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Inclusive Experiential Learning for STEM Students in Sustainable Robotic Agriculture

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Interest in robotics and automation in food prod

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Abstract

As the world grapples with challenges like climate change, population growth, and food security, sustainable agriculture has become a critical area of focus. Robotic agriculture, with its potential to improve efficiency and sustainability, is at the forefront of this transformation. STEM students, as future innovators and leaders, need to be well-equipped with knowledge and skills in this domain. However, the key to effective learning lies in inclusivity and hands-on experience. This paper aims to elucidate strategies for integrating inclusive experiential learning with sustainable robotic agriculture in STEM education.

The student participants from science and engineering explored the potential benefits and challenges of technologies such as Farmbots (an open-source farming technology that combines robotics, automation, and software to facilitate precision farming in small-scale agricultural settings) while considering the equitable distribution of resources, the three P's (People, Planet, and Profit) of sustainability, and the well-being of communities and workers involved in agriculture. One important aspect of the experiential learning project was growing peanuts and hemp with FarmBots. Growing peanuts provided a unique opportunity to not only explore the agricultural contributions of George Washington Carver, an African American scientist in the early 20th century, but also helped shedding light on his remarkable achievements in the context of social justice. By integrating hemp cultivation on the FarmBot platform, the investigators created an engaging space that highlighted the potential of this crop while addressing the historical and contemporary social challenges faced by marginalized communities. The students honed their content on the importance of sustainable economic development, environmental stewardship, accessible healthcare, criminal justice reform, and education as crucial components of a socially just approach to hemp cultivation. Besides receiving hands-on-experiences, the STEM majors working on experiential learning projects explored how these technologies can be made accessible to small-scale farmers, disadvantaged communities, and regions with limited resources.

The experiential learning activities addressed barriers to access and promoting equity in the adoption, and use of robotic agriculture technologies. The primary and the co-authors are collaborating with community-based organizations to design and implement projects that leverage robotic agriculture and FarmBots to address those needs. Some of the initiatives like community-led urban farming projects, training programs, or cooperative models that empower and benefit the community are taken into consideration to enhance such collaborations with the community at large.

1.Introduction

1A. Sustainable Robotic Agriculture

The global population is projected to reach 9.7 billion by 2050, placing immense pressure on food production systems[1]. Concurrently, environmental concerns such as climate change, soil degradation, and water scarcity pose significant challenges to traditional farming methods. Robotic agriculture offers a promising solution by leveraging technology to enhance efficiency, productivity, and sustainability in food production. Robotic agriculture encompasses a wide range of technologies, including autonomous vehicles, drones, robotic arms, sensors, and data analytics. These innovations enable precision farming techniques such as precision planting, targeted spraying, and automated harvesting. By optimizing resource utilization, minimizing waste, and reducing environmental impact, robotic agriculture facilitates sustainable farming practices[2,3,4].

IB. The Vital Nexus: STEM Education and Sustainable Robotic Agriculture

The convergence of STEM education and robotic agriculture offers a transformative approach to address the challenges facing modern agriculture. As the global population burgeons and environmental pressures escalate, the imperative for sustainable food production becomes increasingly urgent. STEM education lays the groundwork for innovative solutions, while robotic agriculture provides practical applications to enhance efficiency, productivity, and environmental stewardship in farming[5,6]. STEM education cultivates critical thinking, problem-solving, and analytical skills essential for addressing complex challenges. By engaging students in inquiry-based learning and hands-on experiences, STEM education fosters creativity, collaboration, and a deep understanding of scientific principles. Moreover, it prepares students for diverse career pathways in technology, engineering, and agriculture, positioning them as catalysts for innovation and change. Embracing STEM education as a catalyst for advancing sustainable robotic agriculture is not only essential for securing the future of food production but also imperative for building a more resilient, equitable, and sustainable agricultural ecosystem[7].

IC. Inclusive Experiential Learning

Inclusive experiential learning goes beyond traditional classroom teaching, emphasizing hands-on experiences, real-world applications, and a diverse, accessible learning environment. In the context of sustainable robotic agriculture, inclusive experiential learning activities may involve designing and programming agricultural robots, analyzing data from smart sensors, and understanding the socio-economic impact of technology in farming communities[8,9]. An inclusive approach ensures that STEM education in sustainable robotic agriculture is accessible to students of all backgrounds, genders, and abilities. This work-in-progress paper addresses the critical need for creating a diverse and equitable learning environment, including mentorship, outreach initiatives where students can get involved, and the integration of diverse perspectives in curriculum development.

