Teaching Sustainability Through Undergraduate Research and K12 Outreach

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Abstract

West Virginia University Institute of Technology (WVU Tech) and its partners are committed to sustainability education and currently engaged in multiple initiatives to incorporate sustainability in K-12 and engineering education through grant funded activities. This paper describes undergraduate research and K-12 outreach as supplementary activities to course-based approaches. The authors share the motivation, background and status of the two initiatives with a goal of stimulating and informing co-curricular and pipeline building efforts in sustainability education.

The first initiative is a semester undergraduate research experience funded by a state grant. The topic is sustainability, and undergraduates are mentored in research topics related to upcycling, Internet of Things (IoT) technology to promote economic sustainability, carbon capture and various others. Undergraduates apply for research positions through Handshake. Upon hire, the undergraduates engage in research during the fall and spring semesters and present their findings at seminars held each semester. They also have other opportunities to present their work at local, statewide and national conferences. This paper will share project descriptions and lessons learned for this approach to sustainability education.

The second initiative is an NSF Innovative Technology Experiences for Students and Teachers (ITEST) grant that focuses on integrating spatial computing to enhance elementary environmental science instruction. The goal of the initiative is multifaceted and includes advancing understanding of local watershed ecosystems, promoting environmental STEM careers, and racing forward with innovative methods in spatial computing to enhance a proven curriculum. The program targets grades 3-5 teachers for intense professional development. The teachers take what they have learned along with materials for the lessons to their elementary school classrooms. Elementary schools also receive funding for field trips to local streams and other outdoor settings to apply what they have learned and reinforce understanding. This paper will share the outcomes of the first year of this project.

Introduction

Sustainability should play a central role in the engineering curriculum. As students learn to design and develop products and processes for everyday use, they must also learn to act as responsible stewards of the planet's biotic and abiotic resources; air, water, and the extractive materials among them. Future engineers should carry this mindset as they prepare to lead. The Engineering for One Planet (EOP) framework [1] provides a systematic tool for integrating sustainability in engineering education. It includes topics like environmental literacy, social responsibility, materials selection, and environmental impact assessment. Over the last few decades, institutions across the globe and across disciplines have undertaken initiatives to ensure sustainability becomes a foundational term in students' educational vocabulary. Some of the initiatives include direct integration of sustainability into the curriculum either through existing courses or specially developed courses [2-5], youth and summer enrichment programs with a focus on the global reach of sustainability [6] and research experience [7]. This broad range of initiatives answers Sabri's [8] call for sustainability to become "a fundamental principle of engineering, not just one of its electives." Consistent with this call and contributing to the work initiated by other institutions, West Virginia University Institute of Technology (WVU Tech) and its partners are currently engaged in multiple initiatives to integrate sustainability in education. This paper describes undergraduate research and K12 outreach as supplementary to course-based approaches. Our goal is to use these methods for students to achieve learning outcomes from the EOP framework [1]:

1. Recognize environmental challenges that need a solution (environmental literacy)
2. Grasp the social impact of their work and choices (social responsibility)
3. Design solutions that positively impact the environment (materials selection and design)
4. Communicate these solutions to a variety of audiences (communication and teamwork)

To date, formal assessments of these goals were not conducted. However, the paper will describe the replicable practices and highlight the lessons learned from implementation.

Initiative 1: Undergraduate Research in Sustainability

Background and Project Operations

Educational researchers studying the benefits of undergraduate research have shown that undergraduate research increases (1) confidence and awareness, (2) interest in STEM careers and (3) expectation of graduate study [9]. More recent studies indicate how undergraduate research positively impacts facets of research identity formation even for students beginning research with high engineering identity [10]. Recognizing the benefits of undergraduate research and with the goal of developing additional pathways for students to help solve environmental challenges, WVU Tech successfully pursued a state grant to administer an undergraduate research program in sustainability. The grant supports ten undergraduates per year over a three year period (2024-2026). The undergraduate research program is structured for semester research to ensure faculty and student availability. Students apply for the program using Handshake [11], a recruitment platform, and are hired by faculty who mentor them in various sustainability projects. Upon hire, the undergraduates engage in research during the fall and spring semesters and present their findings at seminars held each semester. They also have other opportunities to present their work at local, statewide and national conferences. Two of those projects are discussed.

