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An Interdisciplinary Research-Based Education Program for Engaging Plant/Agriculture Sciences, Chemical Sciences, and Engineering Students (iREP-4-PACE) at Minority Institutions

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An Interdisciplinary Research-based Education Program for Engaging Plant/Agriculture Sciences, Chemical Sciences, and Engineering Students (iREP-4-PACE) at Minority Institutions

Dr. Sharanabasaweshwara Asundi, Old Dominion University

Sharan Asundi, a native of INDIA, is a Ph.D. from University of Florida working as an Assistant Professor of Space Systems Engineering in the Department of Mechanical and Aerospace Engineering at Old Dominion University (ODU). Currently, he is engaged in several teaching and research activities, largely focused on furthering the Space Systems Engineering Program at ODU. He has engaged in research collaboration with NASA Goddard as a Science Collaborator and has been awarded grants by the U.S. Air Force, National Science Foundation, U.S. Department of Agriculture to research Magnetic Mapping of Pico/Nano/Micro-Satellites and study the impact of magnetic field exposure on plant germination, growth. Dr. Asundi teaches courses in Space Systems Engineering and is actively engaged in collaboration with academic institutions in India. As part of invited visits, Dr. Asundi has conducted several short courses and workshops in Systems Engineering Based Design of PNMSats.

Dr. Gregory C. Bernard, Tuskegee University

Gregory C. Bernard, Ph.D., is a molecular biologist concentrating in the areas of plant and animal pathology. His research interests are developing nanobiopesticides for agricultural pest management, elucidating biomagnetics in plant growth and development, and transcriptome profiling of plants to identify molecular factors of disease resistance. He currently serves as a Co-PI on USDA-funded undergraduate plant breeding training program and a gene-editing (CRISPR/Cas 9) project with Dr. Marceline Egnin et al. Dr. Bernard has co-established the caprine research unit at N.C. A&T S.U (Dr. Mulumebet Worku) and, is actively working towards improving sustainability in small-scale farming production for local crop producers as well as infrastructure enhancement of the George Washington Carver Experimental Research Station capacity via USDA funding and faculty team collaboration.

Dr. Willard E. Collier, Tuskegee University

Dr. Willard E. Collier is an Assistant Professor of Chemistry at Tuskegee University (TU). He is actively involved in Molecular Farming education and research as a transdisciplinary platform that enhances recruitment and persistence of undergraduate STEM majors. Along with Dr. Mortley from Agricultural Sciences at TU, he helped establish the Tuskegee University Medicinal Plant Garden. Dr. Collier has organized and hosted Medicinal Plants: A Healthy Supplement to the Chemistry Curriculum workshops at Tuskegee University that have drawn college chemistry professors from across the nation. Dr. Collier and five other co-PIs were awarded a Seed Grant from Tuskegee University titled "Engaging Agriculture, Biology, and Chemistry Students Through Interdisciplinary Medicinal Plant Research Across the Curriculum". Dr. Collier and Dr. Chastity Bradford, a TU biology professor, were also awarded a grant titled, "Investigating the Enhancement of Angiotensin 1-7 by Hibiscus sabdariffa as a Novel Therapeutic Strategy for the Treatment of Pulmonary Hypertension" from The Herb Society of America. Dr. Collier's other grants have included "Chemistry for the Future of Water Sustainability" from The Camille & Henry Dreyfus Foundation, Inc. (role as PI) and an NSF grant titled "Targeted Infusion Project: Infusing Inquiry-Based Green Chemistry into Undergraduate Laboratory Courses via Silver Recycling in a Closed Loop, Multi-course Process" (role as Co-PI).

An interdisciplinary Research-based Education Program for Engaging Plant/Agriculture Sciences, Chemical Sciences and Engineering Students (iREP-4-PACE) at Minority Institutions

