://www.wfp.org/countries/egypt

[3] FAS, 2020, “Grain: World Markets and Trade”, https://www.fas.usda.gov/data/grain-world-markets-and-trade

[4] Khalil, I. (World Food Program), 2020, “Community-Based Approaches to the Water-Energy-Food Nexus: Experiences form Upper Egypt”, 66th Cairo Climate Talks Experts Workshop, 2nd March 2020, Cairo. http://cairoclimatetalks.net/sites/default/files/Community-Based%20Approaches%20to%20the%20Water-Energy-Food%20Nexus-Experiences%20from%20Upper%20Egypt-Dr.%20Ithar%20Khalil_1.pdf

[5] World Bank. Data, “Egypt, Arab Republic”, https://data.worldbank.org/country/egypt-arab-rep

[6] UNDP Egypt, “About Egypt”. http://www.eg.undp.org/content/egypt/en/home/countryinfo.html

[7] Ministry of Planning, Monitoring and Administrative Reform (MPMAR): Egypt’s Voluntary National Review 2018 (2018), published on UN, https://sustainabledevelop##ment.un.org/content/documents/20269EGY_VNR_2018_final_with_Hyperlink_9720185b45d.pdf

[8] Jaskolski, M. 2016. "Managing Egypt’s Limited Supply of Fresh Water – Challenges of Sustainability, Water Scarcity and Food Security." *German Science Monitor*, 3-8.

[9] IRENA, 2018: “Renewable Energy Outlook Egypt”, https://www.irena.org/publications/2018/Oct/Renewable-Energy-Outlook-Egypt#:~:text=The%20government%20has%20set%20targets,rapid%20solar%20and%20wind%20deployment.&text=With%20renewable%20power%2C%20heat%20and,just%205%25%20overall%20in%202014.

[10] Wydra, K., Jaskolski, M., Wagner, L. and Essam, Sh., 2019, Nexus Approach to Solar Technology for Energy and Water Supply for Sustainable Rural Development in Egypt: A Review, *Journal of Photonics for Energy*, 9(4), 043108, doi: 10.1117/1.JPE.9.043108.

[11] Grimshaw, S., Sequeira, C., Hewkin-Smith, M., 2017, “A Computational and Experimental Compressor Design Project for Japanese and British High-School Students”, *Journal of Engineering for Gas Turbines and Power*, 139 (5).

[12] H. G. Howard, Joseph & C. Ratz, Herbert.,1997, “The International Engineering Student Exchange Program at the University of Waterloo,” V004T16A004. 10.1115/97-GT-065.

[13] El Gabry, L. and M. Jaskolski, 2019, “Offering Engineering Students Global Perspective through Experiential Learning Project in Wind Energy and Sustainability”, *Journal of Engineering for Gas Turbines and Power*, 141(10), 101008 (11 pages).

[14] A. R. Bielefeldt, K. Paterson, C. Swan, O. Pierrakos, D. Kazmer and A. Soisson, "Spectra of Learning Through Service Programs," in ASEE Annual Conference & Exposition, Atlanta, GA, 2013.

[15] M. McCormick, C. Swan and D. Matson, "Reading Between the Lines: Evaluating Self-Assessment of Skills Acquired During an International Service-Learning Project," in Proceedings of the *2008 American Society for Engineering Education Annual Conference & Exposition*, Pittsburg, PA, 2008.

[16] A. E. Jeffers, P. A. Beata and B. I. Strassmann, "A Qualitative Study to Assess the Learning Outcomes of a Civil Engineering Service Learning Project in Bolivia," *in ASEE Annual Conference & Exposition*, Indianapolis, IN, 2014.

[17] A. R. Bielefeldt and N. E. Canney, "Impacts of Service-Learning on the Professional Social Responsibility Attitudes of Engineering Students," International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship, vol. 9, no. 2, pp. 47-63, 2014.

[18] N. Canney and A. Bielefeldt, "Gender Differences in the Social Responsibility Attitudes of Engineering Students and How they Change over Time," Journal of Women and Minorities in Science and Engineering, vol. 21, no. 3, pp. 215-237, 2015.

[19] J. J. Duffy, L. Barrington and M. A. Heredia Munoz, "Attitudes of Engineering Students from Underrepresented Groups Toward Service Learning," in Proceedings of the Annual ASEE Conference and Exposition, Vancouver, BC, 2011.

[20] Berdanier, C. Tang, X., Cox, M., 2018," Ethics and Sustainability in Global Contexts: Studying Engineering Student Perspectives Through Photoelicitation", *Journal of Engineering Education*, 107(2), 238-262.

[21] Brumsen, M., 2011, "Sustainability, ethics, and technology," *Ethics, technology, and engineering: An introduction*, 277–300, Wiley-Blackwell.

[22] Canney, N., Bielefeldt, A., 2020, "Collegiate service engagement correlations with engineering job selection and satisfaction," *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, Vol. 15, No. 1,1-17

[23] Paterson, K., Swan, C., Watkins, D., 2016, "Going is Not Knowing: Challenges in Creating Intercultural Engineers," *2016 ASEE Annual Conference*, Paper ID 16399

[24] FAO, 2020, "Integrated Agri-Aquaculture in Desert and Arid Lands: Learning from Case Studies from Algeria, Egypt, and Oman", http://www.fao.org/3/ca8610en/ca8610en.pdf