Project 1: Production of Jet Fuel and Hydrogen from Catalytic Conversion of Waste Plastics

A project team, composed of one female student and two male students, engaged in a plastic upcycling undergraduate research project. The project began as a course-based project to design a process for the catalytic conversion of waste plastics, primarily low-density polyethylene (LDPE), into jet fuel. Students based the process on research by Huo et al. [12].

The team started with a review of existing literature to assess the environmental impact of plastic waste, evaluate recycling and upcycling strategies, and examine relevant laboratory findings. Based on their findings, the team identified a catalyst with minimal environmental impact along with the appropriate reaction conditions and developed an impressive process design (Figure 1) that incorporates a heat-exchanger network to minimize energy costs. The projected economics of the process were strong, with a net present value (NPV) of $211.89 million, a discounted rate of return on investment (DROR) of 24.17%, and a discounted payback period (DPBP) of 3.7 years. Although these economic metrics are excellent for design projects, the students recognized that they lacked sufficient data to accurately design and cost their reactor. The chemical reactor, after all, is the core of most chemical processes.

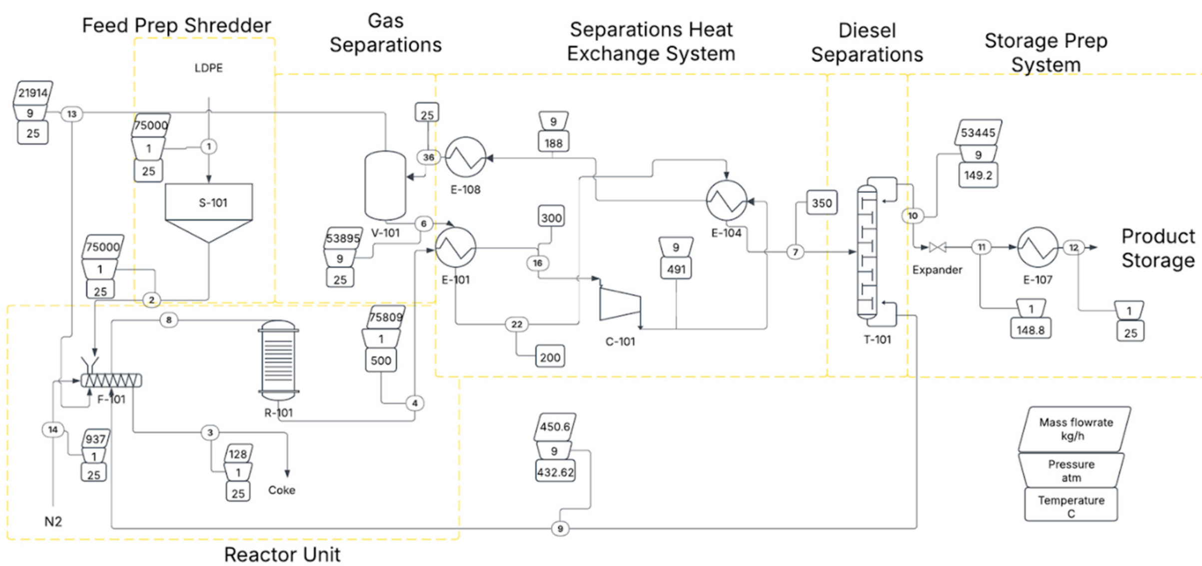

Figure 1: Process flow diagram for catalytic conversion of waste low-density polyethylene to jet fuel

The need for kinetic data to properly design and size the reactor motivated the research project involving laboratory experiments using selected catalysts. Specifically, their project examines the conversion of LDPE using various catalysts and compares the results to non-catalyzed reactions. They are also studying different reaction conditions to identify those that produce a jet-fuel-grade product that meets required specifications. Figure 2 presents pie charts illustrating the reaction products from the students' experiments.

The students presented their research at the 2025 American Institute of Chemical Engineers (AIChE) Undergraduate Conference in Boston, MA. Throughout the presentation, the students articulated a compelling rationale for their project and established clear connections with peers working on related topics. They maintained high audience engagement with approximately 40 poster visitors, provided thorough answers to questions, and showed an openness to feedback. Visitors expressed enthusiasm for the sustainability topic and were interested in the future of the technology and its applications. Suggestions were focused on future research such as using new catalysts and approaches, scaling and alternative feedstocks. In subsequent written reflections, students indicated that participation helped shape their identity as chemical engineers addressing sustainability problems by challenging them to strongly consider "environmental trade-offs" and helping to form a fuller picture of "the effort, time and money invested into finding answers to sustainability challenges and the issues that those answers themselves pose."

