# Enhancing Engineering Education through Undergraduate Research Experiences: A Case Study on Waste Plastic in Sustainable Infrastructure

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## Abstract

Engineering education stands as a pivotal driver of technological progress, and evolving demands necessitate innovative methods to cultivate the next generation of engineers. Integrating active research engagement into undergraduate curricula presents a bridge between theoretical learning and practical application, fostering comprehensive understanding. By merging hands-on projects, interdisciplinary collaboration, and real-world problem-solving, undergraduate research experiences (UREs) can rejuvenate engineering education. Undergraduate research experiences in engineering can merge emerging technologies, interactive platforms, and industry affiliations to provide students with an invaluable learning experience. Concurrently, the escalating concern for environmental responsibility, notably among students, has sparked an interest in pioneering solutions like repurposing waste materials for sustainable infrastructure development. This shift towards eco-friendly alternatives not only aligns with ethical values but also offers a tangible avenue for students to affect positive change. Within this landscape, the incorporation of waste plastic into hot mix asphalt (HMA) emerges as an intriguing pathway for enhancing pavement properties, yet it presents unresolved questions regarding optimal compositions, long-term performance, and environmental implications. This paper presents a case study of an undergraduate research experience aiming to demonstrate how early research engagement opportunities can enhance students' engineering education and shift their career trajectories. Furthermore, it is shown here how sustainable engineering research plays a vital role in attracting undergraduate students to research, transforming students' identities, and contributing to students' development of research and interpersonal skill. It is concluded that UREs create a unique opportunity to integrate undergraduate students into research, enabling interdisciplinary exploration that bridges knowledge gaps while fostering critical thinking, adaptability, and a holistic understanding of sustainable engineering practices. Thus, through such targeted educational experiences, educators can inspire a new generation of engineers capable of initiating large strides in sustainable infrastructure development.

**Keywords:** undergraduate research experience; waste plastics; asphalt research; sustainable infrastructure

## Introduction

Engineering education is a cornerstone of technological advancement, equipping students with the skills to tackle complex challenges and drive innovation. In today's rapidly evolving landscape, traditional teaching methods alone may not suffice to cultivate the next generation of engineers. There is a pressing need to explore innovative approaches that promote active engagement in research and other scholarly activities [1, 2]. By integrating hands-on projects, interdisciplinary collaboration, and real-world problem-solving, engineering educators can bridge the gap between theoretical knowledge and practical application, fostering a deeper understanding and passion for discovery among students. Embracing emerging technologies, interactive learning platforms, and industry partnerships can revitalize engineering education, empowering students to not only grasp foundational principles but also actively contribute to the frontiers of scientific exploration and technological breakthroughs [3].

As concerns about environmental responsibility steadily rise, particularly among younger generations, questions from those who are concerned are posed as to how these issues will be combated [4-6]. This motivation has the potential to spark a keen interest in contributing to innovative solutions such as utilizing waste materials and industrial byproducts for infrastructure development. As awareness of environmental issues deepens, students especially are coming to recognize the significance of reducing the ecological footprint of traditional construction practices. By repurposing residues and waste materials, such as recycled aggregates and industrial byproducts, for applications like asphalt concrete, they can actively contribute to resource conservation, minimize landfill burdens, and mitigate the carbon footprint associated with conventional construction materials. This paradigm shift towards sustainable alternatives not only aligns with students' ethical values but also presents an exciting avenue to apply engineering knowledge for tangible positive impact on the planet.

One promising avenue for sustainable infrastructure development lies in the incorporation of waste plastic (WP) materials into hot mix asphalt (HMA) concrete mixes [7-12]. It is becoming increasingly apparent that a productive use of waste plastics could be incorporating them into HMA compounds, hypothetically improving the mechanical properties of asphalt, enhancing durability, extending pavement lifespan, and offering a practical solution that aligns with both sustainability goals and engineering innovation [8, 9, 14, 15]. There are still many knowledge gaps regarding this application of waste plastics, questions pertaining to the optimal types and percentages of plastic additives, their long-term performance under varying environmental conditions, and potential impacts on recycling and disposal processes remain unanswered. This opens another avenue for potentially integrating undergraduate students into this route of study and presenting the opportunity for more undergraduate research experiences (UREs). Opportunities such as this would provide a stimulating opportunity to explore interdisciplinary research, combining materials science, structural engineering, and environmental studies, to unlock the full potential of WP-modified asphalt while filling critical gaps in the understanding and application of this research avenue.