Abstract

An interdisciplinary Research-based Education Program for Engaging Plant/Agriculture sciences, Chemical sciences and Engineering students **(iREP-4-PACE)** is envisioned with the underlying intent to improve Tuskegee University's (TU's) STEM retention through the introduction of interdisciplinary, guided, inquiry experiments focused on the production of high-value chemicals from plants. At large, chemicals are synthesized from petroleum resources and it is well established that the continued extraction of these resources is detrimental to the environment. On the contrary, synthesizing chemicals from "plant factories" may be a boon to the environment and have a negative carbon footprint. The program uses three initiatives: a) expanded professional development activities for developing, teaching inquiry-based lectures and experiments, b) inclusion of sustainable high-value chemical production from plants across the laboratory curriculum, and c) increase of student hands-on access, competency with instrumentation and cutting-edge techniques. The overarching goal of the **iREP-4-PACE** program is to engage a cohort of undergraduates from plant/agriculture sciences, chemical sciences, and engineering disciplines in the research, education of engineering chemicals from plants of high commercial and medicinal value. The program will educate the undergraduates in engineering environment friendly chemicals. The year-long program will train students in seeking/learning the interdisciplinary knowledge, techniques of molecular synthesis of plant-based chemicals and in doing so, it will train the students in broadly applicable research methods such as literature review, instrument training, basic statistical analysis, and proposal writing. The article describes the design of the iREP-4-PACE program and activities conducted to gauge the interest of potential participants.

Keywords

Farming for molecules, Cross-disciplinary education, Research-based education, Plant sciences, Agricultural sciences, Chemical Sciences, Engineering agriculture, STEM-based agriculture, Plant-based chemical factories, Molecular synthesis of plant-based chemicals

1. Problem Identification and Project Concept

Despite an increase in undergraduate plant/agricultural science majors in the last few years, the growing demand for professionals in this major has significantly exceeded the number graduating each year (Goecker et al. 2010 and Goecker et al. 2015). Goecker et al. have projected that between 2015-2020 there will be only an average of 35,400 graduates yearly in food/agriculture (hands-on plant sciences), renewable natural resources, and environment sciences to fill 57,900 yearly openings (Goecker et al. 2015). While there is a projected shortfall in the required number of college graduates in plant/agricultural science fields, there is an almost crisis-like situation in STEM education, which is well documented. "Engage to Excel", a 2012 report to President

Obama, predicted a shortfall of 1 million STEM graduates over the next decade (PCAST 2012). A more engaged learning method is identified as a critical need to maintain student interest and encourage young minds to seek/pursue a STEM field of study and ultimately a career (PCAST 2012). Chen's statistical analysis report reveals that the number of STEM courses in the first year and the level of success in these courses is a key difference between STEM persisters and STEM leavers (Chen 2013). These may be regarded as manifestations of the same fundamental flaw in the current education system, which is that students have become disengaged from hands-on experience and the rise of on-line education may have compounded it. There is also a widening gulf between hands-on plant sciences within the STEM disciplines in undergraduate education, with consequences for education, research, public policy, and the future. A key challenge is to break down the walls within STEM disciplines and train students to appreciate the intrinsic worth of complementary disciplines. This will promote a deep appreciation of complementary fields and motivate students to practice foundational concepts across disciplines.

An **i**nterdisciplinary **R**esearch-based **E**ducation **P**rogram for Engaging **P**lant/**A**griculture sciences, **C**hemical sciences and **E**ngineering students **(iREP-4-PACE)** is envisioned as a year-long program. The underlying intent of **iREP-4-PACE** is to engage a cohort of undergraduates from plant/agriculture sciences, chemical sciences, and engineering disciplines in the research and education of engineering chemicals from plants of high commercial and medicinal value. The cohort will engage in research/education activities in a cross disciplinary team setting where each team member will be guided to seek competence in a complementary field. A return to hands-on activity in the field/laboratory using Molecular Synthesis of Plant-based Chemicals (MSPC) as an interdisciplinary tool to bridge the gap between plant/agriculture sciences, chemical sciences and engineering is advocated. The year-long program will train students in seeking/learning the interdisciplinary knowledge, techniques of MSPC and in doing so, it will train the students in broadly applicable research methods such as literature review, instrument training, basic statistical analysis, and proposal writing. The proposed program will foster a deeper appreciation of STEM among plant/agricultural science majors and at the same time, expose STEM students to plant/agricultural science, environmental engineering, transform their view of education, and allow them to experience the application of STEM knowledge to plant/agricultural sciences.