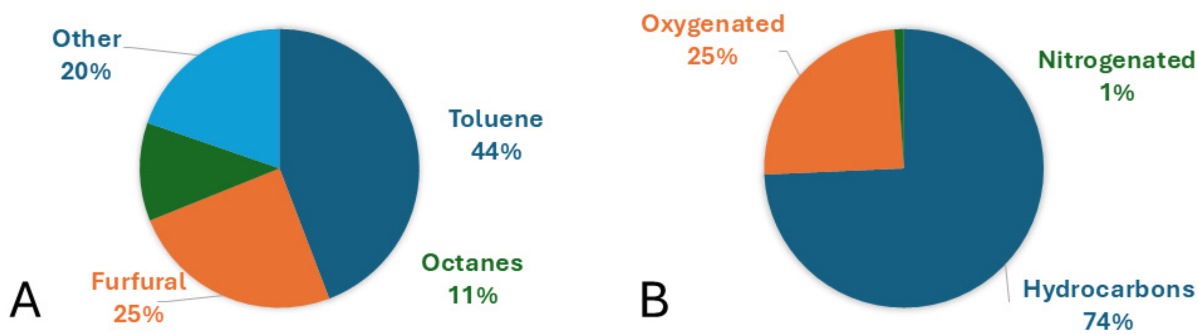

Figure 2: Product composition of (A) non-catalytic and (B) activated carbon/magnesium oxide catalyzed conversion of low-density polyethylene at 500 °C

<u>Project 2: Carbon Capture Using Chemical Looping Schemes</u>

A second undergraduate research project was completed by a student working one-on-one with the faculty member. The work was motivated by concerns over global climate change from anthropogenic carbon emissions, which necessitate the development of power generation technologies with lower carbon footprints. Chemical looping conversion schemes originated with developing ways to combust and gasify carbonaceous fuels with inherent carbon capture during operation [13]. Chemical looping avoids the need for energy intensive separations like other carbon capture processes by using a metal oxide, called an oxygen carrier, and parallel reactors. In the fuel reactor, the oxidized oxygen carrier directly transports oxygen to the carbonaceous fuel. The products of carbon dioxide and water are separated through condensation. Afterwards, the oxygen depleted carrier is transported to a second reactor called the air reactor, in which oxygen is restored through reaction with air. This process is shown in Figure 3.

Typical carrier materials use first-row transition metals such as iron, copper, nickel, and manganese oxides. However, individual uses of metal oxides have problems from low reactivity to environmental hazards. Recently, researchers investigated perovskite oxides as oxygen carriers. Perovskite offers a unique structure of ABO_3, where A and B are earth and transition metals, respectively. This allows for tailoring of the compound for different applications [13]. The project team investigated metal oxides that offer oxygen release at high temperature to enhance conversion of solid fuels such as biomass and coal. The team chose the $CaMnO_3$ perovskite which is composed of naturally occurring minerals and offers minimal environmental impact.

