121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #10570

Four-Way Collaboration Between a Non-Profit, University, Honor Society, and Charter School to Engineer Tropism Machines for Sustainable Space Nutrition Classroom Instruction (Work In Progress)

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Mr. Justin Matthew Collins, Milwaukee School of Engineering

Justin Collins is a junior in the mechanical engineering program at the Milwaukee School of Engineering (MSOE). He has distinguished himself both as a scholar and as a member of the student community through his classroom performance and involvement in extracurricular activities. Justin has been on the Dean's List with High Honors consecutively for every term of his collegiate career and was awarded the Rath Distinguished Scholarship by the Wisconsin Association of Independent Colleges and Universities (WAICU). In addition, Justin is actively involved in multiple on-campus organizations. He has been elected to serve as Vice President of the Wisconsin-Delta chapter of the Tau Beta Pi Engineering Honor Society for the 2014-2015 academic year, and is working closely with the current Vice President on a unique collaborative project to educate high school students on extraterrestrial plant growth. Justin is also engaged in his second Rocket Design Competition, sponsored by the Wisconsin Space Grant Consortium, as well as an active member of the MSOE Swing Dance Club. Justin plans to pursue a graduate-level education in astrophysics.

Jill Frey, Sweet Water Foundation

Jill Frey has worked in several areas of scientific research and education since earning degrees from the University of Wisconsin and Concordia University with Bachelors of Science in Zoology and Education, and a Masters of Science in Progam Development and Evaulation. She has always been a strong believer in the power of authentic learning and has helped to develop a variety of experiential learning programs including: an urban environmental center, a marine and freshwater focused charter school, a youth run urban organic greenhouse business, incorporating aquaponics into classroom curriculum.

In addition to developing in-place educational programs, Jill has collaborated on an web based learning platform AQUAPONS. for youth, families, teacher training and university students. Recently, Jill became Chair for the Milwaukee Branch of the Aquaponics Association. She also works as a teacher mentor and coach and provides educational professional development workshops.

Joey Zocher, Escuela Verde

With over a decade of urban science teaching experience, Joey worked with a team to open a new Milwaukee public charter school, Escuela Verde. Grounded in research and collective voice, Escuela Verde utilizes project-based learning to integrate sustainability and restorative justice into a school-wide curriculum. As an advisor at Escuela Verde, Joey shares both teaching and administrative duties with a team. Her experience also includes four years of leadership and community organizing at the Urban Ecology Center as the Washington Park program director. She has also taught graduate and undergraduate courses on curriculum ideologies and science pedagogy at UW-Milwaukee. Joey's scholarly interests examine the impacts of Youth Participatory Action Research and ecopedagogical praxis on scientific literacy with urban youth. As a teacher researcher, this line of research offers theory to practice as well as a needed voice of urban students and teachers from an insider perspective.

Joey received her B.S. in biology, psychology, womens studies and secondary education and M.S. in environmental education at UW-Stevens Point. She is a Ph.D. candidate in Urban Education with a specialization in curriculum and instruction at UW-Milwaukee. She has also been an active board member for numerous local, state and national boards including Milwaukee Urban Gardens, Brewcity Bruisers, Wisconsin Association for Environmental Education and the North American Association for Environmental Education's Environmental Justice SIG.

Dr. Matthew J. Traum, Milwaukee School of Engineering

Dr. Matthew J. Traum is an assistant professor of mechanical engineering at the Milwaukee School of Engineering (MSOE). He received a Ph.D. in mechanical engineering from the Massachusetts Institute of Technology [2007] where he held a research assistantship at MIT's Institute for Soldier Nanotechnologies (ISN). At MIT he invented a new nano-enabled garment to provide simultaneous ballistic and thermal protection to infantry soldiers. Dr. Traum also holds a master's degree in mechanical engineering from MIT [2003] with a focus on cryogenics and two bachelor's degrees from the University of California, Irvine [2001]: one in mechanical engineering and the second in aerospace engineering. In addition, he attended the University of Bristol, UK as a non-matriculating visiting scholar where he completed an M.Eng thesis in the Department of Aerospace Engineering [2000] on low-speed rotorcraft control. Prior to his appointment at MSOE, Dr. Traum was a founding faculty member of the Mechanical and Energy Engineering Department at the University of North Texas where he established an externally-funded researcher incubator that trained undergraduates how to perform experimental research and encouraged their matriculation to graduate school. Dr. Traum also serves as the founding Chief Technology Officer at EASENET, a start-up renewable energy company he co-founded with his former students to commercialize residential scale waste-to-energy biomass processor systems.