The overall goal of the project is to elucidate strategies for integrating inclusive experiential learning with sustainable robotic agriculture in STEM education. By engaging science and engineering students in exploring the potential benefits and challenges of technologies like Farmbots, which combines robotics, automation, and software for precision farming in small-scale agricultural settings, the project seeks to address the equitable distribution of resources and the three P’s of sustainability (People, Planet, and Profit)[10]. A key aspect of the experiential learning project involved the cultivation of peanuts and hemp with FarmBots. Growing peanuts provided a unique opportunity to delve into the agricultural contributions of George Washington Carver, an African American scientist in the early 20th century[11]. The students not only did research on Carver's remarkable achievements but also explored social justice issues. Integrating hemp cultivation on the FarmBot platform created an engaging space that highlighted the potential of this crop while addressing historical and contemporary social challenges faced by marginalized communities[12]. STEM majors (summer exchange students and the students from the University of Maryland Eastern Shore) participating in these experiential learning projects honed their understanding of sustainable economic development, environmental stewardship, accessible healthcare, criminal justice reform, and education as crucial components of a socially just approach to hemp cultivation. Beyond hands-on experiences, students had discussions related to making these technologies accessible to small-scale farmers, disadvantaged communities, and regions with limited resources.

The experiential learning activities addressed barriers to access in the adoption and use of robotic agriculture technologies. The primary and co-authors are actively collaborating with community-based organizations to design and implement projects that leverage robotic agriculture and FarmBots to address the specific needs of communities. Initiatives such as community-led urban farming projects, training programs, and cooperative models are being considered to enhance these collaborations and empower communities at large.

1.D. Objectives

The following educational objectives for the students participating in the experiential learning include:

a) To foster a comprehensive understanding of the interconnectedness of agriculture and broader societal issues through experiential learning by weaving together the scientific exploration of crops with the historical and social context,
b) To gain insight into the integration of technology within farming/agriculture, including the understanding the potential of robotics in agriculture with Farmbots as case studies;
c) To explore the capabilities of microcontroller platforms such as Arduino and Raspberry Pi in collecting and processing agricultural data, focusing on their adaptability and affordability for farmers and researchers alike.

2. Approach

2.1 Recruitment of Students for Summer Experiential Learning and Academic Year

Summer Programs—The Maryland Space Grant Consortium (MDSGC) Summer Exchange Internship Program is a paid internship that spans across a 10-week period during every summer. It recruits mainly STEM undergraduate students from participating member institutions of the MDSGC to participate in hands-on research experiences outside their home institutions. The students are first required to contact the faculty coordinator at their respective institutions, who play pivotal roles in identifying suitable projects for the students interested in the internship program. The mentors, who are typically faculty, from participating member institutions have to submit project proposals in the STEM areas that are relevant to the National Aeronautics and Space Administration's (NASA's) mission and are aligned with the needs of the future workforce. The student recruitment plan targeting women and members of underrepresented minorities was included. Each project included the learning outcomes, timeline, mentoring plan, and expected deliverables. For each project, financial support for one to two students was requested. The students need to be US citizens and either rising sophomores or juniors or seniors majoring in STEM disciplines pertaining to the project. The interns were required to be enrolled in the member institutions that are participating in this internship. They also made the commitment to work at least for 10 weeks during the summer. Following their applications, the faculty research mentors who supervised the projects interviewed the prospective interns to assess whether they were a good fit for their projects or not. Following selection, the students were assigned to their research mentors during the entire 10-week period of the summer exchange program. Two student interns one student from mechanical engineering from Morgan State University, and another from computer science (University of Maryland Baltimore County) participated in the sustainable robotic agriculture project and worked closely with undergraduates in Agriculture and Engineering majors from the home institution to assist with setting up experiments; collecting and analyzing data. The students were required to submit a short report reflecting on the experience and results of the findings. During the entire academic year, there were 5 students (2 as a part of their undergraduate research experience; and 3 as part of their paid assistantships) participated in this project. Out of the six students; two were from general engineering majors; one from agriculture major; one from computer science major; and two were from Biology majors.