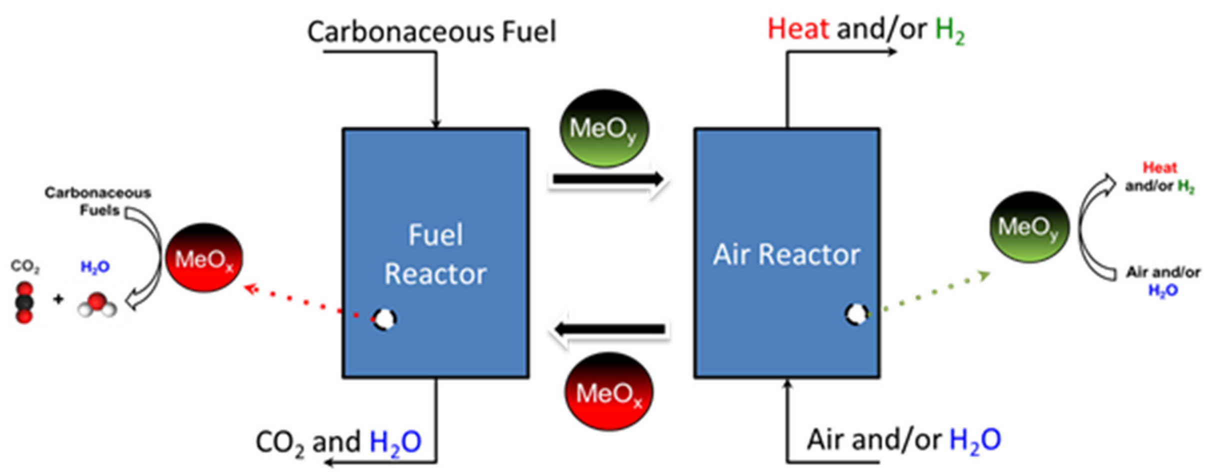

Figure 3: Chemical looping for combustion of carbonaceous fuel reaction scheme

Studies show that the addition of small amounts of another metal like iron onto the B site will allow for the oxygen coupling properties to change [14]. The iron addition was chosen to minimize environmental impacts and costs. However, the full optimization of synthesis conditions, B-site addition, and operating temperatures have not been extensively studied.

The undergraduate research project was a year-long project in which the student focused on designing and optimizing synthesis conditions to achieve the oxygen carriers needed for reaction testing. The student successfully synthesized several compositional changes into the structure using a solution gel process. The procedure requires exact compositional amounts of each metal through dissolving nitrates in water. Afterwards, addition of citric acid in a molar ratio between two and three of citric acid to total metal ions in solution binds the metal ions. The student added ethylene glycol to the solution to act as a gel promoter and removed excess water before ovendrying the sample. After drying, the student annealed the sample in a tube furnace at a range of temperatures between 700-900°C. Figure 4 shows a visual representation of the synthesis procedure.

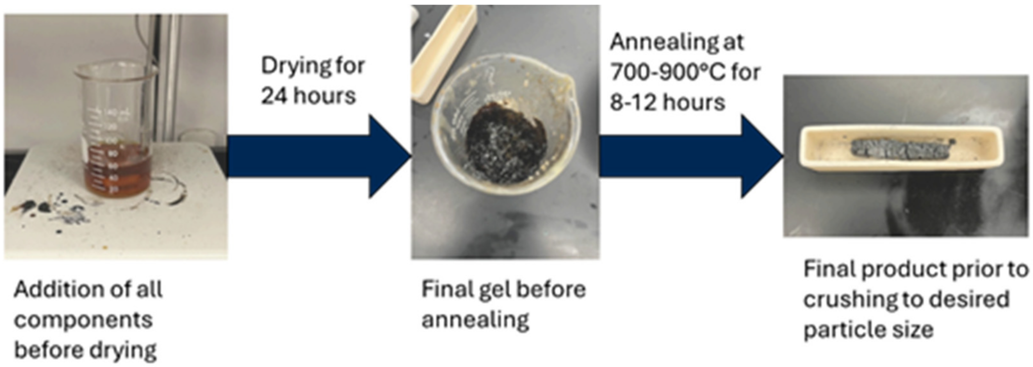

Figure 4: Synthesis procedure of oxygen carriers using the solution-gel method

To further confirm the synthesis procedure, the student imaged the particles using Scanning Electron Microscopy (SEM). The goal of the SEM images was to confirm that few to no micropores were forming. This is to help confirm the hypothesis that oxygen uncoupling is the primary method of conversion during reaction of fuels and to minimize surface reactions. Figure 5 shows images of the oxygen carriers.