2. Project Justification

Student Interest: The millennial generation seems to have limited understanding or appreciation of plant/agriculture sciences in general. It is critical that we take initiatives to engage student interest in plant science research to make an impact in STEM training. The proposing team has conducted a unique engagement activity in the form of "Plant Walks" around Tuskegee University (TU) campus. The Plant Walk activity was initiated to expose students to the flora and fauna on campus, its development, identification, and potential as bio factories. To date, six such activities are conducted, which have attracted students, faculty and several community members as participants. From the surveys conducted as part of the Plant Walk activity, it was evident that the walks were well received by the students and generated an overwhelming interest in having more elaborate/engaging iREP-4-PACE program. To gauge student interest in a potential long-term

MSPC research and training activity, a question was specifically targeted in this direction. It was evident from the activity that students were able to gain a deeper appreciation of the application of MSPC through one-on-one interactions with faculty. They were intrigued and motivated to learn about the economic potential of MSPC and the broad range of STEM skills needed to be successfully in the field. The team is also of the opinion that as the benefits in education, research, leadership potential, scope for career advancement, and skill development is realized by the students of the first iREP-4-PACE program, they will encourage/motivate their peers/juniors to take their path and benefit from it.

Research-Based Education Approach: Research based undergraduate education has been shown to be effective in engaging students' learning (Dekker and Wolff 2016). Studies also suggest that undergraduate research experiences (UREs) can be critical for keeping underrepresented science students on the pathway to a scientific career. One large-scale, 10-year, longitudinal, multi-institutional, propensity-score-matched study designed to compare the academic performance and persistence in science of students who participated in UREs with those of similar students who had no research experience bears out this fact (Hernandez et al., 2018). They reported that students who completed 10 or more hours of cocurricular, faculty-mentored research per week across two or more academic semesters or summers were significantly more likely to graduate with a science-related bachelor's degree, to be accepted into a science-related graduate training program, and to be training for or working in the scientific workforce 6 years after graduation. They concluded that merely having an URE was not enough to influence persistence in science; it required a commitment of 10 or more hours per week over two or more semesters of faculty-mentored research (Hernandez et al., 2018).

Molecular Synthesis of Plant-based Chemicals Theme: Most people are familiar with plants producing food, fiber, and fuel, but few comprehend or appreciate that plants are a significant source of multitude of useful molecules and can complement the efforts of petroleum based chemical industry without depleting the natural resources (Somerville and Bonetta 2001). Molecular Synthesis of Plant-based Chemicals is poised to become a major factor in the global agricultural economy (Alireza and Nader 2015). Over the last few decades, MSPC has been used mainly to describe the production of proteins, antibodies, and vaccines from genetically modified plants. Looking past the hype, MSPC is using organisms to produce a desired molecule, which can be the end-product, or several synthesis steps away from the target molecule, or a feedstock for many useful products. Molecular Synthesis of Plant-based Chemicals is a significantly more sustainable means to produce pharmaceuticals, industrial molecules, but there is a need to educate and train young minds in the methods, practices, and processes of MSPC. Clary sage, *Salvia sclarea*, is an MSPC success story and a cautionary tale of the need to be aware of scientific trends. Clary sage oil contains the diterpene sclareol that is used to produce ambroxide that is a replacement for ambergris, an expensive and rare perfume ingredient. Around 120 family farms in North Carolina depend on Clary sage production, a success story that can be traced back to attempts to commercialize its production in the 1950's in Washington state and R. J. Reynolds' efforts in the 1960's in North Carolina (Leffingwell, et al. 1974). Biotechnology threatens to

disrupt the North Carolina Clary sage story as yeast and E. coli have been engineered to produce synthetic bio Clary sage oil and the company Amyris was reported to have shipped 100 tons from its Brazilian facility in 2016 (ETC Group Report).

It is hard for most Americans to comprehend that over 70% of the world's population depends on medicinal plants as their primary health care source. Even western medicine relies on medicinal plants (Goodman and Walsh 2001), unbeknownst to many. As recently as 1993, over 50% of the most prescribed medicines had their origin in natural products (Newman et al. 2000). Herbal dietary supplements alone were a $7.5 billion market in the United States in 2016 (Smith et al. 2017). Traditional herbal medicine is a repository of knowledge regarding natural products with medicinal properties (Miller and Su 2011). Availability of the required medicinal plants and their purity are rapidly becoming issues throughout the world. The looming antibiotic resistance crisis is an excellent example of the need for MSPC research to produce new antibiotic molecules. A research-based education program, like iREP-4-PACE, to identify new antibiotics from medicinal plants and then produce them using MSPC affords an excellent platform to train students in essential skills that can be applied to their career paths.