In this context, the potential of UREs becomes even more pronounced when combining a topic of keen interest, such as sustainable infrastructure development using waste materials, with hands-on and active learning experiences within a laboratory environment. By involving undergraduate students directly in experimentation, data analysis, and problem-solving processes, educators can foster a deeper understanding of the complexities and subtleties associated with utilizing waste materials for construction purposes [16]. These UREs not only help solidify theoretical concepts but also empower students to actively address knowledge gaps and challenges within the field. Through collaborative projects and open-ended investigations, students can develop critical thinking skills, learn to adapt to unexpected outcomes, and gain a holistic perspective on sustainable engineering practices [2]. By combining motivation to make a positive impact with practical research endeavors, educators can inspire a new generation of engineers who are not only well-versed in theory but also well-equipped to drive transformative change in the realm of sustainable infrastructure.

## Objectives and Scope

This paper aims to demonstrate how early research engagement opportunities, especially opportunities in particularly relevant areas like sustainable infrastructure, can enhance students' engineering education and shift their career trajectories. We specifically examine the research and experiences of three undergraduate student researchers who completed 3-10 months URE in the topic of sustainable infrastructure materials under the supervision of a faculty mentor, Dr. Jamilla Teixeira. Through this apprenticeship-style URE [42], students completed more than  of lab-based research per week and met regularly with their faculty mentor. Students were paired with a graduate student mentor in addition to receiving mentorship from the faculty member. The results we present are two-fold. First, we present the experimental research that students conducted on the use of waste plastics in asphalt pavements and the technical outcomes of that research. Second, we present a reflection from the three undergraduate students involved in this experimental research, including their main motivations to engage in the URE, their learning outcomes, and the impact of URE in their career trajectories. Accordingly, two major goals and deliverables are included in this paper:

**Goal 1:** *Pratical Research Application: Exploring Waste Plastic in Sustainable Infrastructure*

- Present student-led literature review and provide a comprehensive background on the use of waste plastic in infrastructure development.
- Discuss the specific research methods employed, including experimental design and material characterization.
- Present key results and conclusions from the waste plastic research, highlighting innovative formulations, mechanical properties, and environmental benefits.

**Goal 2:** *Reflection on The Role of Undergraduate Research Experiences in Engineering Education:*

- Discuss how the research on waste plastic served as a practical application of UREs.
- Synthesize reflections from students involved in the research project.
- Highlight how engagement in UREs transformed students' identities as engineers and impacted their career aspirations.
- Present evidence of enriched skillsets, increased confidence, and a broader perspective on engineering's societal role.

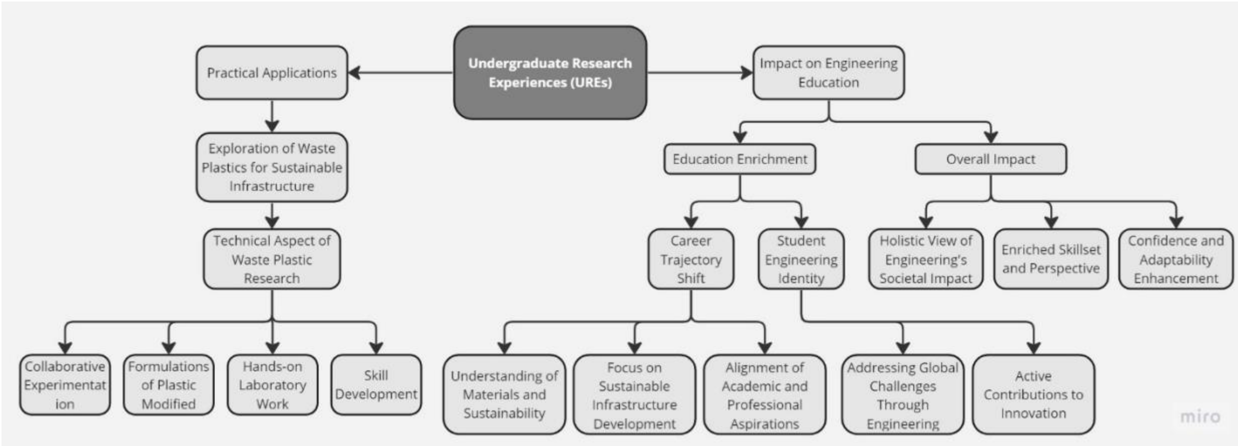


Figure 1: Practical Applications and Engineering Education Implications of the URE