Four-Way Collaboration Between a Non-Profit, University, Honor Society, and Public Charter School to Engineer Tropism Machines for Sustainable Space Nutrition Classroom Instruction (Work In Progress)

Abstract

We have forged a unique collaboration – between a non-profit organization, a university, a student engineering honor society, and a charter public high school – to create and deliver sustainable space nutrition modules for middle school classroom instruction. This complex partnership was forged and is sustained because the collaborative project binding the organizations together was designed to meet goals central to the missions of all four partners. Sweet Water Foundation, the non-profit, educates the community about sustainable agriculture and nutrition. The Milwaukee School Of Engineering, the university, builds community partnerships that facilitate rich hands-on learning experiences for students. Members of the honor society, Tau Beta Pi, hail from a variety of engineering disciplines: architectural, biomedial, bio-molecular, civil, computer, electrical, and mechanical. To maintain good standing in the society, Tau Beta Pi members participate in documented community service, and to create cohesion within the organization, they seek unifying philanthropic projects with elements relevant to all members. Escuela Verde, the public charter school, accesses resources and support to build the STEM knowledge, skills, and competencies of its teachers and students. The collaboration is underpinned through fabrication and classroom demonstration of "tropism machines" that subject plants to conditions that might be experienced during long-term manned space missions to evaluate the impacts on plant growth.

Introduction

Growing plants in space is the first essential step to providing adequate and sustainable space nutrition for humans on long-duration missions. In 2007, NASA performed educational on-orbit plant growth experiments with basil on the International Space Station [1]. More recently, NASA announced a design challenge for elementary, middle, and high school students to design, build and evaluate chambers for lunar plant growth [2]. Major factors impacting plant growth in space include geotropism and phototropism, plant growth directional preference in response to gravity and light, respectively.

To actively engage middle school students in STEM inquiry focused on space-based nutrition, we have forged a unique collaboration – between a non-profit organization, a university, a student engineering honor society, and a charter high school – to create and deliver modules for classroom instruction. To demonstrate in a terrestrial classroom how plant growth responds to non-terrestrial gravity and illumination, our team is following the formal engineering design process [3] to create a "geotropism machine" and a "phototropism machine". The geotropism machine will continuously centrifuge plants to produce artificially high gravity. The phototropism machine will expose plants to various sources of artificial light projected from abnormal directions and of varying intensities. On each apparatus, beds of edible plants at three different development stages will be mounted: 1) newly sprouted, 2) maturing, and 3) harvest-ready. When closely inspected by middle school students in the classroom, these machines will reveal a snapshot of the plants' growth progression under non-terrestrial gravity and illumination respectively. As a control, plants planted at the same times and showing similar development stages under normal Earth gravity and illumination will be available for comparison.

The tropism machines illustrate key aspects of the scientific method used for new knowledge discovery in STEM fields. Students who interact with these machines will learn about variable independence and dependence. For example on the geotropism machine, the magnitude of centripetal acceleration can be controlled (the independent variable) to influence the growth of the plants (the dependent variable). Students will also be taught the importance of experimental controls. Plants growing under normal illumination, for example, are needed to provide a baseline for comparison against plant growth in the phototropism machine under abnormal illumination. Students will also be taught the importance of verifying experimental results with observations made by other researchers – our results will be compared against similar experiments conducted by NASA reported in the literature to validate observed outcomes.