2.2 Farmbots and Specialty Crops

At the University of Maryland Eastern Shore, two FarmBots have been strategically installed—one in an outdoor high tunnel house (Figures 1a-1b) and a smaller counterpart indoors, illuminated by overhead grow lights (Figure 2). These FarmBots epitomize the convergence of technology and agriculture, embodying the principles of smart farming at a micro scale. They are computer numerically controlled (CNC) robots akin to 3D printers, operated by Raspberry Pi and Arduino-like microprocessor boards. Functionally versatile, these machines undertake a range of tasks crucial for efficient crop management. From precise seeding to targeted weed eradication, monitoring soil moisture levels, and individualized plant irrigation, FarmBots exhibit remarkable capabilities over the designated raised bed areas they serve. Users can manipulate FarmBots through user-friendly web applications accessible via smartphones, enhancing ease of operation and control (Figure 3). Equipped with a Raspberry Pi Camera (Pi-Cam), these FarmBots extend their utility beyond mere automation. The integrated camera facilitates weed detection and enables captivating time-lapse photography, adding depth to agricultural monitoring and documentation practices. Moreover, the cloud accessibility feature empowers users to remotely oversee and direct FarmBot operations from any web-enabled device, amplifying flexibility and convenience. At the university, the outdoor Farmbot Genesis XL V1.4 occupies a high tunnel house, extending the growing season and bolstering plant resilience. Powered by renewable energy sources such as wind turbines and solar panels, this outdoor setup exemplifies sustainable farming practices. Additionally, an innovative rainwater harvesting system fulfills the irrigation needs of the outdoor FarmBot, showcasing a self-sufficient farming platform (Figures 1a-1c).

Figure 1a. Outdoor FarmBot set up in high tunnel solar and wind turbine

Figure 1b. View from inside of outdoor Farmbot with solar-powered robotic weeder

Figure 1c. Rainwater harvesting system

Figure 2. Indoor FarmBot with Growlights, the Farmbot bed is on a mobile table

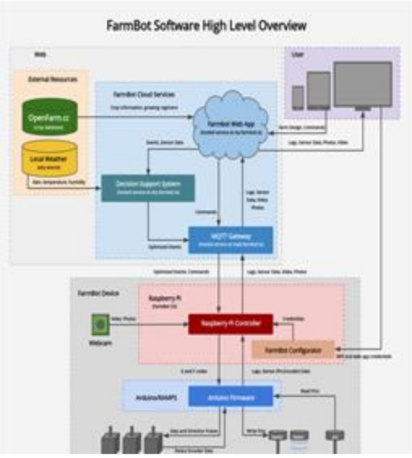


Figure 3. Farmbot software assembly

Meanwhile, indoors within the Food Science and Technology building, the smaller Farmbot Express V1.1 operates beneath overhead grow lights, affording precise control over photoperiods. This feature enables experimentation with specialty crops like hemp, peanuts, radishes, turnips, and carrots, fostering agricultural diversification. Over a span of two years, this indoor FarmBot setup has facilitated the cultivation of two crops of interest: hemp *(Cannabis sativa* L); and peanuts (*Arachis hypogaea*).

2.3 Relevance of growing peanuts

Peanuts (*Arachis hypogaea*), commonly known as groundnuts, represent a fascinating crop with a myriad of distinctive attributes, rendering them ideal subjects for academic inquiry and experimental exploration. This leguminous plant's growth pattern, characterized by its subterranean pods, presents a curious phenomenon. While its flowering occurs above ground, the resulting pods develop beneath the soil's surface. Emerging from peanut seeds, or kernels, this crop gives rise to verdant, oval-leafed plants measuring approximately 15-20 inches in height. Delicate yellow flowers adorn the lower reaches of these plants, undergoing self-pollination before shedding their petals. Following fertilization, the ovary swells, initiating the formation of a small peg that extends into the soil. At the tip of this peg lies the peanut embryo, which matures into the recognizable legume. From planting to harvest, this growth cycle spans four to five months, subject to varietal differences[13]. Peanut cultivation necessitates careful attention to water requirements, with plants typically requiring 1.5 to 2 inches of water weekly during kernel development. Notably, the water needs of peanuts are significantly lower than those of almonds, with approximately one-ninth the water consumption per ounce. Precise irrigation practices can optimize kernel growth, contributing to enhanced yield potential. A single peanut plant, under optimal conditions, has the potential to yield anywhere from 25 to 50 peanuts. Beyond their agronomic significance, peanuts play a crucial role in soil nitrogen fixation, a process facilitated by the presence of *Rhizobium leguminosarum* bacteria[14]. Application of inoculants containing these beneficial bacteria during planting has been observed to confer notable benefits to peanut crops, underscoring the importance of microbial symbiosis in agricultural ecosystems[13,14].

