A Community-Based Capstone Design Project to Build an Automated Urban Greenhouse

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***Abstract*—Over the past few years, the engineering programs at York College of Pennsylvania have added more community-based projects into the two-course capstone design sequence that all engineering majors take in their senior year. With capstone design already organized as a multi-disciplinary project-based learning course, it was a natural extension to develop opportunities for community-based projects. As a part of the initiative an automated urban greenhouse was designed, built, and delivered to a local city school to engage school students in sustainability and developing food awareness. A curriculum is being designed to include the greenhouse into the school activities. This paper discusses the process of including community-based projects into capstone projects involving a multidisciplinary student team. Expectations of the community-based project are presented. Detailed descriptions of the mechanical system, the electrical system, the sensor network, and the programmable logic controller are presented. System integration, on-site testing, and student outcomes assessment are also included.**

***Index Terms*—Greenhouse, Community-based project, Capstone, K-8 Education**

I. Introduction

The objective of this automated urban greenhouse (AUGH) was to combat the city's agricultural crisis while also providing a year-round learning environment for elementary students. The US Department of Agriculture classifies the City of York, Pennsylvania as a "food desert" which is defined as an urban area where it is difficult to purchase affordable or good-quality fresh food [1]. Residents of food deserts statistically suffer from poorer health than residents of non-food deserts due to the sparsity of fresh fruits and vegetables and the ease of access to calorie-dense foods. The automated urban greenhouse project aims to combat this deficiency by spreading awareness of the negative effects that food deserts have on communities and by educating students on how to grow their own produce. This incorporated the following constraints during the designing and prototyping of the greenhouse: health and safety of the elementary school students and teachers, sustainability of the greenhouse, and appropriate environment for healthy plants. This project experienced significant issues with permitting. The team learned about city permitting processes as well as political, ethical, social, and environmental aspects of building design and construction. This provided a unique opportunity for students to experience the broader circumstances of a community-based project. The educational requirements of the school were:

- A safe, year-round, hands-on learning and teaching space for students and instructors;
- A fully automated greenhouse including, but not limited to, temperature regulation, lighting, and watering;
- To allow for manual overrides of all automated functionality in the greenhouse; and
- To enable school teachers with little to no technical experience the ability to operate the greenhouse.

II. Literature Review

Engineers are involved in solving problems that include all aspects of the human society. A traditional engineering education might not be enough for graduating engineers to comprehend the process of community-based problem solving. Future engineers need to have a comprehensive understanding of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. They also need to consider ethical and professional responsibilities of an engineer to make an informed judgement when faced with an ethical issue in the context of an engineering task [2]. Engineering programs need to provide opportunities beyond the classroom to produce well-rounded engineers for the society. Coyle, Jamieson, and Oakes described engineering projects in community service (EPICS), which was developed at Purdue University in 1995 and now have more than 30 consortium institutions [3]. EPICS is a service-learning design program in which teams of students partner with local and global community organizations to address human, community, and environmental needs [4]. The

Manuscript received January 21, 2021; revised April 29, 2021.

doi: 10.18178/ijlt.7.2.59-67

Colorado School of Mines initiated a community-based project "Humanitarian Engineering" to benefit underserved communities both within the U.S. and abroad [5]. This initiative reported that faculty and students had more positive attitudes with respect to community service after they had completed the project. Community-based projects enhance academic knowledge through a situative perspective where theoretical concepts meet community service in a project-based learning environment. Creativity, communication, trust, and assertiveness are important elements of a community-based project because community partners often expect a tangible product for their time and investment. Incomplete and inappropriate solutions have little to no benefits for the community partners. As suggested by Connolly, ill solutions may actually be detrimental to partner organizations [6]. An IEEE meta-analysis of higher education research found that "more concrete, nontechnical skills like project management, business knowledge, and understanding methodologies are agreed to be areas for improvement in preparing ICT graduates for the job market" [7]. These conditions also apply to engineering graduates. Community-based projects provide opportunities for students beyond the academic curriculum such as networking, teamwork, supervising, coordinating, organizing, public speaking, and more [8]. Students also gain a broader understanding of the society in which they live.