## Students Outcome 1: Pratical Research Application: Exploring Waste Plastic in Sustainable Infrastructure

### *Literature Review*

The global concern over the deposition and accumulation of mismanaged waste plastics (WPs) in the environment is growing [5]. Currently, about 60% of all WPs generated across the globe are disposed in landfills or in the natural environment [17]. Only the US, 35.7 Mt of WPs were generated in 2018, according to the Environmental Protection Agency[18], having a low recycling rate of 8.7%. The majority of WPs (75%) which were generated ended up in landfills. Since the rate of recycling for WPs are incriminatingly low, and the paving industry has a history of utilizing waste products in their road surfaces, the use of WPs for paving applications proposes a promising sustainable solution. There are several different possible applications for the addition of WP into a compound including adding it as an aggregate, a binder modifier or mixture modifier, or any combination of these [7]. Numerous research efforts are currently underway to establish weather or not the addition of WP is a feasible course of action[8-10]. Although there have been promising results presented in regard to mechanical performance gain, there still exists numerous knowledge gaps which need to be confronted in order to produce an optimal use of WPs for hot mix asphalt (HMA) production and utilization. Some examples include possible variations in the types of WP as well as WP particle size limitations for HMA production, WP particle limitations, WP integration methods for a respective type, percentage of WP that needs to be added in, etc.

In regard to the type of WPs studied as a HMA component, most of the selected studies we observed focused on the use of high density polyethylene (HDPE), low density polyethylene (LDPE), and Polyethylene Terephthalate (PET) for their WP addition [7,19,13,20,21-29]. Few studies were found which utilized Polypropylene (PP) WP in paving applications. PP is the most largely produced form of municipal solid waste accounting for 32.1 percent, this is followed by PE with 29.2 percent [7,15,28,29]. The melting point of PP ranges from 160 - 170°C [19,15,30,31-35], which is higher than the typical mixing temperature range for almost all asphalt binders commonly used in HMA production. Thus, the use of PP can lead to issues such as instability and inhomogeneity of WPs in a modified binder. To overcome that, some studies attemped to add PP in HMA through the dry method [7,15,29].

Different studies have evaluated alternate forms and concentrations of PP addition in asphalt concrete utilising the dry method. Most experiments attempted the utilization of PP fibers as an addative as the addition of PP fibers was shown toimprove Marshall stability, indirect tensile strength, and cracking resistance [31,36]. Other studies which were assessed evaluated the use of shredded PP or pelletized PP WP for HMA fabrication using the dry method, these presented promising results showing improved rutting and cracking resistance. Each of these studies however, employed a different method for introducing PP plastic into the HMA mixture [11,30]. Further, most of these studies also only used simple empirical tests to evaluate the effect of PP WP addition into the HMA resistance. Therefore, there is a need to verify PP reinforced HMA considering current performance-based indicators recommended by the balanced mix design approach.

### *Defining the research goals, materials, and methods*

This study explores the effects of the addition of 1% PP in HMA performance, when this material is added via dry method, i.e., adding the PP WP directly into the mixture, after pre-heating the aggregates. To verify that, two mixtures were selected: HMA1, a mixture produced only with virgin aggregates and asphalt binder, and HMA2, a mixture contained 65% of reclaimed asphalt pavement (RAP), an recycled material that has been greatly used in HMA. Then, the studied mixtures were subjected to the Hamburg Wheel Tracking Test (HWTT) to evaluate their rutting and moisture damage susceptibility. Figure 2 shows the materials, mixtures, and the HWTT performance test used herein (outputs, equipment, and samples after test).