The historical legacy of peanuts is intricately intertwined with the pioneering contributions of George Washington Carver, an esteemed African-American scientist and educator. Revered as the "Father of the Peanut Industry," Carver's groundbreaking research and innovations have left an indelible mark on agricultural science. His legacy continues to inspire generations of students, researchers, and scientists to explore the boundless potential of peanuts and other crops, exemplifying the enduring impact of visionary scholarship[15]. The unique characteristics and historical significance of peanuts render them an invaluable subject for academic study and experimental inquiry, particularly within the educational milieu of historically black colleges and universities. As students engage with the multifaceted aspects of peanut cultivation, they not only enrich their understanding of agricultural science but also honor the legacy of trailblazing scholars like George Washington Carver. Figure 4 depicts peanut cultivation conducted with indoor Farmbot.

Figure 4. Peanut cultivation in indoor Farmbot

2.4 Relevance of growing hemp

The hemp plant, scientifically known as *Cannabis sativa*, is a versatile and robust herbaceous annual plant that has been cultivated for thousands of years for various purposes. Hemp plants typically grow tall and slender, reaching heights of up to 10 to 15 feet. They have a distinct branching structure with narrow, palmate leaves arranged spirally along the stem. The leaves are compound, with serrated edges and usually have seven to nine leaflets. Hemp plants also produce small, inconspicuous flowers that are typically greenish-yellow. hardy and adaptable plant that can thrive in diverse climates and soil conditions. It is typically grown outdoors but can also be cultivated indoors or in controlled environments like greenhouses[16,17]. Hemp plants require well-drained soil, adequate sunlight, and sufficient water to support healthy growth[16,17]. Growing hemp plants on indoor Farmbots holds immense relevance in the context of modern agriculture, offering a myriad of benefits ranging from controlled environment cultivation to resource efficiency and product quality assurance. Integrating hemp cultivation into the FarmBot platform created an engaging space for students to explore the potential of this crop. Hemp, with its versatile uses, presented an opportunity to discuss sustainable practices in various industries, from textiles to construction[17].

The project was designed to address both historical and contemporary social challenges faced by marginalized communities. Hemp cultivation on the FarmBot platform became a lens through which students could examine the potential economic, environmental, and social benefits of this versatile crop[18]. Figures 5 depicts hemp cultivation with indoor Farmbot.

Figure 5. Hemp cultivation in indoor Farmbot

2.5 Farmbot Programming

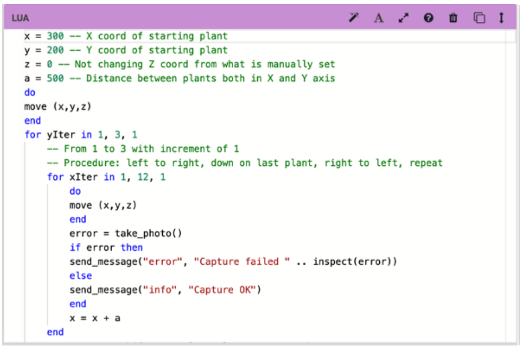
In the era of precision agriculture and automated farming systems, the FarmBot stands out as a innovation, revolutionizing traditional farming practices through its advanced technology and programming capabilities. Central to its functionality is the Lua programming language, which empowers the FarmBot to execute commands and functions beyond the limitations of the sequence editor[19]. The students participating in this project explored the significance of Lua in FarmBot programming, highlighting its similarities to Python and its role in enhancing agricultural automation[19,20]. Through this experience, the students documented as well as listed the many benefits/power of Lua in Farmbot programming[20], which can be extended to real world situations.