3. Plan of Operation and Methodology

The complete process, graphically depicted in **Figure 1**, is designed with the intent to achieve quick, research-based education outcomes and in doing so, engage the students from these STEM disciplines in hands-on activity. As stated earlier, the overarching goal and the vision of this engagement activity is to emphasize the need and train students in hands-on skills in a field that is increasingly becoming relevant, but is being neglected and overlooked at large. The proposed integrative approach will specifically achieve the following objectives:

Objective 1: Develop and implement a year-long, learner-centered experiential learning-based program that trains plant/agriculture sciences, chemical sciences and engineering undergraduate students in the basics of MSPC that will form the foundation for a new course in MPSC.

Recruitment and Application Process: Each year the iREP-4PACE Program will recruit/select a cohort of participants from incoming freshmen and returning sophomore students and form teams of 3 students. The program will recruit six students in Year 1, nine students in Year 2, and nine students in Year 3. Each team will consist of one student each from plant/agriculture sciences, chemical sciences, and engineering. The program will be advertised by posted flyers, mass email, and visits to selected introductory classes in the first week of the fall semester. The applicants will complete a short application form and submit a short essay describing why they want to participate and how the program fits their career plans. The applications will be reviewed, and participants chosen in the second week of the fall semester. These selected participants will receive a $1,000 stipend per semester for both the fall and spring semesters. The program for each new cohort will start in the first week of September. It is to be noted that the program will recruit one graduate student per team to assist with day-to-day activities.