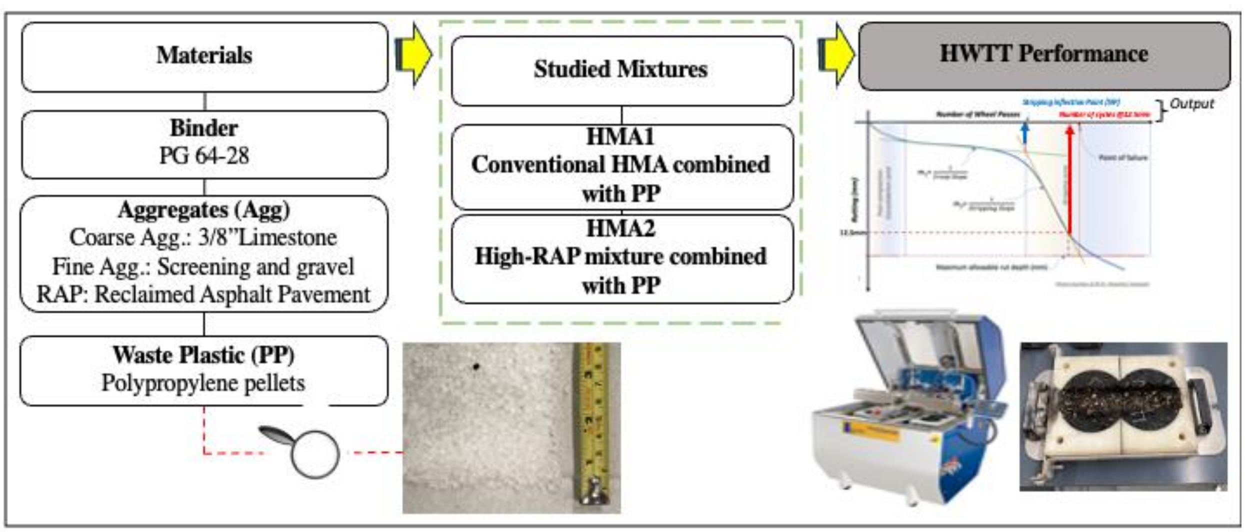


Figure 2: Layout of experimental plan

### *Waste Plastic Addition – Pre-heating Temperature Analysis*

The waste polypropylene (PP) plastic employed in this study. One of the undergraduate students (Author#2) accompanied by his faculty mentor (Author #5) collected samples from WPs from the First Star Recycling facility situated in Omaha, Nebraska. Figure 3 shows the undergraduate student (Author #5) and a representative from the company given information about the recycling procedure used (Figure 3a), and the collected PP sample obtained during the visit

(Figure 3b). After the visit, 2 kg of PP with particle dimensions of 2-5 mm was provided for this research.


**Figure 1 - The polypropylene waste used in this study: (a) site visit; (b) collected sample.**

The critical inherent property of PP is its melting point, which significantly influences the behavior of PP within the HMA mixture. When incorporated using the dry method, PP can function as a constituent particle, a modifier for the mixture, a modifier for binding, or a combination of these roles [7]. According to prior literature sources [19,30,32-35], the assumed melting point range for the PP employed in this study was 160°C to 165°C. To allow the melting of PP and better PP-aggregate adhesion, several studies used temperature beyong the melting point [15,29,32, 38]. Therefore, to ensure the proper melting of the PP, this study pre-heated the aggregates at a temperature of 185°C ± 10°C. The aftermath of PP inclusion is depicted in Figure 4.


**(a)** **(b)**

**Figure 2 - Aggregates and PP mixed at: a) Virgin aggregates w/PP in HMA1, b) RAP aggregates w/PP in HMA2**

Based on visual empirical analysis, it is clear that the adjusted pre-heat temperature was enough to melt the PP particles, allowing for the coating of coarse aggregates by PP. The PP appears to coat the aggregates, acting as a mixture enhancer. Pre-heat temperature higher than the melting point was also suggested in other studies [15,29,32-34,3]).

### *Mechanical Performance*

In order to evaluate rutting and moisture damage susceptibility, the mixtures were subjected to hamburg wheel tracking tests (HWTT). For this test, 62 mm thick gyratory compacted samples were prepared with targeted air void levels of 7 ± 0.5%. The sample was trimmed based on the AASHTO TP 324 procedure. A metallic wheel loading of 52 passes per minute was applied to the test specimen maintained at 50° C. Throughout the progression of the test, the number of wheel passes and respective rutting depth were recorded in the system. This data was analyzed in order to understand the rutting and moisture performance of the asphalt mixture samples. The number of cycles at 12.5 mm rutting depth was utilized as a rutting performance indicator, and stripping inflection point (SIP) was used as a moisture performance indicator.