> ***Flexibility and Extensibility***: Lua enables FarmBot users to go beyond the predefined sequences offered by the sequence editor, allowing for the creation of custom scripts tailored to specific tasks and requirements. This flexibility empowers farmers and researchers to design complex workflows, implement custom logic, and integrate external sensors and devices seamlessly.
>
> ***Real-Time Control and Decision Making***: By leveraging Lua scripts, FarmBot can make real-time decisions based on sensor data, environmental conditions, and user-defined parameters. This capability enhances the adaptability and responsiveness of the system, enabling it to adjust planting, watering, and harvesting operations dynamically to optimize crop growth and resource utilization.
>
> ***Integration with External Systems***: Lua's versatility extends to its ability to interface with external systems and APIs (Application Programming Interfaces), facilitating integration

with third-party software, databases, and cloud services. This enables FarmBot to exchange data, retrieve weather forecasts, access crop databases, and even communicate with other smart devices on the farm, fostering a connected and intelligent agricultural ecosystem.

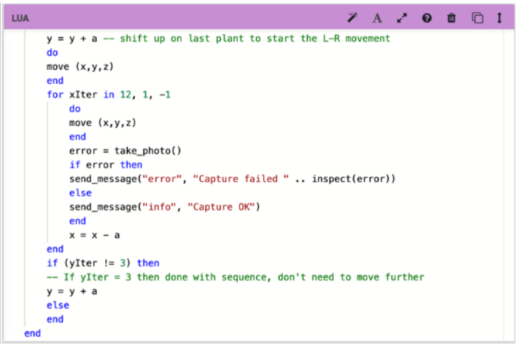
Advanced Algorithms and Data Processing: Lua's lightweight nature and efficient runtime make it well-suited for implementing advanced algorithms and data processing tasks on FarmBot. From machine learning algorithms to optimization algorithms for route planning and resource allocation, Lua can empower farmers to harness the power of data-driven decision-making in agricultural management.

Figures 6 a and 6b show examples of Lua programming; and 6c shows Lua AI code generation.



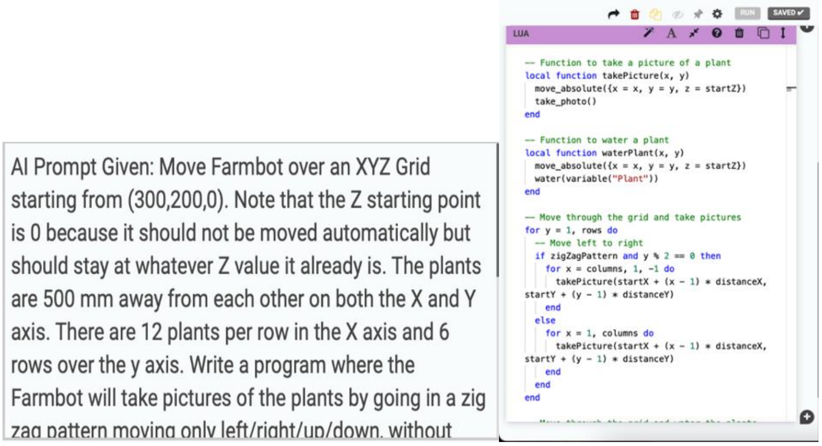
```
x = 300 -- X coord of starting plant
y = 200 -- Y coord of starting plant
z = 0 -- Not changing Z coord from what is manually set
a = 500 -- Distance between plants both in X and Y axis
do
move (x,y,z)
end
for yIter in 1, 3, 1
    -- From 1 to 3 with increment of 1
    -- Procedure: left to right, down on last plant, right to left, repeat
    for xIter in 1, 12, 1
        do
        move (x,y,z)
        end
        error = take_photo()
        if error then
        send_message("error", "Capture failed " .. inspect(error))
        else
        send_message("info", "Capture OK")
        end
        x = x + a
    end
```