Overall long-term goals for this program include the following:
1) Providing curriculum that utilizes the Next Generation Science Framework to middle school classroom teachers that build STEM skills and knowledge around local food production;
2) Providing collegiate honor society members with an outlet to connect to their community, build servant leadership skills; [4] and serve as role models and mentors;
3) Providing high school and middle school students with the opportunity to apply content through hands-on projects while developing engineering skills and gaining exposure engineering careers;
4) Developing a model/framework to continue and expand the project by drawing in other institutions of higher education in ways that clearly benefit those institutions.

Certainly, there are other university programs that link college students, K-12 students, and teachers with engineering projects to help community organizations. For example, EPICS (Engineering Projects in Community Service), founded and headquartered at Purdue University, has created its EPICS High program in which student teams partner with not-for-profits to design and build projects to meet the needs of each partner. [5] What sets our collaboration apart is that its impetus for creation and sustainment did not arise as a pre-planned program through a pre-existing university office. Instead it arose spontaneously through the initiative and student leadership of our Tau Beta Pi (TBΠ) student chapter as a solution to a particular challenge faced by the organization. TBΠ members 1) come from all engineering majors and 2) must participate in community service to maintain good standing. The society sought a long-term service project broad enough to involve all members across engineering disciplines, and the collaboration described here is the result. The work-in-progress reported in this paper, therefore, is suggested as a model for engineering student organizations with broad membership as they develop community service programs targeted for K-12 student audiences.

Methods and Implementation Plan

With the long-term plan of developing a series of space nutrition teaching modules for middle school students, we are rolling out a pilot version of the program to students enrolled in Escuela Verde, our partner charter public high school. Escuela Verde students will benefit by learning the STEM content delivered, and they will contribute actively to the tropism machine design-and-build processes to inject into that process the perspective of student end-users of the machines.

The high school students will also provide critical feedback on what aspects of the program's content and its delivery can be improved to make them more robust when the program is eventually rolled out for middle school students.

The pilot-scale program to be vetted by high school students will consist of six modules. Each module will take place in a 3-hour meeting between the Escuela Verde high school students, the TBΠ collegiate honor society members, and the non-profit organization staff. Among the meetings, there will be one 8-hour session, a full-day workshop during which the tropism machines will be designed and some components built. The location of module instruction will oscillate between the Escuela Verde campus and the Milwaukee School Of Engineering (MSOE), the university partner. We believe the benefits of rotating module meeting location include 1) exposing participating high school students to a college campus will spark their interest in pursuing STEM careers through higher education and 2) providing context for the TBΠ members who are designing the tropism machines by approximating the physical space and feel of a public school, the environment in which the middle school modules will eventually be taught. Together, the six modules will achieve the following specific outcomes:
1) Provide middle school teachers with experience using the new Next Generation Science Framework via turn-key classroom modules;
2) Design seed sprouting kits that can be assembled by middle school students to build their hands-on STEM skills;
3) Expose middle school students to STEM, space-related careers, and nutrition sciences;
4) Expose middle school students to experimental research, the scientific method, and techniques for new knowledge generation through discovery; and
5) Develop best-practices for collaboration between a non-profit organization, a university, a student engineering honor society, and a charter public high school; knowledge that can be broadly disseminated to the national engineering education community for use by others.

Getting engineering students in the K-12 classroom to assist with content delivery is an outcome the Sweet Water Foundation (SWF), the not-for-profit partner, has always sought to provide toward its goal of building STEAM (Science, Technology, Engineering, Art, and Mathematic) skills through the application of sustainable agriculture practices. It is with this diverse menu of disciplines and skills that SWF implements its mission: to build resilient sustainable communities. The SWF-MSOE partnership pre-dates the Tropism Machine program initiated by the TBΠ student chapter. The SWF-MSOE partnership began in 2011 with a collaboration in which senior mechanical engineering students designed and built aquaponic miniatures for SWF that were used to educate school groups and the general public about aquaponics. [4] In particular, the miniatures were used to train a group of students from a different university that traveled to India to introduce aquaponics to a college there through the SWF Growing Networks Project. Leveraging this successful pre-existing SWF-MSOE partnership as a foundation for the new tropism machine partnership was a key factor for success since the people involved already knew each other and could draw on past project success for guidance in the new design challenge.