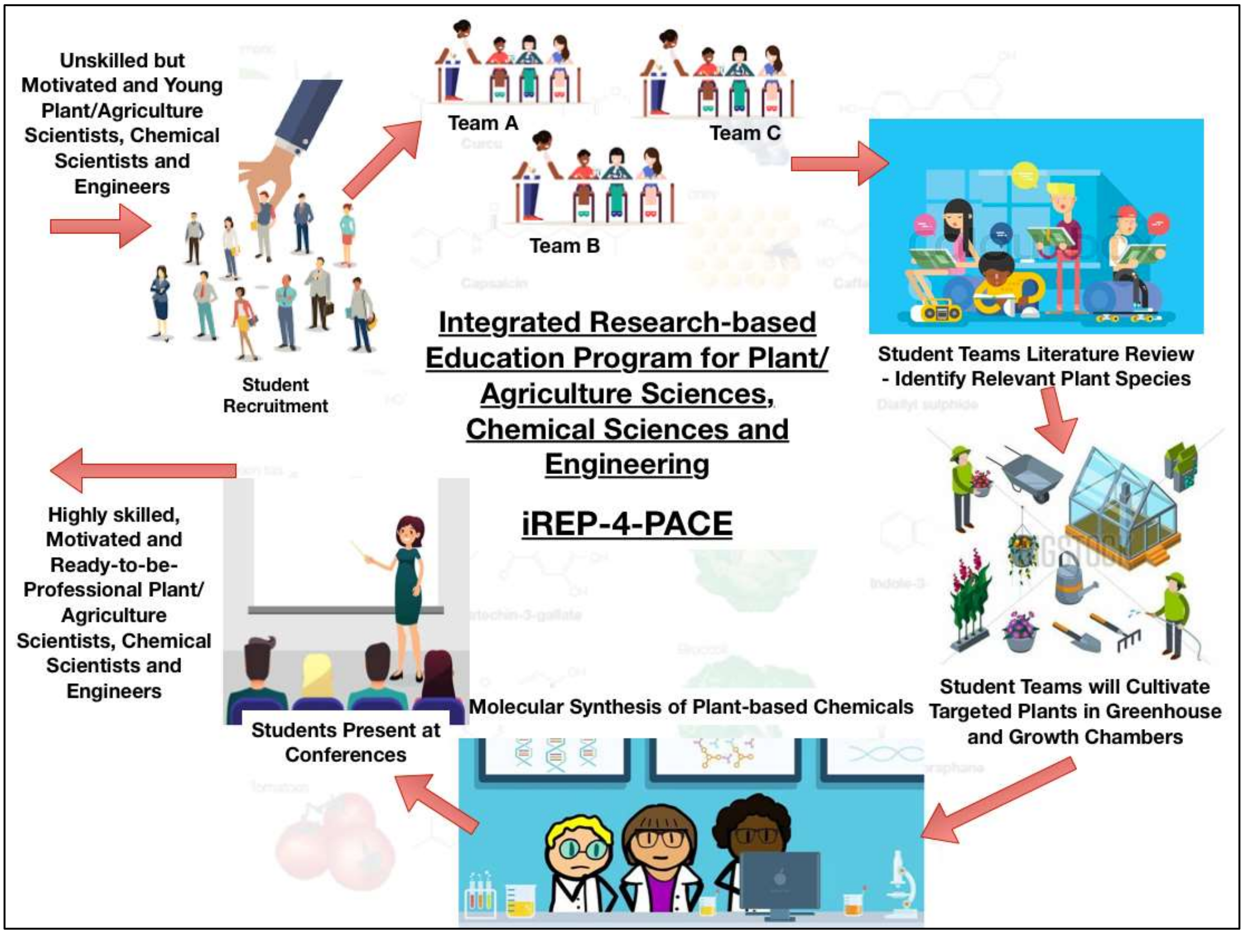


Figure 1 – iREP-4-PACE Program Overall Approach

Education and Training Activity: During this phase, the participants will explore the past, present, and future of MSPC with emphasis on using plants. They will practice basic tools of research including searching the scientific literature, posing a research problem, ethical research, proposal writing, presenting research posters/talks, and writing a research paper. The cohorts will be required to attend 12 weekly meetings per semester during the year-long program in a variety of settings, including conference room, laboratory, or the field depending on the topic of that week's meeting. During these meetings, they will receive hands-on training in laboratory skills like extraction techniques, separation techniques, and analytical techniques including nuclear magnetic resonance (NMR) spectroscopy and liquid chromatography-mass spectrometry (LC-MS). They will receive hands-on training in identifying plant species, planting/potting process, propagating plants and harvesting plant material.

Objective 2: Develop a practicum experience to engage students in original research involving the MSPC process; from plant selection, cultivation, extraction, etc. to final commercial applications.

Team Projects: The students will be divided into teams of three and each team will meet and work independently, with faculty consultation/guidance, under the observation of their graduate student

assistant to investigate potential MSPC projects appropriate to the Black Belt region of Alabama. Over the fall semester, each team will develop an MSPC project proposal, present and defend their proposal before a selected panel of faculty. After successful presentation and defense, each team will be awarded funds for materials and supplies to pursue preliminary research during the spring semester. At the end of the academic year, spring semester, the teams will present their research proposal and preliminary data to an audience of faculty, students, and community members. One student from each team will be chosen to receive a $5,000 stipend to continue their MSPC project during the summer. The continuation of the research will ensure the work of all team members towards the project is fruitful.

Objective 3: Advance the leadership skills of undergraduate students through experiential learning, original research, development of curriculum modules and outreach activities.

Ownership of Education: The first component is in the experiential learning design where topics are not presented in a lecture format but in an interactive seminar style where all students are expected to actively participate and contribute to the discussion. The students will acquire skills such as being thoroughly prepared, engaging in thoughtful discussion, and respectfully advocating for their position.

Research Practicum and Peer Outreach: The team research practicum will reinforce skills acquired in the weekly meetings to ensure the team functions smoothly while dealing with the inevitable personality conflicts. Each team will develop one curriculum module (either lecture or laboratory experiment) over the course of the year in collaboration with the faculty member teaching that lecture or lab course (e.g. Organic Chemistry). The curriculum development activity will allow the students to interact with both outside faculty and students. After development, the students will pilot the module in a lecture or lab setting and gain valuable experience with undergraduates not in the program.

Outreach to K-12: Each team will develop one K-12 outreach module over the course of the program. A crucial component of the outreach will be to encourage K-12 students to build critical thinking and problem-solving skills. The K-12 students will also be introduced to the creative application of new technology to solve problems. Each team will be encouraged to meet and interview local experts to help assess the practicality and desirability of their MSPC projects.

Successful implementation of interdisciplinary research-based learning would serve as a model nation-wide and even globally. The MSPC research-based education will also benefit the agricultural industry of Alabama and surrounding states by assisting in the development of MSPC targets and optimizing the cultivation of the plants used for MSPC for local climate conditions. Table 1 shows the products, results and impacts for the proposal.