III. Challenges and Opportunities of Community-based Projects

Community-based capstone design projects have some unique challenges due to lack of standard guidelines. Faculty need to conduct background research and work with clients to define project outcomes, goals, and guidelines. Due to the involvement of community clients, the project design needs to consider sustainability, user interface, a maintenance plan, client training, and safety. Capstone design is an opportunity to provide students with real-world experiences and is a gateway for industry and community partnerships [9]. The automated urban greenhouse (AUGH) project was a yearlong, real-world, large-scale design project to benefit the local school community. Students learned about the state/city permitting processes, national electrical code, volunteer service, and client interactions. None of these could be taught effectively in an academic setting. This project was a perfect fit to connect community service to academia. The AUGH project successfully integrated previous learning, prompted new learning, and provided realistic experiences as mentioned by Pembridge and Paretti [10]. This open-ended capstone design project challenged students with technical and non-technical requirements and constraints. Typically, laboratory exercises are limited to taking measurements and validating them with equations. Rarely, these laboratory exercises connect to broader multidisciplinary real-world applications. The AUGH was a student-centered project where their learning was extended beyond the classroom. All members of the team communicated effectively and relied on each other to propel the project forward. This teamwork instilled responsibility and ownership in them.

The AUGH was a large-scale multifaceted community-based project that required highly coordinated planning among the engineering programs at York College of Pennsylvania, York City School District, Goode Elementary School, the volunteering organizations, and the City Council. The planning for the project started in 2015 when the York City School District approached the engineering programs at York College of Pennsylvania with an idea to build a greenhouse. The engineering faculty visited all schools in the district to select a site. Goode Elementary School was selected because of its spacious sunny secure courtyard. The engineering faculty had previous experience with a community-based capstone project [11, 12, 13]. Based on those experiences, in AY2016-2017, the faculty adopted this project as a community-based capstone design project and recruited interested students to work on the initial prototype of the greenhouse. This project had two faculty advisors: one from the electrical and computer engineering program and one from the mechanical engineering program.

Funding for the project was sourced from a combination of department funds allocated to capstone design projects ($8,000), a Great-to-Greater grant from York College of Pennsylvania ($17,000), donations from industry partners ($6,000), and in-kind donations of materials/labor (estimated at $15,000). Total cash outlays for the project amounted to $31,000, with an additional $15,000 in in-kind donations resulting in a net cost of $46,000. The project could not have been completed without the extensive support of the program's industry and community partners. Significant cost increases occurred as the project transitioned from a proof of concept design to a robust design intended for continuous operation.

The capstone design team prototyped the concept of an automated urban greenhouse with a smart sensor network [14]. The operation of the AUGH was demonstrated during the capstone rollout in May 2017. The engineering faculty and the school district were planning to start building the greenhouse onsite in summer 2017. In the process, the team discovered the permitting issues and realized that nothing would move forward without the permit. The engineering faculty and the school district agreed to pause the site construction and implementation of the project until the permitting issues were resolved. In the meantime, the faculty were working on improving the central control system and the sensor network. Finally, the project restarted in AY2018-2019 and the completed AUGH was delivered to Goode Elementary School in August 2019. The rest of the paper provides detailed descriptions of the electro-mechanical design, sensor network design, controller design, onsite testing and handover, curriculum development, and assessment.