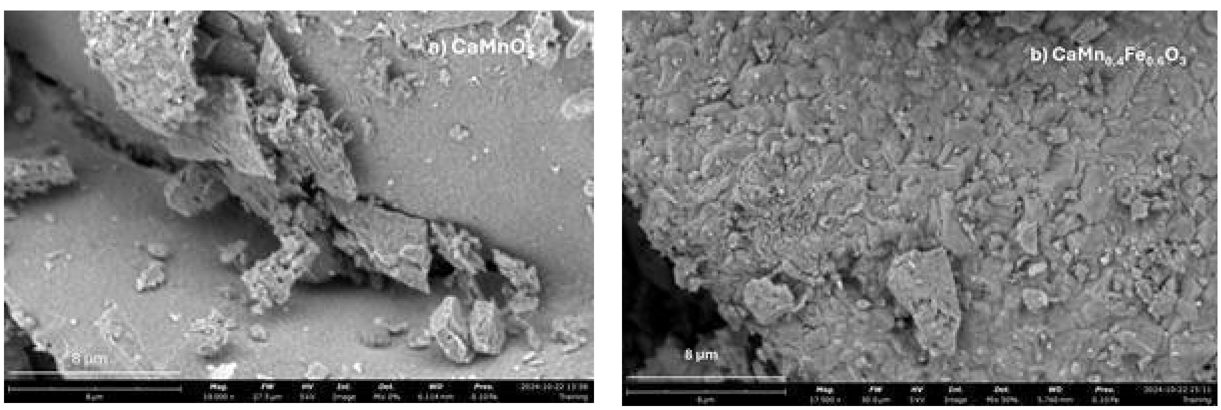

Figure 5: SEM images of (a) $CaMnO_3$ and (b) 40% Fe doped $CaMnO_3$ oxygen carrier

Future work for additional students is to confirm the composition of the materials using X-ray diffraction (XRD) to identify that the phases are, indeed, uniform and singular. Students will also test these particles with reactions of solid fuels such as coal and biomass at various temperatures. This type of project gives the student practical applications of kinetics, thermodynamics, reactor design, material science, and how sustainability connects these topics through providing environmentally friendly energy alternatives. The student presented the work at university seminars and state events, including a legislative event to inform lawmakers about research by their constituents. One lawmaker requested a copy of the research poster and followed up after the event. In an audience survey following a presentation, one audience member commented that the presenter was “great at simplifying the complex chemistry and explaining the purpose behind the work.”

Lessons Learned and Future Work

The work represented by the two sample projects confirms previous work that undergraduate research is a vehicle for providing sustainability education to undergraduates. Valuable lessons from the work thus far are as follows:

1. Course-based design projects can lead to well-motivated undergraduate research projects.
2. Undergraduate research in sustainability immerses the student to an extent that is difficult to achieve through course-based instruction. The immersion supports the ability to articulate the motivation behind the work and simplify the underlying theory for a range of audiences.
3. Audience engagement is strong because the topic of sustainability is accessible to a range of audiences. Even children can appreciate that we need to maintain a world that is environmentally safe with sufficient resources. Topic accessibility has the secondary impact of educating the public through presentations about the research.
4. Qualitative data, obtained in the form of student reflections, suggest that undergraduate research in sustainability helps shape students’ identity as chemical engineers dedicated to sustainability.

To further advance sustainability education, in addition to current elective course offerings and undergraduate research in sustainability described in this paper, a sustainability minor for engineering students is in the planning phase. There may be existing minors at the system-level for WVU Tech such as "Sustainable Design” which is suitable for engineering students. Mainly, the minor requires nine credit hours of sustainable design and development, sustainable living, environmental regulation classes and three credit hours of leadership in energy and environmental design. There are also six elective credit hours in sustainable construction, design for energy efficiency, etc. Some of those courses are offered online within the system which would allow WVU Tech to narrow its focus to courses that are not offered online. In addition to all courses mentioned, students who participate in undergraduate research in sustainability as described above or have sustainability focus in their senior design projects are positioned to earn elective credits through a special topics class.

Initiative 2: Innovative Technology Experiences for Students and Teachers - Clean Water Education for Elementary School Students

WVU Tech and its partners also promote sustainability education using K12 outreach. This paper describes progress in the first year of an Innovative Technology Experiences for Students and Teachers (ITEST) project on clean water education for elementary school students. Every year, the project is structured to include 12 elementary school teachers and their corresponding elementary school students. At the project's present stage, the goal of this paper is to replicate the use of a mature and publicly available curriculum for expanded audiences and to share lessons learned during the formative phase of the project. Later phases of the project will include a technology enhancement that is not the subject of this paper.

Curriculum Overview

The Shared Waters Curriculum [15] is an established watershed education program that has been refined over time to support teacher professional development in water quality and watershed science, equipping educators to engage students ages 8-11 in investigating local watershed issues, examining the impacts of human activities on watershed health, and taking informed environmental action. The curriculum includes modules on watersheds, water runoff, filtration, chemical analysis of water and aquatic macroinvertebrates. Students also use simulators and conduct stream studies to generate and analyze authentic data. This instructional design is phenomenon based, anchored in locally relevant watershed issues that drive student questioning and sensemaking. All lessons are aligned to the Next Generation Science Standards (NGSS) and corresponding state academic standards, ensuring coherence with the three-dimensional learning experiences. Learning gains are measured using a validated pre and post assessment to document changes in students' watershed knowledge and environmental reasoning.