Figure 6a



```
    y = y + a -- shift up on last plant to start the L-R movement
    do
    move (x,y,z)
    end
    for xIter in 12, 1, -1
        do
        move (x,y,z)
        end
        error = take_photo()
        if error then
        send_message("error", "Capture failed " .. inspect(error))
        else
        send_message("info", "Capture OK")
        end
        x = x - a
    end
    if (yIter != 3) then
    -- If yIter = 3 then done with sequence, don't need to move further
    y = y + a
    else
    end
end
```

Figure 6b



AI Prompt Given: Move Farmbot over an XYZ Grid starting from (300,200,0). Note that the Z starting point is 0 because it should not be moved automatically but should stay at whatever Z value it already is. The plants are 500 mm away from each other on both the X and Y axis. There are 12 plants per row in the X axis and 6 rows over the y axis. Write a program where the Farmbot will take pictures of the plants by going in a zig zag pattern moving only left/right/up/down, without

```
-- Function to take a picture of a plant
local function takePicture(x, y)
  move_absolute({x = x, y = y, z = startZ})
  take_photo()
end

-- Function to water a plant
local function waterPlant(x, y)
  move_absolute({x = x, y = y, z = startZ})
  water(variable("Plant"))
end

-- Move through the grid and take pictures
for y = 1, rows do
  -- Move left to right
  if zigZagPattern and y % 2 == 0 then
    for x = columns, 1, -1 do
      takePicture(startX + (x - 1) * distanceX,
startY + (y - 1) * distanceY)
    end
  else
    for x = 1, columns do
      takePicture(startX + (x - 1) * distanceX,
startY + (y - 1) * distanceY)
    end
  end
end
```

Figure 6c

2.6 Assessments of Experiential Learning in Sustainable Robotic Agriculture

Assessing students' experiential learning in sustainable robotic agriculture with FarmBots requires a multifaceted approach that evaluates both academic knowledge and practical skills. Here are a few assessment methods that were and are currently employed:

Project Reports and Presentations: The students were required to submit comprehensive project reports detailing their contributions, methodologies used, challenges encountered, and outcomes achieved. Additionally, the authors/investigators organized presentations where students showcased their project findings, shared insights, and reflected on their learning experiences. Evaluation criteria included clarity of communication, depth of analysis, and demonstration of critical thinking.

Problem-Solving Exercises: Problem-solving exercises or case studies were desgined related to sustainable robotic agriculture with FarmBots. These assessed students' ability to apply theoretical concepts to practical scenarios, identify issues, propose solutions, and justify their reasoning. This assessment method evaluates students' analytical skills, creativity, and ability to apply knowledge in real-world contexts.

Hands-On Demonstrations and Prototypes: Evaluated students' proficiency in operating FarmBots and implementing sustainable agricultural practices through hands-on demonstrations or prototype showcases. This approach assessed their technical skills, attention to detail, and adherence to safety protocols. Additionally, solicit feedback from peers and mentors (including graduate students) to assess teamwork and collaboration was incorporated.

Reflective Journals and Portfolios: The students maintained reflective journals throughout the project, documenting their experiences, challenges, successes, and lessons learned. This assessed their ability to critically reflect on their learning process, identify areas for improvement, and set goals for future development. Evaluation criteria included depth of reflection, self-awareness, and evidence of growth over time.

Peer and Self-Assessment: The project incorporated peer and self-assessment components where students evaluated their own performance and that of their peers based on predetermined criteria. This fosters accountability, encourages constructive feedback, and promotes metacognitive skills development. The project investigators ensured clear guidelines and training on assessment criteria to enhance reliability and fairness.

Interviews: Individual and group interviews were conducted to assess students' understanding, problem-solving abilities, and critical thinking skills. These included open-ended questions related to sustainable robotic agriculture with FarmBots, allowing students to demonstrate their depth of knowledge, analytical reasoning, and communication skills.

By employing a combination of these assessment methods, mentors leading the projects can effectively evaluate students' experiential learning, providing holistic feedback and promoting continuous improvement.