4. Assessment of Student Interest – Survey Results

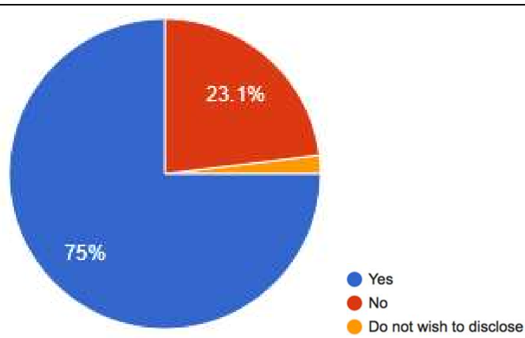
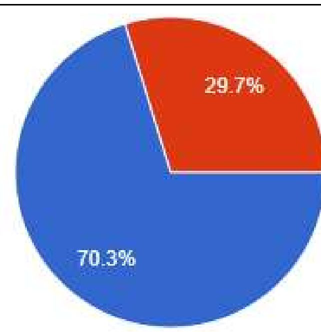
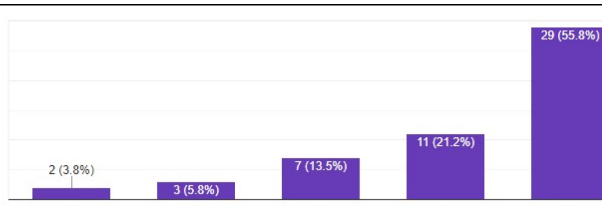
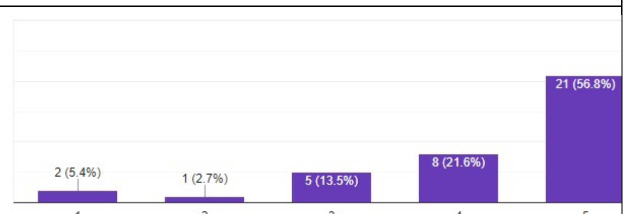
As mentioned previously, several Plant Walk activities have been conducted to gauge the interest of students in an iREP-4-PACE offering. Although, these activities have had their own impact on the student's perception of agriculture and STEM, they have provided a much needed insight into

the need for a program like iREP-4-PACE. To seek this insight, the proposing team conducted two surveys for the participants – (i) Pre Plant Walk and (ii) Post Plant Walk. Largely, the surveys have been administered in paper form. The participants were handed the first set of surveys before the Plant Walk activity and the second set of surveys were handed upon the conclusion of the activity. An attempt to administer online surveys was made but it was observed that the participants were reluctant to use that medium. It is important to mention that the post-plant walk groups were, at large, subsets of pre plant walk groups. The team will make efforts to consolidate responses from participants who engaged in both surveys. The following inquiries were made in both the surveys:

- Participant's affiliation with TU as a student
- Participant's knowledge of farming
- Participant's inclination towards walking in nature
- Participant's knowledge of molecular farming
- Participant's interest in being a part of iREP-4-PACE
- Participant's knowledge of chemical production