The number of cycles it took to reach 12.5mm depth for HMA2 was 20,000 passes, while for HMA1 it was 9,416. Many state DOT's recommend a minimum of 7,500 passes on this test. It can be observed that both mixtures passed this criteria even though HMA1 was significantly lower than HMA2. Some studies presented that they evaluated the stiffness of mixtures with PP using different test methods and came to the conclusion that the addition of the WP could make the reference mixture stiffer, which could explain the gain on rutting resistance [30,31,40]. Further, the enhancement of this property could be due to the PP increasing the adhesion and the mechanical friction between all components of the mixture, and in turn the bonding amongst the binder and aggregate, increasing the mixture resistance to permanent. When it comes to moisture damage resistance, coating aggregates with plastic can help prevent penetration of water between binder and aggregates, this aids in reducing the moisture susceptibility of the mixture. Apart from that, in the mixture HMA2, the RAP was heated to meet the requirement of PP's melting point, which could lead to aging-induced stiffness gain and enhanced rutting performance [41]. The stripping inflection point (SIP) was 6,250 and 14,200 respectively for HMA1 and HMA2. This leads to the idea that the addition of PP with RAP resulted in a better bonding than that of the virgin aggregates, resulting in higher SIP values.

In conclusion, this initial assessment of the effects of WP on HMA performance yielded promising results. Considering the sample type and shape used in this study, the inclusion of PP WP demonstrated the potential to improve rutting and moisture damage resistance in asphalt mixtures. This enhancement can be attributed to the aggregate coating facilitated by melted PP particles, safeguarding them against moisture damage and potentially leading to improved binder-aggregate adhesion. The authors are actively conducting further investigations to validate the primary mechanism that contributed to the observed performance improvements.

## Students Outcome 2: Reflection on The Role of Undergraduate Research Experiences in Engineering Education

Students were asked to complete a written reflection at the conclusion of their URE. Reflection questions were developed by the faculty mentor (Author #4) in consultation with an expert in engineering education research (Author #5). The students then analyzed their own reflections, with guidance from Author (# 5), to identify themes that answered the research questions. Findings for each research question are presented below.

RQ1: What were your primary motivations for becoming a part of Dr. Teixeira's lab?

***Understanding of Engineering***

Initial perceptions of research activities tend to be somewhat rudimentary, revealing a gap between theoretical classroom education and comprehensive grasp of ongoing research. The UREs conducted in Dr. Teixeira's lab effectively bridge this gap by immersing students in an environment that exposes them to the intricate tapestry of research endeavors. This immersive exposure fosters a deeper appreciation for the multifaceted nature of engineering research. In their reflections, students all noted that the main motivations driving students to join the lab emerge as a complex interplay of factors, all converging on the allure of experimental (hands-on) learning. Author #1, who also serves as a tour guide to recruit new students to the college of engineering, commented that prior to joining Dr. Teixeira's group, her knowledge of research activities was primarily informed by the information she shared with prospective students as a tour guide. While she could introduce them to some lab spaces, she did not possess in-depth insights into ongoing research projects within the department. She said "*Being part of Dr. Teixeira's lab has since provided me with a more comprehensive understanding of the diverse research endeavors and collaborative environment within CEE*". Furthermore, she said: "*This exposure allowed me to gain a new conceptual understanding of research methodologies, materials science, and the intricacies of asphalt engineering. I developed skills in laboratory techniques, data analysis, and scientific communication that were previously unfamiliar to me*.

The experience in working in a lab enviroment is benefitial and lead to a great way of active learning. Author #2 reported that "*The experience of working with Dr. Teixeira as an undergraduate research student has increased my conceptual knowledge of the mechanics of asphalt concrete pavement. Conceptually I have a much greater understanding of how the blends of aggregates used for asphalt concrete pavements are created, mixed, and prepared [...] and how different constituents added to asphalt concrete mixtures can affect its performance*".

***Identity as Engineers***

Engagement with intricate research methodologies and interdisciplinary collaboration expands their intellectual horizons and refines practical proficiencies. Beyond technical skills, the UREs reshape students' identities, infusing a sense of purpose and belonging within the engineering domain. This shift from uncertain novices to confident participants speaks volumes about the ability of UREs to catalyze personal and professional growth, ultimately molding a new generation of engineers poised to address complex global challenges with innovation and fervor.

RQ2: What aspects of studying sustainable infrastructure materials hold your interest?

***Understanding of Engineering***

The resonance of studying recycled materials within students reflects an intersection of sustainability principles and practical engineering applications. This alignment not only taps into students' motivation but also channels their passion toward addressing real world challenges which relate with larger global and societal concerns. This connection between research themes and pressing real-world issues underscores the power of UREs to improve the understanding of engineering. Author #1 reported that she lacked a background in materials, asphalt or recycling research. This experience was a "*possibility of contribute to the development of sustainable solutions for infrastructure like plastic, RAP, and RCA into asphalt compounds and introduced me to the concept's potential for sustainable infrastructure development*".

***Identity as Engineers***

One student (Author#3) reported that the main motivation to join Dr. Teixeira's group was to improve his prior knowledge on the field of pavements. Moreover, the student highlighted that the suggested topic of research during his URE really attracted him, since he could investigate the potential of sustainable materials to solve real problems and yet develop his research skills. He said "*the use of RAP solves a real issue in the world and therefore presents an engaging research opportunity that can make a difference. This combination of subject that I am passionate about and the ability to do meaningful research is what interested me the most about Dr. Teixeira's lab*". Furthermore, author #3 said that "*having the ability to work towards a more sustainable asphalt practice is a way to solve a problem, which is really the core of engineering in my opinion. In that sense, it is very fulfilling to pursue such a challenge and progress towards a solution that hopefully makes the world better*".

Author #1 reported that after this experience, she understood that "*the study of recycled materials has now become a means to contribute to environmentally conscious engineering practices, a path I had not considered previously*". This highlights the pivotal role of tangible, real-world showcases in igniting curiosity and steering students toward areas within the vast landscape of engineering they might have otherwise overlooked.

<u>RQ3: How did this experience impact your conceptual knowledge, skillset, and your identity as an engineer.</u>

***Understanding of Engineering***

The transformative impact of UREs on students' conceptual knowledge, skillsets, professional identities, and career aspirations is evident in their reflections. According to Author #1, joining Dr. Teixeira's lab has been a transformative experience, especially considering her initial lack of interest and knowledge in asphalt and research. She commented how valuable was the experience to engage with graduate students. "*As an undergraduate entering my junior year, I was fortunate to have the opportunity to become a part of a research group primarily consisting of graduate and PhD students. This exposure allowed me to gain a new conceptual understanding of research methodologies, materials science, and the intricacies of asphalt engineering. I developed skills in laboratory techniques, data analysis, and scientificcommunication that were previously unfamiliar to me*".

According to Author #2, collaborating with Dr. Teixeira has enhanced their proficiency in professional communication, cultivating connections with peers, and adeptly managing time and resources to meet deadlines, whether working independently or within a team. These skills, often less emphasized in traditional classroom settings, are crucial. Undergraduate Research Experiences (UREs) offer a platform to nurture both academic and soft skills in students.

In terms of skillset, students reported their growth to read scientific papers and their research skills in general. "*Reading through many different articles in creating my own literature review made me familiar with the general paper structure and allowed me to better extract information* […]. *Following the procedures for creating and testing asphalt mixtures instilled in me the attention to detail and persistence required to be a successful researcher. Being able to work in a team-oriented environment also developed my cooperative and communicative skills. Furthermore, this experience showed me the importance of presentations"*.

***Identity as Engineers***

Engaging in academic research opens a new avenue toward the student's professional journey. This experience has provided insight into a career path centered on academic research, revealing what it entails and helping them understand their aspirations as an engineer. Author #1 reported that this journey influenced her identity as an engineer: *"I've discovered a passion for sustainable engineering practices and innovative solutions. Being part of a research team has highlighted the importance of interdisciplinary collaboration and creative problem-solving in addressing complex challenges"*.

According to Author #2, collaborating with Dr. Teixeira has been instrumental in shaping their engineering identity and defining career aspirations. He reported *"working with Dr. Teixeira has helped me to identify who I want to be as an engineer and the career goals that I want to achieve by showing me what it would be like to pursue a career primarily focused on academic research"*.

Furthermore, Author #3 reported his potential career path after this URE. He reported that *"this experience opened my eyes to the world of research and the value of postgraduate education. Before, I would not have pictured this type of research as the typical engineering mold, but I now see its importance. Gaining this experience in the lab has made me realize that I would like to pursue a graduate degree in the future and continue to do research as well"*.

## Conclusion

Overall, we see that the URE within the domain of sustainable infrastructure has yielded not only meaningful research results but has also conditioned a significant impact on students' comprehension of engineering principles and the trajectories of their careers. The narratives shared by students underscore the power of experiential learning, bridging the gap between theoretical classroom knowledge and practical applications in real-world challenges.

The implications drawn from these reflections resonate deeply within the broader landscape of engineering education and research. The transformative effects of UREs, as elaborated by the students, call for a reconsideration of the allocation of resources. The tangible outcomes, whether in the form of sustainable materials or refined skillsets, emphasize the need for further investment in funding undergraduate research opportunities. The direct connection between engagement and learning outcomes suggests that enhancing the accessibility and availability of such experiences could be a strategic avenue for fostering a generation of innovative engineers. Furthermore, the experiences recounted by the students underscore the potential for researchers and institutions to shape their offerings. The resonance of research topics with broader societal concerns and students' interests highlights a call for expansion in the scope of undergraduate research offerings. In the context of sustainable infrastructure, this could involve a broader range of projects, exposing students to multifaceted dimensions of the field and aligning their learning experiences with modern challenges.

In conclusion, the revelations stemming from this study elucidate not only the impact of UREs but also the ripple effects they could generate within the realm of engineering education and research. The relationship between students' experiences and the expansion of research offerings has the potential to foster a shift in the way we cultivate the next generation of engineers. By nurturing a culture of experiential learning and aligning research pursuits with critical global concerns, we can forge a path toward holistic education, innovation, and transformative change.

## References


[1] Goodwin, E. C., Cary, J. R., Phan, V. D., Therrien, H., & Shortlidge, E. E. (2023). Graduate teaching assistants impact student motivation and engagement in course-based undergraduate research experiences. Journal of Research in Science Teaching. Advance online publication. https://doi.org/10.1002/tea.21848

[2] Hunter, A. B., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. Science education, 91(1), 36-74.

[3] Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. Science, 316(5824), 548-549.

[4] Yin, F., M. Fortunatus, R. Moraes, M. D. Elwardany, N. Tran, and J.-P. Planche. Performance Evaluation of Asphalt Mixtures Modified with Recycled Polyethylene via the Wet Process. Transportation Research Record, Vol. 2675, No. 10, 2021, pp. 491–502. https://doi.org/10.1177/03611981211011650

[5] Lebreton, L., and A. L. Andrady. Future Scenarios of Global Plastic Waste Generation and Disposal. Palgrave Communications, Vol. 5, No. 1, 2019. https://doi.org/10.1057/s41599-018-0212-7.

[6] Muench, S.T and Dam, T.V. Pavement Sustainability, TechBrief, FHWA Publication No. FHWA-HIF-14-012, 2014.

[7] NCAT, WRI, GHK, and Dow. Performance Properties of Laboratory Produced Recycled Plastic Modified (RPM) Asphalt Binders and Mixtures. NCHRP Project 9-66 Interim Report, 2021.

[8] Sabina, T. A. Khan, Sangita, D. Sharma, and B. M. Sharma. Performance Evaluation of Waste Plastic/Polymer Modified Bituminous Concrete Mixes. Journal of Scientific & Industrial Research, Vol. 68, No. 11, 2009, pp. 975–979.

[9] Khurshid, M. B., N. A. Qureshi, A. Hussain, and M. J. Iqbal. Enhancement of Hot Mix Asphalt (HMA) Properties Using Waste Polymers. Arabian Journal for Science and Engineering, Vol. 44, No. 10, 2019, pp. 8239–8248. https://doi.org/10.1007/s13369-019-03748-3.

[10] Movilla-Quesada, D., A. C. Raposeiras, L. T. Silva-Klein, P. Lastra-González, and D. Castro-Fresno. Use of Plastic Scrap in Asphalt Mixtures Added by Dry Method as a Partial

Substitute for Bitumen. Waste Management, Vol. 87, 2019, pp. 751–760. https://doi.org/10.1016/j.wasman.2019.03.018.
[11] Kamada, O., and M. Yamada. Utilization of waste plastics in asphalt mixtures. Memoirs of the Faculty of Engineering, Osaka City University, Vol. 43, No. 43, 2002, pp. 111–118.
[12] Mashaan, N. S., A. Chegenizadeh, and H. Nikraz. Evaluation of the Performance of Two Australian Waste-Plastic-Modified Hot Mix Asphalts. Recycling, Vol. 7, No. 2, 2022, p. 16. https://doi.org/10.3390/recycling7020016.
[13] Poulikakos, L. D., E. Pasquini, M. Tušar, D. Hernando, D. Wang, P. Mikhailenko, M. Pasetto, A Baliello, A. C. Falchetto, M. Miljković, M. Orešković, N. Viscione, N. Saboo, G. Orozco, É.Lachance-Tremblay, M. Vaillancourt, M. R. Kakar, N. Bueche, J. Stoop, L. Wouters, D. Dalmazzo, G. D. S. Pinheiro, K. Vasconcelos, and F. Moreno-Navarro. RILEM Interlaboratory Study on the Mechanical Properties of Asphalt Mixtures Modified with Polyethylene Waste. Journal of Cleaner Production, Vol. 375, 2022, p. 134124. https://doi.org/10.1016/j.jclepro.2022.134124.
[14] Al-Hadidy, A. I., and Y. Tan. Mechanistic Approach for Polypropylene-Modified Flexible Pavements. Materials in Engineering, Vol. 30, No. 4, 2009, pp. 1133–1140. https://doi.org/10.1016/j.matdes.2008.06.021.
[15] Ma, Y., H. Zhou, X. Jiang, P. Polaczyk, R. Xiao, M. Zhang, and B. Huang. The Utilization of Waste Plastics in Asphalt Pavements: A Review. Cleaner Materials, Vol. 2, 2021, p. 100031. https://doi.org/10.1016/j.clema.2021.100031.
[16] Adedokun, O. A., Bessenbacher, A. B., Parker, L. C., Kirkham, L. L., & Burgess, W. D. (2013). Research skills and STEM undergraduate research students' aspirations for research careers: Mediating effects of research self-efficacy. Journal of Research in Science Teaching, 50(8), 940-951. https://doi.org/10.1002/tea.21100
[17] Geyer, R., J. Jambeck, and K. L. Law. Production, Use, and Fate of All Plastics Ever Made. Science Advances, Vol. 3, No. 7, 2017. https://doi.org/10.1126/sciadv.1700782.
[18] Brasileiro, L. L., F. Moreno-Navarro, R. Tauste, J. M. E. De Matos, and M. C. Rubio-Gámez. Reclaimed Polymers as Asphalt Binder Modifiers for More Sustainable Roads: A Review. Sustainability, Vol. 11, No. 3, 2019, p. 646. https://doi.org/10.3390/su11030646.
[19] Chin, C., and P. M. M. Damen. Viability of Using Recycled Plastics in Asphalt and Sprayed Sealing Applications. Austrodas, 2019.
[20] Lu, D. X., and F. Giustozzi. Recycled Plastics as Synthetic Coarse and Fine Asphalt Aggregate. International Journal of Pavement Engineering, 2022, pp. 1–16. https://doi.org/10.1080/10298436.2022.2068550
[21] Liu, T., X. Li, R. Li, J. Pei, and X. Zhao. Performance of Dry Mixed Rubber–Plastic Composite Modified Asphalt Mixture. Journal of Materials in Civil Engineering, Vol. 34, No. 10, 2022. https://doi.org/10.1061/(asce)mt.1943-5533.0004407.
[22] Modarres, A., and H. Hamedi. Effect of Waste Plastic Bottles on the Stiffness and Fatigue Properties of Modified Asphalt Mixes. Materials in Engineering, Vol. 61, 2014, pp. 8–15. https://doi.org/10.1016/j.matdes.2014.04.046.
[23] . Buncher, M. Learning more about recycled plastics in asphalt pavements. Asphalt Magazine. https://Learning more about recycled plastics in asphalt pavements - Asphalt magazine. (Accessed 22 June 2023)
[24] Awwad, M. T., and L. Shbeeb. The Use of Polyethylene in Hot Asphalt Mixtures. American Journal of Applied Sciences, Vol. 4, No. 6, 2007, pp. 390–396. https://doi.org/10.3844/ajassp.2007.390.396.

[25] Köfteci, S. Effect of HDPE Based Wastes on the Performance of Modified Asphalt Mixtures. Procedia Engineering, Vol. 161, 2016, pp. 1268–1274. https://doi.org/10.1016/j.proeng.2016.08.567.
[26] Movilla-Quesada, D., A. C. Raposeiras, and J. Olavarría. Effects of Recycled Polyethylene Terephthalate (PET) on Stiffness of Hot Asphalt Mixtures. Advances in Civil Engineering, Vol. 2019, 2019, pp. 1–6. https://doi.org/10.1155/2019/6969826.
[27] Ma, Y., H. