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Integrating Sustainability and Civic Engagement through Engineering Design: Automated Food Pantry and Aquaponics System Projects

Dr. Rajani Muraleedharan, Saginaw Valley State University

Dr. Rajani Muraleedharan is an Interim Associate Vice President and Professor of Electrical and Computer Engineering (ECE). She earned her Ph.D. and M.S. in Electrical and Computer Engineering from Syracuse University. She was a postdoctoral research associate at the University of Rochester, and a research intern at Mitsubishi Electric Research Lab.

At SVSU, Dr. Muraleedharan has made significant contributions to STEM education and community engagement. She is the founder of SVSU's GoBabyGo program, which enhances mobility for individuals with special needs through assistive technology. She is the faculty advisor for Society of Women Engineers (SWE), IEEE Student Chapter, Robotics Club as well as the Women in Engineering chair for IEEE Northeast Michigan, WIE ILS sub-committee and supports many initiatives both nationally and internationally.

An accomplished scholar, Dr. Muraleedharan has authored over 50 publications, served as an NSF reviewer, ABET program evaluator and been elevated to senior IEEE member status for her professional contributions. Her research interests include computational intelligence, robotics, behavioral science, and network security.

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Abstract: This paper presents two community-engaged engineering initiatives at Saginaw Valley State University that integrate sustainability, automation, and civic responsibility through experiential learning. In the first initiative, engineering students partnered with a local Salvation Army Food Pantry to design and implement a sensor-based automated food distribution system that extends service hours, improves accessibility, and enhances operational efficiency with minimal human intervention. The project enabled students to apply sensing, control, and automation concepts to address real-world community needs.

The second initiative involves the development of an aquaponics system in the University's greenhouse to support sustainable food production through vertical plant growth and incorporates plans for fish integration, real-time environmental and water-quality monitoring, and automated filtration and circulation. Assessment data from reports, presentations, demonstrations, reflections, and partner feedback indicate gains in student technical competence, teamwork, systems thinking, and civic awareness. Community partners reported strong interest in continued collaboration and practical value from both projects. Collectively, these initiatives demonstrate a replicable model for aligning engineering education with social impact, sustainability, and ethical leadership.

Introduction:

As the Earth's population increases, the amount of arable farmland available continues to decrease. To counteract the potentially catastrophic consequences of this trend, innovation must occur, and has occurred, that can maximize the usage of spaces typically not considered fit for agricultural use. Food insecurity and limited access to fresh, nutritious produce remain persistent challenges in many communities [3-5], particularly in urban and underserved areas. Addressing these complex societal issues requires interdisciplinary, system-oriented solutions that extend beyond traditional technical approaches [6-9]. Engineering programs are uniquely positioned to respond by integrating sustainability-focused design with civic engagement and experiential learning, preparing students to become engineers who are not only technically proficient but also socially responsible and capable of collaborating with diverse community stakeholders.

In recent years, engineering education has increasingly emphasized community-engaged learning as means to connect classroom instruction with real-world impact. Such approaches align with national calls and accreditation expectations to educate engineers who can apply technical knowledge in ethical, inclusive, and socially relevant contexts. Project-based learning that centers on community needs allows students to develop technical competencies while gaining a deeper understanding of societal challenges, equity considerations, and the broader implications of engineering solutions.

This paper presents two complementary, community-engaged engineering design projects implemented within an undergraduate engineering curriculum: (1) an Automated Food Pantry system designed to improve equitable food access and operational efficiency, and (2) a student-designed Aquaponics System developed as a senior design project to support sustainable food production and STEM education. The Automated Food Pantry leverages sensing, control, and automation technologies to extend service hours and enhance accessibility for community members, while the Aquaponics System integrates sustainable agriculture, monitoring technologies, and systems thinking to promote local food production and experiential learning. Together, these projects illustrate how engineering design can serve as a powerful framework for sustainability education, civic engagement, and student development. By embedding community-centered projects within undergraduate coursework and capstone experiences [1], this work demonstrates a replicable model for integrating technical rigor with social impact.