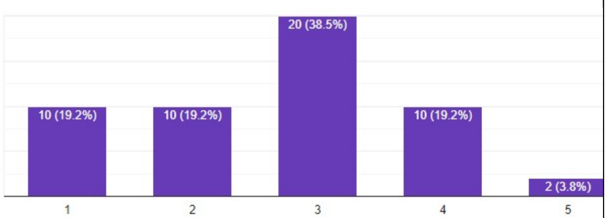
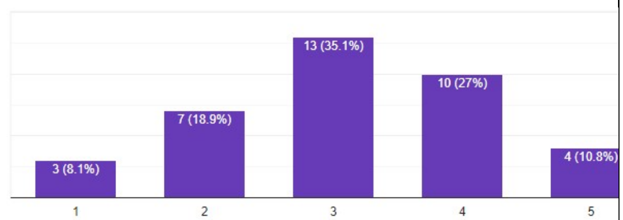
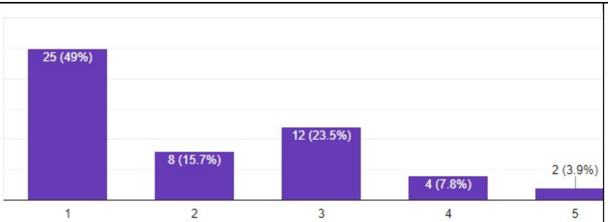
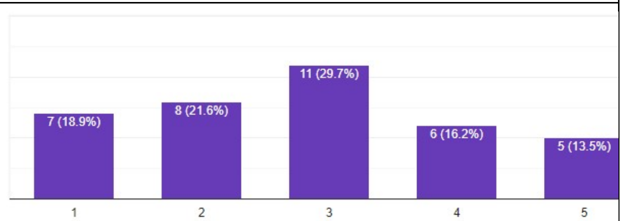
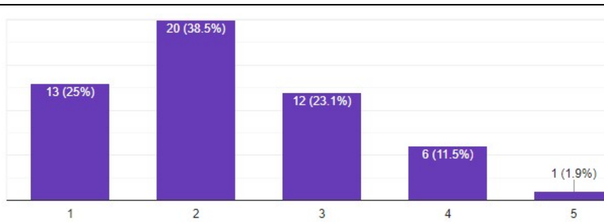
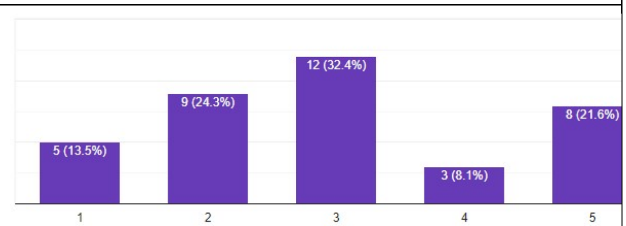
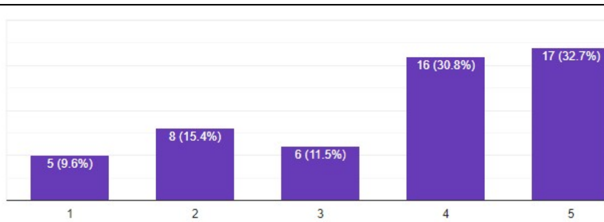
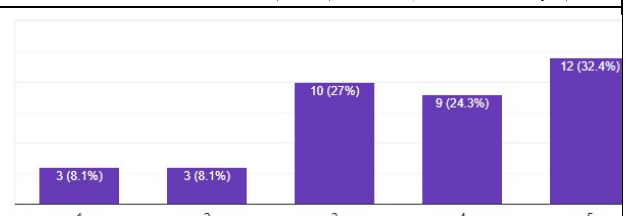
The results of these surveys (**Table 1** and **Table 2**) are summarized and analyzed in the remainder of this section. The first question, which queried the affiliation of the participants just showed that the activity was overwhelmingly attended by TU students. It was quite motivating to know that many of the participants, although students, did enjoy walking in the nature. It was evident from the responses that a significant percentage of them enjoyed a nature walk and the activity positively impacted it, if any.

Table 1 - Results of Plant Walk Surveys to Gauge Interest in iREP-4-PACE

Pre Plant Walk Responses	**Post Plant Walk Responses**
Are you a TU student (Yes, No, Do not wish to disclose)	
	
Do you enjoy walking in nature – Scale of 1 (No!) to 5 (Yes!)	
	

The next set of questions queried the knowledge of the participants – farming in general and molecular farming in particular. The responses for these questions were critical to the assessment and they were overwhelmingly positive as shown below. Although, it was unlikely that a Plant Walk made the participants experts in farming, it was precisely the kind of interest, which the proposing team hoped to generate in the minds, hearts of the youngsters. It is important to note that very few were aware of molecular farming before the activity. The last two set of questions were intended to gauge the interest of participants in a potential iREP-4-PACE involvement. It was evident that the participants gained knowledge of chemical production by engaging in the Plant Walk activity and, more critically, the activity had positively impacted their interest in being a part of the iREP-4-PACE like program. It is important to underscore that the event generated credible interest in the community and an article was published in the local newspaper (**Figure 2**).

Table 2 - Results of Plant Walk Surveys to Gauge Interest in iREP-4-PACE (Contd...)

Pre Plant Walk Responses	**Post Plant Walk Responses**
How good is your knowledge of farming – Scale of 1 (None) to 5 (Expert)?	
	