Curriculum Components

The Sustainable Space Nutrition program includes six formal modules in which Escuela Verde public charter high school students and teachers will meet with TBΠ members and SWF staff over a 5-month period. A key deliverable arising from these meetings will be design, fabrication, and testing of two tropism machine classroom demonstration units for future teaching sessions targeted to middle school students. In these modules teacher training and instruction for high school students will be provided. The overall educational framework for the curriculum being developed is the Next Generation Science Framework. Descriptions of the individual planned modules are provided here.

Module 1 - Space Nutrition Introduction and Motivation: To spark curiosity, motivate interest, and build background knowledge, students will first be introduced to the aspirations of human space exploration. Literature and multi-media connections will provide a historical perspective underpinning humans in space by drawing connections to popular media from students' common experiences. To provide context for students to appreciate the challenges of long-term human habitation in space, they will watch NASA's *Living On The Moon* video. [6] The importance of human space flight to advances in knowledge and technology will be illuminated by discussing current events familiar to high school students: the Curiosity Mars Rover, the Ansari X Prize sparking the advent of space tourism, near-miss asteroid flybys of Earth, and the visit to Jupiter by the Juno spacecraft. Moreover common commercial products that began as NASA innovations will be showcased: temper foam, IR ear thermometers, and freeze-dried food. After these introductions, Escuela Verde students will work in small groups with TBΠ members and SWF staff to brainstorm problems and potential solutions for sustained human exploration of space.

Module 2 - The Formal Engineering Design Process: To show students how engineers solve technical problems, they will be introduced to an eight-step formal engineering design process: 1) customer needs identification and quantification, 2) knowledge search, 3) brainstorming, 4) down-selection, 5) detailed design, 6) fabrication, 7) testing, and 8) reflection. TBΠ members will draw upon their own design experiences, sharing personal examples from project courses, senior design, and industry internships. Using the tropism machines featured in later modules as the ultimate product goal, Escuela Verde students will complete the formal engineering design process to develop, design, and build one critical tropism machine module. This component is the housing where seeds will be planted, placed in the tropism machines, and allowed to grow under artificial illumination or gravity. As part of the design process reflection step, a review of the students' final built designs will be conducted, and the best attributes from each will be identified to help students connect how their design decisions impacted the final outcome.

In preparation for the Plant Nutrition Biochemistry Module, students will set up fast-growing plant seeds (mustard, beans, and fast plants) in their planter modules to grow with different pre-determined amounts of incomplete fertilizer. Control plants will also be seeded. Resulting plant growth characteristics will be evaluated in the next module.

Module 3 - Plant Nutrition Biochemistry: In this module, Escuela Verde students will be taught about the three main elements (the primary macronutrients) for plant nutrition: nitrogen, phosphorus, and potassium. They will learn how plants take up nutrients through their root systems from water and soil they are planted in and the biochemical uses of each of the three nutrients in the plant. They will also learn some of the traits of plants when they are lacking nutrients (emphasizing common plants and house plants that students may take care of). Finally, they will learn about fertilizer's effects on plant growth. To demonstrate these topics, several visual and experimental aids will be used. For root uptake, atom models will demonstrate the reactions that allow roots to absorb nutrients. For biochemical uses of these nutrients and plant conditions from improper nutrition, print or presentation visuals will be used. For the main portion of the lesson, the students will complete their experiment with fast-growing plants (mustard, beans, and fast plants) planted in the previous module session. In that earlier session, students set up plants to grow with different amounts of incomplete fertilizer that provide various deficiencies of the three main nutrients. Using these plant growing experiments, they will observe and report on which combinations and amounts of nutrients helped the plants grow best.