IV. Mechanical Structure Design

A solid foundation is crucial for a greenhouse to maintain long-term durability and functionality as well as to prevent the greenhouse from structural damage. The foundation design depends on greenhouse style, climate, site situation (soil, slope, etc.), desired thermal efficiency, budget, available materials and building codes [15]. Based on the available space in the school courtyard an 18-foot wide by 24-foot long greenhouse structure was selected. This is the minimum size to qualify the greenhouse as a classroom. The structural design team worked with a Professional Engineer to ensure that the construction complied with the latest edition of the International Building Code (IBC) [16] and the American Institute of Steel Construction (AISC) [17]. The design team considered dead load, snow load, and wind load of the structure. After the load calculations the team checked the purlin/girt, column/arch, and foundation to select appropriate materials [18]. The calculations showed that snow load and roof live load should be at least 12 pound per square foot (psf), but a live load rating of 20 psf is recommended to maintain a good factor of safety. The design team also stated that all concrete shall withstand 2500 lbs/in^2. Soil bearing pressure should be equal 1500 psf.

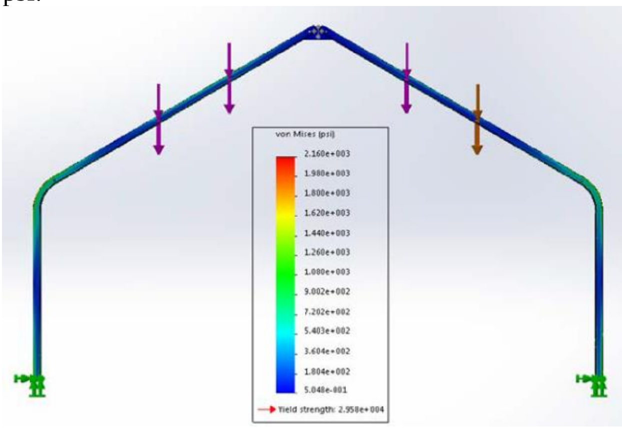

Figure 1. FEA results for von Mises stresses

Computer aided design (CAD) models of a single beam were developed and tested for three scenarios to gain a greater understanding of how the actual beam's unique geometry would react to loads from hanging heaters and fans. Two beams connected by an assumed chevron piece, fixed at both bottom ends, and two 15 lb loads on one beam representing a heater and two 10 lb loads on the other beam representing a circulating fan. Fig. 1 shows the finite element analysis (FEA) results of stresses. The maximum deflection seen in this configuration was 0.0457 inches and the maximum stress was 2.16 ksi, providing a factor of safety of 13.5. This calculation is also only for a single beam without trusses connecting the single beam to a system of eight beams. The FEA analysis confirmed the calculation conducted by the design team. After the structure analysis, the team researched credentialed greenhouse structure suppliers to meet the requirements. Gothic Arch Greenhouse [19] was found suitable to meet the design criteria reported in reference [18].

Official permits were required to place an order for the greenhouse structure. Permits were also required for breaking ground before the foundation could be constructed. Upon placing the initial application in early 2017, the permit was rejected, and accompanied by a clause stating the location of the greenhouse would need to be 25 feet from every external wall of the school. In the Goode Elementary School courtyard, it was not possible to meet this clause. The structural design team created an argument for the greenhouse to be located 10 feet from external walls based on its construction type VB (IBC 2015 Table 601 and 602). With this argument the team worked with an architect and the county officials to find a suitable and reasonable location in the courtyard. After going through more reviews and minor changes, the city approved the permit to build a 24-foot by 18-foot greenhouse in late 2017. Fig. 2 shows a 3D model and the completed AUGH at Goode School.

The mechanical design process provided an opportunity for the students to bring their theoretical knowledge to the community service. The mechanical engineering team created a unique structural design to fulfill the community need. Creativity, communication, trust, and assertiveness were tested while facing the permit issues. The team was very successful working with the legal issues while maintaining appropriate ethical and professional behavior.