How good is your knowledge of molecular farming – Scale of 1 (None) to 5 (Expert)?	
	
How good is your knowledge of chemical production – Scale of 1 (None) to 5 (Expert)?	
	
What is your interest level to be part of iREP-4-PACE – Scale of 1 (No!) to 5 (Absolutely!)?	
	

5. Conclusion - Intellectual Merit and Projected Outcomes

Intellectual Merit - The intellectual merit of the program lies in developing an integrated series of interdisciplinary-guided inquiry experiments for research-based education through the MSPC for learning the methods and practices for production of high-value chemicals from plants. These experiments will reinforce STEM concepts and techniques in students while captivating their long-term interest through real-world problem-solving. A return to hands-on activity in the field/laboratory using MSPC as an interdisciplinary tool to bridge the gap between plant/agriculture sciences, chemical sciences and engineering is advocated. Students and faculty will be drawn from across disciplines, including plant/agriculture sciences, chemistry, biology, and engineering from the Colleges of Agriculture, Arts and Sciences, and Engineering. There will be involvement of all the disciplines in each step of the program as the student teams research and develop their MSPC targets. The proposed program has an almost 100% problem-based focus, the development of new MSPC targets appropriate for the Black Belt region of Alabama.

Page B-2, The Tuskegee News, June 28, 2018

Tuskegee University offers a medicinal plant walking tour

Contributed photos

The Tuskegee Civitan Club and others after the Walking Tour.

In early May, the Tuskegee Civitan Club, TU students and staff participated in a Medicinal Plant Walking Tour hosted by Tuskegee University.

Lead by forestry specialist Ronald Smith, the tour consisted of a short introduction into the botanical world, a trek across the Tuskegee University campus, and a cool-down with food and fellowship.

The purpose of the workshop was to show how the plants around us impact our lives and can influence our health if we choose to use them in the proper ways.

Forest specialist Ronald Smith, left, points out characteristics of trees to Jess Colson, center, and Ronald Humphrey.

Tia Gonzales, left, and Jess Colson, right, examining a plant from the Tuskegee University campus.

TU students and staff from left: Jayla Caffey, Velma Campbell and Kia Littlejohn, look at the pretty flowers from the Elizabeth Magnolia Tree.

Dr. Maxwell speaker at All Macon County Awards Banquet

The All Macon County Day Festival was created to find a way to bring all communities in Macon County together. There was a concern that residents outside the city limits of Tuskegee felt isolated and estranged. Therefore, a committee was formed to bridge the gap, to foster unity among the communities and to enhance the economic status of Macon County.

Figure 2 - Local Newspaper Coverage of Plant Walk

Projected Outcomes - This project will help to expand opportunities to our undergraduates as well as introduce local K-12 students to the role that STEM can play in achieving a sustainable, and environmentally friendly future through MSPC. This will help to bridge the gap of disparities that have stymied the ability to pipeline K-12 students, particularly the underserved minorities, into the degree programs in plant/agriculture sciences. It will assist in providing hands-on training in TU's research laboratories. Community outreach and service are also important aspects of TU's strategic plan. This project will enhance collaborative efforts with TU Cooperative Extension Program (TUCEP) and Alabama Cooperative Extension Service (ACES) in outreach to local Alabama population. The labs or lectures developed by the students will significantly enhance the learning experience of other TU students. The results and data generated will facilitate the submission of grants. The K-12 outreach activities developed will impact local K-12 students over the years. This program will significantly increase research and academic opportunities for

underrepresented minority students here at TU in the identified majors. Ultimately, the excitement and energy generated among the undergraduate participants will impact recruitment and retention of undergraduate students from these disciplines.

Tuskegee University has consistently encouraged interdisciplinary collaborations in research and higher education training programs. This project is integrative in nature and demands interdisciplinary, multidisciplinary and team-oriented approaches to address the challenges. The integration of plant breeding and genetics, agronomy, horticulture, chemistry, biology, biochemistry, microbiology, food science, agricultural engineering, agricultural economics, and social science will be used for successful implementation of the project. Faculty from different disciplines across the University will be invited to assist and contribute to the project. We will also collaborate with other institutions, government, and private organizations involved in research, development, and production of molecules from plants. As the program progresses, collaborations with regional, national, and international MSPC interests will be pursued.

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