3. Project Learning Outcomes

3.1 Overall Student Learning Outcomes

Learning encompasses the development of skills across three broad domains: cognitive, affective, and psychomotor. While higher education traditionally emphasizes cognitive skills based on Bloom's taxonomy—ranging from knowledge acquisition to evaluation[21]—engineering education standards set by ABET emphasize the importance of both cognitive and affective development. Integrating active learning experiences outside the classroom, such as the project described, yields multifaceted learning outcomes that bridge academic knowledge with practical skills and civic responsibilities, particularly in land grant settings where addressing interdisciplinary challenges is paramount[22]. The expansive nature of this project aligns with the overarching mission objectives of land grant institutions like UMES, where experiential learning opportunities can engage students from various majors. Furthermore, by incorporating considerations of food security, energy efficiency, environmental sustainability, and water management, this project fosters discussions around the United Nations' Sustainable Development Goals—a critical component of preparing students for future global challenges[,23].

Past and current experiments with FarmBots have explored/exploring the cultivation of various crops. By leveraging indoor FarmBots for the cultivation of hemp and peanuts, efforts can be made to address systemic inequities and disparities within the agricultural sector. Historically marginalized groups, including minority farmers, women farmers, and indigenous communities, often face barriers to accessing land, resources, and market opportunities. Indoor farming technologies offer a level playing field, enabling small-scale producers and underrepresented groups to participate in high-tech agriculture and access niche markets. Moreover, initiatives that celebrate the cultural heritage and contributions of diverse communities to agriculture, such as highlighting the legacy of African American scientist Dr. George Washington Carver in peanut cultivation, promote inclusivity, diversity, and social cohesion within the agricultural community.

These initiatives like the peanut and hemp cultivation project not only offer invaluable experiential learning opportunities but also serve as platforms for interdisciplinary collaboration, cultural appreciation, and the celebration of historical contributions to science and innovation. By integrating such projects into STEM curricula, institutions like UMES can inspire and empower the next generation of diverse STEM leaders while addressing critical global challenges.

3.2 Experiential Learning Outcomes

The experiential learning outcomes are paramount to fostering interdisciplinary collaboration and preparing students for future academic and professional endeavors[24]. The following outcomes are listed depicting how students developed/can develop key skills and competencies through this project:

> **Working with Students from Different Disciplines**: By engaging with peers from various academic backgrounds, students will cultivate collaboration skills essential for navigating diverse perspectives and knowledge domains. Collaborating with individuals from fields such as engineering, agronomy, computer science, biology, and environmental science fosters an appreciation for interdisciplinary approaches and enriches problem-solving strategies.

Developing a Shared Understanding of the Problem: Effective collaboration hinges on establishing a shared understanding of the project's objectives, challenges, and potential solutions. Through active communication, active listening, and respectful dialogue, students learn to articulate their ideas, clarify misunderstandings, and synthesize diverse viewpoints into a coherent strategy.

Identifying and Leveraging Individual Strengths: In interdisciplinary teams, each member brings unique strengths, expertise, and perspectives. Encouraging students to recognize and leverage these individual strengths promotes a culture of mutual respect, cooperation, and collective success. By valuing diverse contributions, students cultivate inclusive teamwork skills essential for tackling complex challenges.

Integrating Different Approaches and Methodologies: The complexity of sustainable agriculture requires integrating diverse approaches, methodologies, and technologies. Students learn to navigate this complexity by blending insights from fields such as precision farming, robotics, sustainable agriculture, and data analytics. This interdisciplinary integration fosters critical thinking, creativity, and adaptability in problem-solving.

Developing a Shared Vision and Goals: Successful collaboration hinges on establishing a shared vision and aligning goals among team members. Through ongoing communication, consensus-building, and iterative planning, students cultivate skills in goal-setting, project management, and collective decision-making. This collaborative process fosters a sense of ownership, accountability, and motivation among team members.

The current project (work in progress) in Sustainable Robotic Agriculture with FarmBots offers a rich learning environment for students to develop essential interdisciplinary collaboration skills. By honing effective communication, active listening, collaboration, leveraging individual strengths, integrating diverse approaches, and establishing shared vision and goals, students are equipped with the competencies needed to excel in academic, professional, and personal contexts. Moreover, these inclusive experiential learning outcomes contribute to building a more resilient, innovative, and socially responsible workforce prepared to address the complex challenges of sustainable agriculture and environmental stewardship.

3.3 Incorporating social justice, diversity, and accessibility into learning outcomes

Incorporating social justice, diversity, and accessibility into assessments and learning outcomes for experiential learning activities in sustainable robotic agriculture for STEM students, with a focus on growing peanuts and hemp, requires a deliberate and comprehensive approach. Here is the approach the authors have undertaken to these principles into the educational framework[25]:

Learning Outcomes:

Social Justice: Learning outcomes should emphasize students' ability to critically analyze the social, economic, and environmental impacts of their agricultural practices. For example, students involved in this project were required to articulate how their farming methods contribute to or mitigate issues such as food insecurity, land degradation, or income inequality. It was done through weekly presentations

Diversity: Learning outcomes should encourage students to explore and appreciate diverse cultural perspectives on agriculture and to incorporate this diversity into their own farming practices. For instance, the participating students in the experiential learning were expected to demonstrate an understanding of traditional farming techniques used by diverse cultural groups and to consider how these techniques can be adapted and integrated with robotic agriculture technologies.

Accessibility: Learning outcomes should focus on students' ability to design inclusive agricultural systems that are accessible to individuals with diverse abilities and resources. Discussions around designing farming equipment that can be operated by people with mobility impairments or developing low-cost, sustainable farming methods that require minimal financial investment are underway, and both the students and faculty mentors have been involved in brainstorming relevant ideas on making sustainable robotic agriculture accessible.

By integrating social justice, diversity, and accessibility into learning outcomes, STEM students can develop a more holistic understanding of sustainable robotic agriculture and its implications for society, while also gaining practical skills and knowledge that can contribute to positive social change.

4.0 Conclusions

Robotic agriculture can contribute to environmental sustainability by optimizing resource use, reducing chemical inputs, and minimizing waste through precision farming techniques. It may widen the economic gap between large-scale commercial farms that can afford expensive technology and smaller, resource-constrained farms that cannot. Sustainable agriculture prioritizes environmental stewardship by promoting practices that conserve soil health, preserve biodiversity, and mitigate climate change. It aims to minimize negative impacts on ecosystems and wildlife habitats. Sustainable agriculture aims to be accessible to smallholders and subsistence farmers by emphasizing low-cost, locally available solutions. It focuses on improving the livelihoods of rural communities and promoting equitable distribution of resources.

Navigating the tension between robotic agriculture and sustainable agriculture requires careful consideration of their respective benefits and drawbacks, as well as contextual factors such as local socio-economic conditions, ecological sensitivities, and cultural values. A balanced approach that integrates technological innovations with indigenous knowledge and sustainable practices may offer the most promising path forward for addressing global food security challenges while safeguarding environmental integrity and promoting social equity.

Recognizing the importance of community involvement, the primary and co-authors are partnering with local organizations to design and implement projects centered around robotic agriculture technologies. By collaborating with these community-based organizations, they can better understand the specific needs and challenges faced by the community and tailor their initiatives accordingly. Various initiatives are being considered to strengthen collaborations with the community. Examples include community-led urban farming projects, which empower residents to grow their own food using robotic agriculture technologies, training programs to equip community members with the skills needed to effectively utilize these technologies, and cooperative models that enable collective ownership and management of agricultural resources. These initiatives aim to not only enhance access to robotic agriculture technologies but also to create sustainable and inclusive solutions that benefit the community as a whole. Overall, the approach outlined in this paper reflects a commitment to inclusive experiential learning activities, so that the educational endeavors and community collaboration are leveraged to promote equitable access to and utilization of robotic agriculture technologies, ultimately contributing to the empowerment and well-being of the community.

5.0 Future Directions: Space/Lunar Agriculture

The current project team intends to utilize a range of lunar regolith simulants coupled with appropriate soil amendments to cultivate assorted leafy greens and vegetables. This cultivation will be conducted within an indoor FarmBot setup, subject to varying LED lighting conditions and meticulously controlled indoor environments. Water for irrigation purposes will be drawn upon in these experiments, operating under the premise that overcoming the significant challenge of harvesting water from reserves found on the lunar surface is an achievable goal in the future. Notably, FarmBot and other open-source food initiatives have recently been engaged by NASA’s Kennedy Space Center to collaboratively explore open-source methodologies for food production. Such endeavors hold promise for eventually yielding viable technologies conducive to food cultivation within environments such as the International Space Station (ISS), lunar gateway, and eventually on the Moon, Mars, and beyond.

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