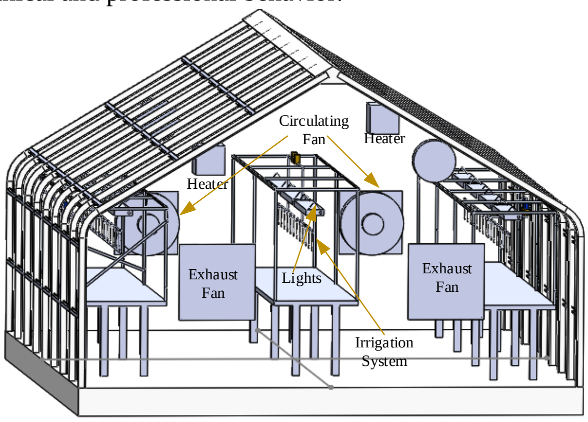

Figure 2(a). 3-D model of the automated urban greenhouse

Figure 2(b). Physical automated urban greenhouse

V. Electrical System Design

The greenhouse consists of many electrical components that are controlled by a sensor network designed to maintain a hospitable environment for plants year around. These components can be divided into two categories: ac components and dc components. The electrical service for the greenhouse is a 3-phase 120 V/208 V delta-wye configuration. It is beneficial for the school and the power distribution company to draw power evenly from the three phases. The design team distributed electrical loads among the 3-phases to balance them within the limitations. Phases 1 and 2 were each connected to one of the two redundant dc power supplies. Phase 3 was connected directly to the appliances. The rating for breakers is typically 125% of the expected load for regular appliances and 150% for inductive loads such as fans and solenoids. The total maximum current of all of the 24 V dc components added up to 18.213 A. The nominal current is much lower than the maximum current. A 20 A, 24 V dc power supply is sufficient for the greenhouse. Fig. 3 shows the electro-mechanical layout of the greenhouse.

The heater's power source does not come from the electrical enclosure. It is plugged into a separate 3-phase, 208 V ac outlet and is powered constantly. It is controlled partly through the control enclosure. It contains its own 24 volt power supply, and relays to turns itself on and off. It is controlled from two terminals on the heater which are designed to connect to a thermostat.

The electrical team expanded their classroom knowledge to create an industry standard electrical system for the greenhouse. Each student was responsible for a part of the system that includes sizing the component and selecting a vendor appropriately. The team not only designed the system but also tested it in real-time to ensure the safety and security of the system. This was a great experience for the team beyond the academic settings.

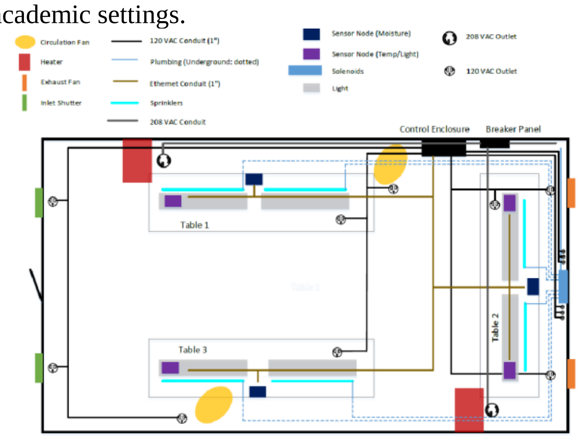

Figure 3. Electro-mechanical layout of the greenhouse

VI. Sensor Network Design

A sensor network consists of three moisture sensor nodes and four temperature, humidity, and light (THL) sensor nodes as shown in Fig. 3. Each moisture sensor node contains four 10HS [20] Decagon Devices moisture sensors that can be placed in different plant pots located at each table. The THL sensor node consists of a TSL2591 [21] light sensor and a DHT22 [22] temperature/humidity sensor.

Power-over-Ethernet (PoE) [23] technology was selected to power each sensor node to overcome the voltage drop issues in the sensor wiring. This technology was a perfect fit for this project given that the Ethernet connection was already in place for each of the sensor nodes for data transmission. An Arduino Ethernet shield and an Arduino PoE module were selected as this design can harness the PoE technology and can also be connected to an Arduino Uno to send sensor data via Ethernet. Students used appropriate printed circuit board (PCB) technology to design and manufacture sensor nodes. Figures 4 and 5 show the finalized moisture node and THL node, respectively.