Professional Development Workshops

In year 1, project leaders conducted professional development workshops for 12 3rd-5th grade science teachers from the Red Clay Consolidated School District in Wilmington, Delaware and from four school districts in West Virginia. The primary objective of the sessions was to introduce participants to Shared Waters Curriculum [15] which focuses on integrating Meaningful Watershed Educational Experiences (MWEE) into elementary science education. The workshops commenced by introducing a phenomenon-based teaching approach, prioritizing exploration over elaboration, and focusing on water conservation and quality monitoring. Teachers engaged in an observational exercise to analyze building design features that influence natural water flow into watersheds, underscoring the pedagogical rationale for initiating instruction with real-world exploration to stimulate student curiosity. Subsequently, participants received focused training on the first five lesson plans, including a thorough review of the rationale and alignment with the overall curriculum objectives.

The latter half of the curriculum workshop focused on hands-on application through a field visit to a nearby stream to cover the remaining lesson plans. During the practical component, teachers collected water samples and practiced the identification of macroinvertebrates, which serve as biological indicators of water quality. They also quantified key chemical indicators of water quality, including dissolved oxygen, phosphates, nitrates, and pH. Complete instructional materials necessary for the implementation of all lesson plans, packaged in boxes, were distributed to each teacher, at the conclusion of the curriculum sessions. The initiative was led by team members for WVU Tech, Stroud Water Research Center and Millersville University.

A second workshop focused on community partnerships to support the action learning project that the elementary school teachers will implement within their classrooms. Teachers and program organizers visited local water improvement project sites and water-related industries such as a waste water treatment facility and recreation sites.

Figure 6: A snapshot of activities during a professional development workshop and packaged kits that teachers received to use in their classrooms

Lessons Learned and Future Work

Constructive feedback was collected from teachers after the professional development workshops. From the feedback it is clear that the project's success rests on the ability to balance high-tech innovation with the fundamental joy of outdoor discovery. The lessons learned from the K12 educators demonstrate that the scientific content is robust and every educator appreciates the hands-on support they received via the workshop. This helped them visualize the implementation of this project within their respective learning spaces.

Looking ahead, the future of the project represents a bold step toward democratizing high-level science. The project is not just teaching about watersheds; it is teaching students how to inhabit the role of a scientist in a digital and physical world. The movement from the rural landscapes to the coastal watersheds provides a diverse testing ground for ideas, ensuring that the resulting curriculum is resilient and adaptable. The commitment to professional development and the continuous refinement of assessment tools all point toward a future where environmental literacy, a pillar of the EOP framework [1], is as fundamental as traditional literacy. Ultimately, the transition from "hands-on" experiments to "career-ready" Environmental Science Technology Engineering and Math (E-STEM) education is the defining arc of the project, aiming to ensure that the next generation of students possesses not only the knowledge to understand Earth's systems but also the passion and technical proficiency to protect them. The workshops will continue to evolve, learning from participants to better serve its ultimate goal: fostering a world of responsible stewards of freshwater resources.

Concluding Remarks

WVU Tech and partners describe two current sustainability efforts: an undergraduate research program in sustainability and a K12 project to train teachers and also provide classroom resources to use with their elementary school students. The three-year undergraduate research project is in its final year, and the K12 project is in its first year. The ongoing nature of the projects is one of the limitations of this paper. Additional limitations are the relatively small sample sizes of 30 undergraduate researchers and 12 elementary teachers during the first year of the ITEST project. The scale of the projects won't change, but future work will include summative assessment of the undergraduate research project and multiple years of implementation and curriculum enhancement for the K12 project.

In addition to both being pathways to incorporate sustainability through extramural activities, both initiatives are examples of approaches that have positive cascading consequences. In the example of undergraduate research, not only are the undergraduates immersed in the topic of sustainability and shaping their engineering identity toward sustainability, but the program also provides a pathway to continue capstone design projects, a mechanism to educate the masses through dissemination of research findings and a future foundation for degree programs. In the example of K12 outreach, not only are teachers trained in an area of sustainability, but they educate their students who are the pipeline for future sustainability scientists, engineers, policy makers and an educated citizenry.

Acknowledgements

This material is based upon work supported by the West Virginia Higher Education Policy Commission (HEPC) Division of Science and Research and the National Science Foundation under Award Nos. 2445736, 2445737 and 2445738.

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