Module 4 - Plant Phototropism: One major factor impacting plant growth in space is phototropism, plant growth directional preference and nutrition content in response to unusual, non-terrestrial lighting. After reviewing a summary of literature-based knowledge on phototropism, the Escuela Verde students will apply the scientific method to formulate hypotheses about how exposure to unusual lighting will impact plant growth. Building upon the formal engineering design process introduced in previous modules, a phototropism demonstration machine will be developed, designed, and built by ΤΒΠ members to demonstrate these effects. The apparatus will contain beds for edible sprouts planted at intervals to achieve at least three different development stages when observed: 1) newly sprouted, 2) maturing, and 3) harvest-ready. To connect this system to previous nutrition module knowledge, the infusion of nutrition into the soil feeding choices for the plants will match the nutrient mix previously identified by Escuela Verde students as optimal. Sample control plants will also be grown under normal illumination to provide a baseline for quantitative comparison against the plants grown in the phototropism machine. By comparing control group plants against experimental group plants students will apply the scientific method by testing their hypotheses and reporting results.

Module 5 - Plant Geotropism: Another major factor impacting plant growth in space is geotropism, a plant's growth and nutrition response to unusual, non-terrestrial gravity. To demonstrate how plant growth rate and direction responds to different gravity magnitudes, ΤΒΠ members will design and build a centrifugal apparatus to simulate varying effects of gravity. Beds of edible sprouts will be planted at different times within the machine to produce at least three different development stages when observed: 1) newly sprouted, 2) maturing, and 3) harvest-ready. As with the previous phototropism student meeting, Escuela Verde students will first be taught about geotropism. The students will also be taught about variable independence and dependence, by describing how the direction and magnitude of centripetal acceleration can be controlled (the independent variables) to influence the growth direction and size of the plants (the dependent variables). Armed with this knowledge, they will then develop hypotheses to predict how they think plants will grow under artificial gravity in the geotropism machine. When stopped momentarily for inspection by students, the artificial gravity wheels will reveal a snapshot of the plants' growth progression under abnormal gravity. As a control, sprouts planted at the same time and showing similar development stages under normal gravity and illumination will be available for comparison. By comparing the experimental group to the control group plants, students will validate their hypotheses and report results. These experimental results will also be compared against similar experiments conducted by NASA and other researchers reported in the literature.

Module 6 - Experimental Results Evaluation and Reporting: This module is the capstone experience for the entire space nutrition module series. Escuela Verde students will work in teams to analyze all their findings, experience, and experimental results obtained in the previous five modules. They will review engineering design, plant nutrition, and impacts of artificial light and gravity and synthesize this knowledge into short written summaries. They will also create and deliver short oral presentations supported by overhead slides to showcase their knowledge, hypothesis development, testing, analysis, and conclusions. TBΠ members and SWF staff will support the students as they develop their reports and presentations and provide feedback on each team's presentation to reinforce for the students what they learned by participating in the module series and how well they were able to analyze the resulting data and articulate the results.

Contributions of Each Partner Organization

Tau Beta Pi contributes by providing members to work with the Escuela Verde students toward designing and building the geotropic and phototropic devices for demonstrating the effects of varying gravity and illumination on the growth of plants. TBΠ members serve dual purposes: 1) to lead the development of the devices and 2) to work directly with the Escuela Verde students involved in the project. TBΠ ensures tropism machine customer needs are met so the machines can be used later in middle schools when the full-scale program is rolled out. They also act as mentors, modeling the behavior of successful engineers to motivate Escuela Verde students' interest in engineering as a possible future profession. In addition, TBΠ members will work with SWF staff to maintain the tropism machines and teach future users how they work and how to properly use them.

Sweet Water Foundation connects ideas, people, and resources to provide teacher professional development around the integration of curricular content with experiential learning. SWF assists teachers in lesson implementation by providing technical knowledge and training and classroom resources: lesson plans, curriculum, tools, and additional community partners. For the tropism machine project, SWF is providing guidance and training to TBΠ students in modeling the engineering design and build process for the high school and middle school students. SWF is also responsible for the development of middle school curriculum utilizing the Next Generation Science Framework.

Escuela Verde Public Charter School is providing high school students to work through the pilot version of the six program modules and provide feedback for TBΠ and SWF from the perspective of a student. This information will be used to improve the modules for full-scale roll-out to middle schools. Escuela Verde students are also participating actively in the tropism machine design and build process both for their own enrichment and to provide a student user perspective throughout the design of the machines.