In a traditional classroom setting students work with sensors to characterize and collect data. Design of a network incorporating PoE for real-world applications is rare in a classroom environment. This project incorporated the practical application into academic learning where students gained experiences on the sensor network and PCB design.

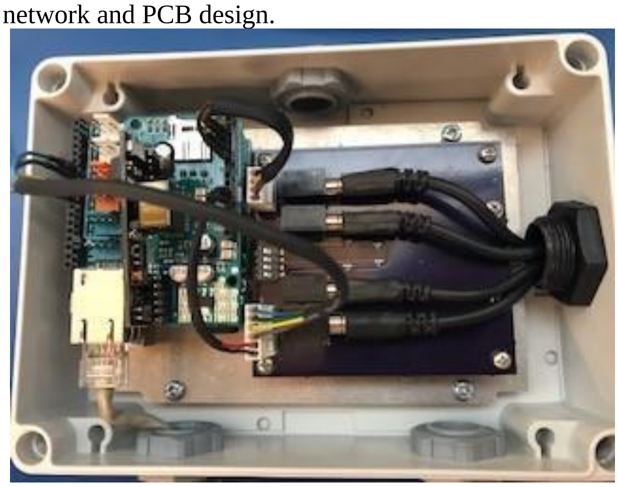

Figure 4. Moisture sensor node

Figure 5. THL node sensor

VII. Programmable Logic Controller (PLC) Based Controller Design

PLCnext technology provides industry standard robustness and reliability for the control systems. The Phoenix Contact PLCnext [24] AXC F 2152 was used for the control system along with an input module, AXL F

DI32/1, and an output module, AXL F DO16/1. This controller was programmed using IEC61131-3 and C++. The PLCnext device is connected over the network and from there it is possible to load and debug programs. Once a program is installed on the PLCnext it will remain on the device unless hard reset or updated through the PLCnext Engineer software. The controller program separates the code to cover the functions of receiving data, sorting the data, and processing the data into their own programs. This allows for troubleshooting the programs in a design that ensures ease of testing and maintenance. The user can configure the system to operate in fully automatic mode, fully manual mode, or a mix of manual and automatic mode by appliance.

The first program "Main1" is a simple program that receives all of the information from the sensor network. It takes JSON packets received from the sensors and stores them in an array of bytes. The second program "CppDataTypeTestProgram1" is a C++. This program converts the byte array of JSON packets into a string and parses the JSON string based on the type of sensor from which the data was received. If the string has a "type" of 1 it represents the data was received from a THL sensor box and returns a data value for sensor id, temperature, light, and humidity. If "type" 2 it represents a moisture sensor box and returns a data value for sensor id and values for 4 moisture sensors feeding data to that sensor box.

The next four programs in the task, "TempControl1", "humControl1", "LightControl1", and "moisSensorControl1" all have similar functions. They check to see if new data was received and then store it in an array for the specific data type based on the sensor from which the data was received.

The final program in the task, "inputSwitchReadings1", has the task of reading the state of every physical switch on the main control panel. This program reads this information from the 32 input Module attached to the PLC in order to display the state of the switches even if they are in manual mode and not being controlled by the PLC. This allows for accuracy on the state of the system so the user can look at the HMI for all the information on the system and won't have to examine the state of the physical switches.

The first program, "thlControl1", has the task of controlling the heating ventilation and air conditioning (HVAC) parts of the greenhouse. The first part of the program determines which sensors are online and reporting data, if no new data has been received for a sensor it will consider any data that it previously received as old data and not use it in any calculations. The reason for this is that old data may no longer be relevant to the state of the greenhouse and may throw off calculations. Once this is determined, the temperature, humidity, and light values are averaged with all working sensor values. This information is used to determine if any environmental conditions in the greenhouse need to change. The user is able to set the desired temperature value and depending on the difference between the average and desired temperature the PLC will turn on/off circulation fans, exhaust fans, and heaters and open/close inlet shutters in the greenhouse by turning outputs on or off on the output module connected to the PLCnext. Additionally, the light sensors can determine when the greenhouse lights should be turned on and turned off.

The second program, "moisControl1", has the task of controlling the solenoids which supply water to each table in the greenhouse. The first part of the program determines which sensors are online and reporting data. Once again, old stale data is ignored, only new data is incorporated into calculations. The program can also determine if sensors are embedded into the soil. This is important because sensor readings from a sensor out of soil will produce inaccurate results when computing the average wetness of the soil. Therefore, any sensors reporting out of soil are not considered in the average. Once this is determined, the moisture values for each table are averaged. The user is able to set the desired wetness of the plants for each table and if the average is below or above the set point the solenoids will turn on/off for each table. Fig. 6 shows the PLCnext based controller with all peripheral devices.

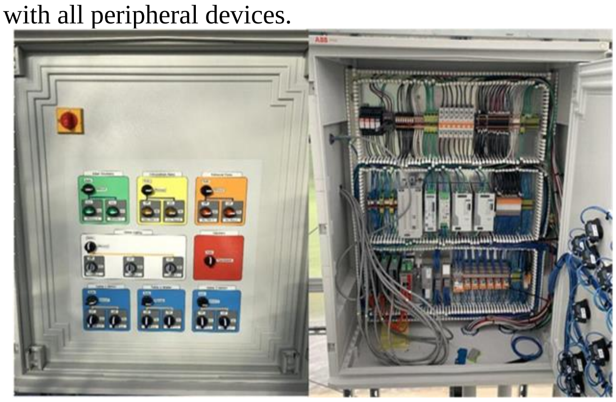

Figure 6. PLC based controller: front panel (left); control circuitry (right)

Figure 7. HMI home screen

The final part of the PLC is the Human Machine Interface (HMI). The HMI uses values throughout the program to display the current state of the greenhouse controls to the user through a simple user Interface. The user is able to see the state of every physical switch located on the control panel, the readings from the sensors, and are able to set the desired temperature value in the greenhouse as well as the desired soil wetness for each table of plants. The HMI also has an authentication feature to prevent unauthorized users from changing set points. Fig. 7 shows the home screen for the HMI.

The software team focused on the hardware and software interaction, reliability, security, and safety. The team worked with industry standard equipment and designed a robust PLC-based control system for the greenhouse. Through this multifaceted software design project, students learned to communicate with clients and teammates to make sure that the software system is user friendly and secure.

VIII. System Integration, Testing, and Handover

The PLCnext is located inside the control enclosure and receives data from the sensor network. The PLC receives information from all the sensors and then determines if it needs to make environmental changes in the greenhouse. Once this is determined the output modules connected to the PLCnext are turned on or off to control the relays to which they are connected. The relays control power to the components in the greenhouse. The relays are also connected to the input module on the PLCnext which allows for the PLCnext to know if a component is turned on or off even when the system is not in automatic mode and being controlled by the PLC.

The entire system has been integrated into the greenhouse at Goode Elementary as shown in Figure 8. The four THL sensor boxes are located throughout the greenhouse to provide a good average of the temperature, humidity, and light in the greenhouse. The three moisture boxes are deployed on each of the tables as well as two solenoids per table to supply water based on the moisture sensors values. Two industrial plant lights are hung over each table to provide light to the plants when the sensors determine there is not sufficient light in the greenhouse for the plants. There are also circulation fans and heaters installed for temperature control. All of these components are wired back to the control enclosure where they can be controlled by the PLCnext.

After system integration, the team created an emulated environment to test the functionality of the sensor network and the electro-mechanical system. Temperature sensors control the operation of heaters, circulation fans, exhaust fans, and inlet shutters. A heat gun and freezer spray were used to vary the temperature and verify the operation of the PLC controller, the heater, inlet shutters, and the various fans. The moisture sensors control the irrigation solenoid valves. This operation was verified using dry soil and wet soil in pots. Light sensors control all the lights in the greenhouse. Artificial darkness was created around the light sensors using boxes to test the operation of the lights. The complete system operation testing was a success.

The greenhouse was ready for the handover and the team created a manual for the client. The manual consists of a detailed description of the operating, troubleshooting, and maintenance procedures of the following: system startup and shutdown, appliance operation, HMI, moisture sensor nodes and monitoring values, temperature, humidity, and light sensor nodes and monitoring values, PLCnext, and the control enclosure. The manual also includes a parts list, electrical schematics, and wiring diagrams.

Figure 8. Interior of the greenhouse with all components connected

IX. K-8 Curriculum Development

When the engineering partnership with Goode School began, a simultaneous partnership with the Education Department at York College of Pennsylvania began as well. The Education department began placing pre-service teachers at Goode Elementary School starting in the fall semester of 2017. Preservice teachers who were placed at Goode were a subset of those enrolled in an elementary teaching science methods course. The initial plan was that preservice teachers would develop K-12 science curriculum that incorporated the AUGH. However, because of delays with construction of the AUGH, preservice teachers were unable to utilize it for lessons until the fall semester of 2019. During the first semester of lesson implementation, it was decided that only a small group of the preservice teachers would pilot lessons in the greenhouse. Four preservice teachers worked in teams of two to develop and implement two distinct science lessons in the AUGH. Rules and procedures for working in the greenhouse were established with the students prior to the day of the lessons in the greenhouse. The first team worked with fourth grade students to plant two varieties of bean seeds in the greenhouse. During their lesson, the students tasted a fully developed version of the bean they were planting, compared the two different seeds, and predicted how tall their seeds would grow. The seedlings were used to begin a discussion of the life cycle of plants. The second team worked with third graders to examine what seeds need to grow. After planting the seeds, the class returned to observe and measure the growth progress of the seeds. While both lessons required relatively simple utilization of the greenhouse, they still served as a way to get students outside during the late fall and early winter months of November and December. Furthermore, a trip to the greenhouse was a small field trip that got students out of their normal classroom as they completed a science experiment. In both lessons, preservice teachers focused on the Next Generation Science Standards (NGSS) Science and Engineering Practices. Preservice teachers in upcoming semesters will continue to develop lessons in the greenhouse, using mostly seeds and plants. Other lessons may focus on integrating math skills with graphing and measuring. Initial interactions with utilization of the greenhouse have been positive. Future research is slated to focus on opinions of stakeholders (like teachers and administrators) on the greenhouse. At early grades, an emphasis on such practices as asking questions, carrying out investigations, and obtaining/communicating information is more important for scientific literacy than the memorization of facts. As the partnership with the Education department and Goode Elementary School moves forward, future semesters of preservice teachers will continue to develop curriculum. Our hope is that enough curriculum will be designed and implemented across a variety of grade levels so that in-service teachers at Goode Elementary School will be able to utilize the greenhouse without assistance from preservice teachers.

X. Assessment of Student Outcomes

The goal of this project was to design, build, test, and deliver an automated urban greenhouse to be used as an educational tool at a local school. Students were challenged with a real-world problem that did not have a readily available solution. In AY2016-2017 three Electrical Engineering (EE), four Computer Engineering (CE), and five Mechanical Engineering (ME) students worked on this project. In AY2018-2019 two EE and 1 CE students worked on the projects. In summer 2019 the same three students finished the project as their independent study. Onsite mechanical structure and civil construction work were completed by faculty, students, volunteers, and a contractor. The following student outcomes were assessed in this project [2]:

- Complex problem-solving ability;
- Design an application specific system while maintaining ethical and professional responsibilities; and
- Effective communication.

This community-based project was presented to the team as a complex abstract problem. The team used the academic knowledge of science, engineering, and mathematics to identify constraints and specifications for mechanical systems, electrical systems, a sensor network, a PLC-based controller, and communication protocols. During this period the team had continuous communication with the school to transform their requirements into a set constraints and specifications for the project. The team used the constraints and specifications to formulate each subsystem with mathematical/engineering analysis and developed models and a plan for integration. Finally, they solved this complex engineering problem using the models developed to satisfy the constraints and specifications.

This project evolved around the specific needs of the school mentioned in the introduction section. The team paid particular attention to the safety and welfare of teachers and students while designing the greenhouse: no exposed wiring and equipment, no sharp edges, only the teachers can operate the greenhouse, train the teachers, and limit the number of students at any given time. This is an educational tool for the school. The capstone design team consulted with many experts and practicing engineers to design and build a safe learning environment within the given budget constraints. The team maintained ethical and professional responsibilities during the design, build, test, and implementation period. The judgement used in a particular engineering situation follows the ethical and professional responsibilities of an engineer. Ethical and professional standards were carefully and explicitly considered in the decision making process. Overall, this was a student centric community-based capstone design project, where students were involved in all aspects of the project ranging from meeting with customers, city officials, contractors, professional engineers, and reporting to the faculty. At every step of this process each student maintained integrity, professionalism, and ethical behavior. When they were designing the AUGH, the students ensured that the school understood the technical terms they using to convert their requirements. Students also accurately conveyed the school requirements to the city officials and the contractors. This was a lifelong lesson for the students.

During the design, build, and test period students developed and conducted appropriate experimentation to analyze and interpret data, and used engineering judgment to draw conclusions. Students had to learn new knowledge such as PLCnext, PoE, HMI, and greenhouse specific structure and electrical system. They applied this new knowledge and academic practices to prototype subsystems and system integration.

Communication and teamwork were very crucial for a successful implementation of a community-based complex engineering project. Students experienced multifaceted communication throughout the project between team, sub-team, faculty, client (school), experts, vendors, contractors, and volunteers. Students also made numerous presentations and wrote technical reports based on their work. This was a practical opportunity for students to learn and improve their communication and teamwork skills. Some students came forward with initiative and became leaders and others helped the team to achieve the objectives.

This was a very challenging capstone design project for the faculty and students. There were many unknowns such as industry standard structural design requirements, permit approval process, commercial electromechanical equipment sizing, development of robust control systems, sensor network design, and system level integration. During the process students not only learned the engineering part but also the management part of the project. Students volunteered their time during the construction of the greenhouse and maintained a very positive attitude knowing that they were making an impact to the community. Students experienced all elements of a real-world engineering project with the end-to-end design and implementation process. According to the faculty assessment, each student attained all outcomes discussed in this section.

XI. Conclusion

This paper presented a successful implementation of an automated urban greenhouse for a local school as a community-based capstone design project. Students designed, built, and tested each subsystem of the greenhouse such as the mechanical structure, the electro-mechanical system, sensor network, programmable logic based controller, human machine interface, and Power-over-Ethernet to satisfy the health and safety of school students and teachers, sustainability of the greenhouse, and to provide a year-round habitat for healthy plants. The system integration and field testing validated the overall system design. Students combined academic learning and new knowledge from their research to solve this complex multifaceted real-world engineering problem. The Education Department is helping the school to create a curriculum to integrate the greenhouse into school activities. Assessment results show that students attained all outcomes of a real-world engineering design project while fulfilling the educational requirements.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Kala Meah wrote the paper, supervised electromechanical system design, and coordinated the greenhouse construction. Wayne Blanding supervised the system integration and handover process. James Moscola supervised the control system and sensor network design process. Nicole Hesson worked with the school to design the curriculum. All authors approved the final version of the paper.

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