Project Context and Educational Framework:

Course and Program Integration: The Automated Food Pantry and Aquaponics System projects were embedded within existing undergraduate engineering coursework and senior design sequences, enabling students to meet required curricular outcomes while engaging in authentic, community-centered problem solving. Both projects were intentionally structured to reinforce key engineering competencies aligned with ABET student outcomes, including the ability to apply engineering design to produce solutions that consider public health, safety, welfare, and sustainability; function effectively on multidisciplinary teams; and communicate engineering solutions to diverse audiences. Through iterative, human-centered design processes, students incorporated community input into system requirements, constraints, and performance metrics, fostering systems thinking and ethical responsibility. The project-based format further strengthened students' abilities to integrate technical knowledge with real-world constraints, manage open-ended design challenges, and reflect on the broader societal impacts of engineering decisions.

Community partnerships: They are central to the educational framework and serve as a mechanism for reciprocal engagement rather than one-directional service. Partners included local food pantries, K–12 schools, and youth-serving organizations focused on food security and sustainable urban agriculture. These stakeholders actively contributed to project scoping, participated in design reviews, and supported system implementation and outreach activities. Regular interaction with non-technical partners required students to translate complex technical concepts into accessible language, directly supporting ABET outcomes related to effective communication and professional responsibility. By grounding technical work in community-defined needs, the projects ensured relevance, authenticity, and mutual benefit while reinforcing the role of engineers as collaborative problem solvers working in service of society.

Automated Food Pantry System Design

The Automated Food Pantry project was motivated by persistent challenges faced by traditional food pantries, including limited-service hours, inefficiencies in inventory management, barriers to equitable access, and concerns related to user privacy and dignity. In collaboration with community partners, students engaged in problem definition and requirements development that prioritized accessibility, operational efficiency, and respectful user interaction. This process directly supported ABET student outcomes related to identifying and solving complex engineering problems and applying engineering design within realistic constraints, including social, ethical, and economic considerations.

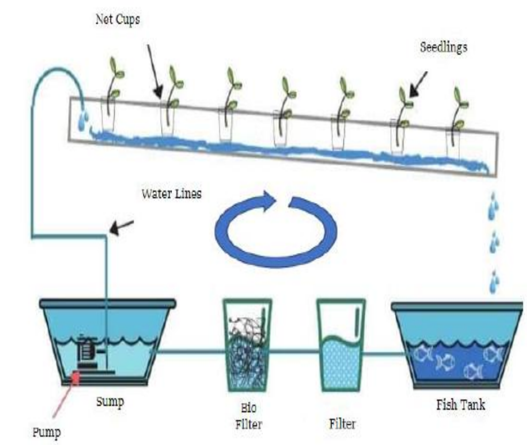
The system architecture as shown in Figure 1 was designed as a modular, scalable platform that integrates microcontroller-based control units, secure access mechanisms such as identification or code-based entry, sensor-driven inventory tracking, and database-supported management tools. User-friendly interfaces were developed for both pantry clients and administrators to ensure usability across diverse stakeholder groups. Students applied concepts from embedded systems, control systems, and software engineering to design, implement, and test the system, reinforcing ABET outcomes associated with applying engineering knowledge, designing systems to meet specified needs, and functioning effectively on multidisciplinary teams. Iterative prototyping and testing allowed students to refine system performance while incorporating feedback from non-technical community partners.

Figure 1 Sensor-based Pantry

Sustainability considerations were embedded throughout the design process, aligning technical decisions with long-term community impact. Energy-efficient components were selected to minimize operational costs, while real-time inventory monitoring reduced food waste by enabling timely restocking and redistribution. The system was designed for maintainability and future expansion by community partners, supporting ABET outcomes related to ethical and professional responsibility and the consideration of sustainability and societal impact in engineering solutions. Collectively, the Automated Food Pantry project demonstrates how community-engaged engineering design can simultaneously address technical challenges, social equity, and sustainable operation.