Milwaukee School Of Engineering is providing facilities to host student meetings, tools to facilitate the tropism machine build, and technical consulting expertise of engineering faculty to support tropism machine design. MSOE also contributes its expertise in creating and implementing hands-on, open-ended, space-themed activities for students. [7,8] MSOE is also leading the dissemination of knowledge and best practices arising from the projects (i.e., via this paper) as well as leveraging faculty expertise with fundraising to seek external resources to support and expand the program.

Target Demographic Served, Project Scalability, and Assessment
Once developed, deployed, and vetted at the partner charter school, the team plans to deploy these modules to other schools in the Milwaukee, WI area, particularly at middle schools. Approximately 29.4% of Milwaukeeans live in poverty and the rate increases to 43.0% for children under the age of 18. For Milwaukee County as a whole, the poverty rate is 21.6% and 31.6% for children under 18 years old. [9] This cohort is the group ultimately served by the activities described in this paper through this ongoing partnership.

When the program is rolled out in final form, we envision the machines in 3 classrooms per year, which will mean up to 100 middle school students will be involved annually. We anticipate scaling the program by implementing it at other engineering universities with TBΠ chapters. For example in the current program, other Milwaukee-area TBΠ chapters are being engaged to coordinate use of their universities as host sites for one program module. Not only does this technique allow other TBΠ chapters to become engaged with a low initial investment of resources and member time, but it also allows Escuela Verde students to visit multiple engineering schools in the local area and interact with TBΠ student members representing the different cultures within each unique school. Ultimately, if TBΠ chapters at other universities become full partners in the program, the number of engaged middle school students could be multiplied by the number of universities involved, provided each TBΠ chapter built its own tropism machines.

Since the program has not yet been implemented, data collection from participants has not yet occurred. However, the following program assessment data will be collected in the future. As required by the project sponsors, school-specific metrics will be logged: 1) school demographic information and 2) state and district student test scores. Teacher feedback via indirect assessment will evaluate 1) ease of implementation and thoroughness of lessons; 2) logical progression; 3) model and kit effectiveness; 4) implementation timing; 5) suggestions for future implementation; and 6) teaching team effectiveness/preparedness as measured by ability to adapt higher-level skills and vocabulary to the student level, engage students in dynamic discourse, and model for students critical thinking skills. Also, pre-/post-surveys will be given to participating students on career interest and choices. Surveys will include quantitative Likert scale questions as well as qualitative multiple choice answer questions concerning how well student expectations were met. This assessment instrument will address 1) students' perceived development of technical skills and knowledge and 2) students' perceived interest in engineering careers.

Conclusions
This complex partnership – between a non-profit organization (SWF), a university (MSOE), a student engineering honor society (TBΠ), and a charter public high school (Escuela Verde) – was forged and is sustained because the collaborative project binding the organizations together meets goals central to the missions of all four partners. Our project raises exposure and interest of K-12 school teachers, students, and the general public toward space sciences and engineering, human health and wellbeing in space, and technology realized through engineering design. We are preparing to teach middle school students space-related STEM skills that are tied into nutrition (a familiar topic they can relate to) by vetting modules with high school students. Both the pilot program described here and the full-scale program to be rolled out later will increase

interest, recruitment, and training of pre-college students in the pursuit of space-related science, design, and technology careers.

Participating TBΠ honor society members, who provide the impetus for creation and sustainment of the program, also benefit by thinking about how to break down complex information for delivery of content that can be understood and processed by middle school students. Bringing engineers to the classroom is an outcome the SWF has always sought to provide. By giving college engineering honor society students the opportunity to educate middle and high school students, this project could spark their interest in becoming volunteers in classrooms when they become practicing engineers, and it may even inspire in them a desire to pursue academic teaching careers.

Acknowledgements
We acknowledge the Wisconsin Space Grant Consortium for supporting this project through its Aerospace Outreach Program. We also acknowledge the Tau Beta Pi MindSET Program for funding module component supplies and equipment.

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