Aquaponics System Design

The aquaponics system was designed using a closed-loop approach that integrates aquaculture and hydroponics, in which nutrients generated from fish waste support plant growth while plants simultaneously contribute to water filtration and system balance. This system-based design minimizes water usage, reduces external inputs, and supports sustainable food production, providing an applied context for students to engage with sustainability, resource efficiency, and environmental stewardship. Two main downsides of a traditional aquaponics system as shown in Figure 2 are their need for constant monitoring/upkeep, and the difficulty of fitting them into a confined space. Both these issues were addressed by creating a one-of-a-kind mobile, autonomous aquaponics system that utilizes as small of a footprint as possible while also minimizing the need for user interaction. Figure 3 shows the system that was built using Nutrient Film Technique (NFT) methodologies and Internet of Things (IOT) interactions. In an NFT system, water containing essential nutrients and minerals is continuously circulated past the roots of plants growing in narrow troughs [2]. Through this approach, students addressed ABET student outcomes related to applying engineering design to produce solutions that consider environmental sustainability, public welfare, and long-term system performance.



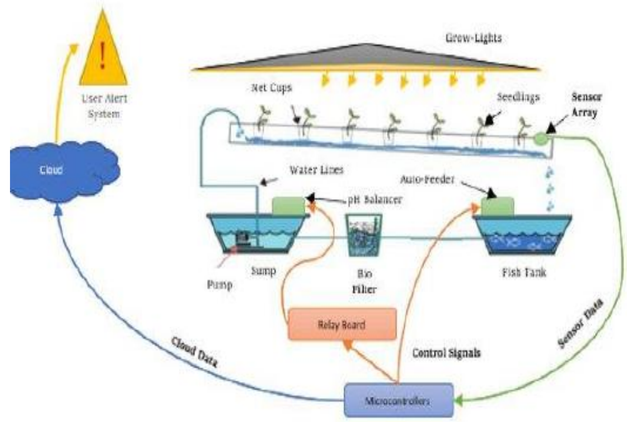


Figure 2. Traditional NFT Aquaponics system Figure 3. Autonomous Aquaponics

Implemented as part of a capstone course, the project required students to design, build, and test a functional aquaponics system under realistic technical, budgetary, and safety constraints. The system incorporated fish tanks and grow beds, water circulation and filtration subsystems, environmental and water-quality sensors for monitoring pH, temperature, and water levels, and control logic to ensure safe and reliable operation of pumps and related equipment. Students integrated mechanical structures, electrical hardware, and software control systems, reinforcing ABET outcomes associated with solving complex engineering problems, conducting appropriate experimentation, analyzing system performance, and functioning effectively on multidisciplinary teams. Design decisions were informed by iterative testing and consultation with stakeholders, promoting systems thinking and professional responsibility.

In addition to its role in sustainable food production, the aquaponics system was intentionally designed as an educational and outreach platform to support experiential learning and community engagement. The system has been used for demonstrations, student-led tours, and youth-focused STEM activities that introduce concepts related to engineering design, sustainability, and food systems. These outreach efforts strengthened students' ability to communicate technical concepts to non-technical audiences and reflect on the societal impact of engineering solutions, directly supporting ABET outcomes related to effective communication, ethical responsibility, and lifelong learning. Collectively, the aquaponics project illustrates how capstone design experiences can integrate technical rigor, sustainability, and civic engagement within engineering education.

Sustainability, Community Engagement, and Civic Impact

Sustainability and community engagement were central to both projects and were intentionally embedded throughout the design, implementation, and reflection phases to promote civic-minded engineering practice. Students engaged directly with community partners through needs assessments, iterative design feedback sessions, and system demonstrations, ensuring that technical solutions were responsive to real community contexts. These interactions strengthened students' understanding of ethical responsibility, equity, and the societal role of engineers, directly supporting ABET student outcomes related to ethical and professional responsibility, effective communication, and the consideration of public welfare and sustainability in engineering design. Consistent with the Engineering for One Planet (EOP) framework's *Implement* outcome, students translated sustainability principles into actionable design decisions by developing solutions that were feasible, maintainable, and aligned with community-defined priorities.

The aquaponics project further extended civic impact through youth and community outreach, serving as a hands-on educational platform for sustainable urban agriculture and STEM engagement. Workshops and demonstrations introduced K–12 students and youth-serving organizations to systems thinking, environmental stewardship, and engineering pathways, with particular attention to engaging learners from historically underrepresented backgrounds. By designing learning experiences that were accessible, culturally responsive, and relevant to local food systems, the project reinforced the importance of diversity, equity, and inclusion as essential components of successful community engagement. These efforts align with ABET outcomes emphasizing communication with diverse audiences and lifelong learning, as well as EOP goals that call for inclusive implementation of sustainability solutions that empower communities.

The reciprocal nature of these partnerships resulted in mutual benefits for both students and community stakeholders. Community partners gained access to innovative technological solutions, sustainable food systems, and educational resources that addressed locally identified needs, while students gained authentic design experience, increased civic awareness, and a deeper appreciation for inclusive engineering practice. By centering DEI principles and sustainability outcomes within community-engaged design, these projects demonstrate how engineering education can advance social impact while preparing students to implement equitable, sustainable solutions in alignment with both ABET accreditation expectations and the Engineering for One Planet (EOP) [10, 11] framework.

Outcomes and Assessment

The technical outcomes of the Automated Food Pantry and Aquaponics System projects demonstrate the feasibility of integrating community-engaged, sustainability-focused design into core engineering curricula at scale. Students successfully developed a functional prototype of an automated food pantry system that integrates sensing, control, secure access, and data collection technologies to support equitable food distribution. In parallel, the aquaponics project resulted in a functional system capable of sustaining plant growth and supporting fish life through integrated circulation, filtration, and monitoring subsystems. Together, these projects required students to apply engineering design principles, conduct system-level integration, and evaluate performance under realistic constraints, directly supporting ABET student outcomes related to solving complex engineering problems, applying engineering design with consideration of sustainability, and conducting experimentation and analysis. Consistent with the EOP *Implement* outcome, students translated sustainability concepts into deployable systems that address real community needs.

The Automated Food Pantry project produced a functional prototype that integrated secure keypad access, occupancy sensing, inventory detection, and administrator monitoring tools. Bench testing demonstrated reliable sensor response and successful logging of simulated transactions. Students reported improved confidence in system integration, troubleshooting, and translating stakeholder requests into engineering specifications. The Aquaponics project resulted in a fully operational closed-loop prototype consisting of nutrient-film grow channels, water recirculation pumps, filtration, environmental sensors, and mobile framing. During pilot operation, the system successfully sustained leafy greens. Initial harvest cycles yielded produce used for demonstrations and campus outreach events. Water recirculation reduced freshwater demand compared with conventional soil-based cultivation. Additionally, the resources used for checking plant growth in the green house has been reduced significantly.

Assessment of student learning was conducted through design reports, oral presentations, demonstrations, and structured reflection activities. Results indicate measurable gains in engineering design competence, teamwork, and project management skills, as well as increased understanding of sustainability principles and community-defined constraints. By embedding these projects within existing coursework and senior design sequences, the instructional model enabled scalable community engagement across multiple student teams without adding standalone service-learning requirements. This approach supports ABET outcomes related to effective teamwork, communication, and ethical responsibility while demonstrating an innovative, curriculum-integrated strategy for engaging large numbers of engineering students in community-based work aligned with EOP implementation goals.

Community impact assessment was informed through partner feedback, informal interviews, and post-implementation discussions. Community partners reported improved engagement with students, increased awareness of sustainable food systems, and strong interest in continued collaboration and system expansion. The modular and replicable nature of both projects allows for adaptation across different community contexts, supporting sustained partnerships rather than one-time interventions. One student reflected that *"this was the first time engineering decisions had immediate consequences for real users, not just a grade."* Another noted that *"community feedback changed our design priorities more than technical assumptions did."*

Community Partner and Organizational Outcomes

Feedback from community partners indicated that the projects generated tangible value beyond the classroom. Representatives from the Salvation Army food pantry noted that the automated pantry concept could expand food access beyond standard volunteer hours, reduce wait times, and preserve client privacy by allowing more independent retrieval options. One partner commented that *"the student team approached our operational challenges seriously and proposed solutions we had not considered internally."*

K–12 educators and youth program staff reported that aquaponics demonstrations increased student curiosity about engineering, sustainability, and agriculture. Teachers noted that students were particularly engaged by seeing how sensors, pumps, and biology worked together in a single system. Several schools requested future visits or collaborative programming.

These responses suggest that the projects served both immediate organizational needs and broader educational outreach goals.

By integrating assessment, scalability, and community relevance, these outcomes highlight an innovative model for embedding community-based sustainability efforts into engineering education that aligns with ABET accreditation expectations and the Engineering for One Planet framework.

Sustainability, Community Engagement, and Civic Impact

The reciprocal nature of the partnerships produced benefits for both students and community stakeholders. Community organizations received prototypes, technical recommendations, outreach programming, and continuing consultation. Students gained direct exposure to food insecurity, sustainability barriers, and the realities of implementing systems in resource-constrained environments. The aquaponics project continues to make developments that has further supported civic engagement and capable of serving as a demonstration site for local school groups and community visitors. K-12 students can gain knowledge on water reuse, nutrient cycling, automation, and urban food production. These interactions strengthened communication skills while helping younger learners connect STEM concepts to visible community challenges.

Lessons Learned and Challenges

A key lesson learned from these projects was the critical importance of diversity, equity, and inclusion in achieving meaningful and sustainable community engagement. Early and continuous involvement of community partners representing diverse socio-economic backgrounds, age groups, and lived experiences related to food insecurity was essential to ensuring that engineering solutions were responsive, respectful, and accessible. Projects that prioritized inclusive design practices, such as accommodating varying levels of technological literacy and respecting user dignity and privacy, were more readily adopted by partners. Students learned that balancing technical ambition with partner capacity is a key equity consideration, as overly complex systems can unintentionally exclude community members or create long-term maintenance burdens. Challenges related to system upkeep, long-term ownership, and scalability highlighted the need for flexible timelines, shared responsibility models, and ongoing institutional support, particularly when working with under-resourced organizations.

By addressing food security and sustainable urban agriculture; issues that disproportionately affect communities based on socio-economic status, race, and geographic location the work reflects highly impactful efforts to reduce inequities in engineering practice and education. The projects intentionally engaged diverse populations, including youth, community members experiencing food insecurity, and students from varied disciplinary and personal backgrounds, reinforcing the value of inclusive participation in engineering design. By embedding DEI principles into project definition, stakeholder interaction, and system implementation, these efforts contribute to an inclusive and diverse future of engineering that values multiple perspectives, lived experiences, and community knowledge alongside technical expertise.

Conclusions and Future Work

The Automated Food Pantry and Aquaponics System projects demonstrate the potential of community-engaged engineering design to address real societal challenges while advancing inclusive undergraduate engineering education. Through sustainability-focused, community-centered projects, students developed technical competence, civic awareness, and an appreciation for diversity and equity as foundational elements of effective engineering practice. Future work will focus on longitudinal assessment of student and community outcomes, continued system refinement to enhance accessibility and maintainability, and expansion of partnerships to broaden participation across additional communities and diversity dimensions.

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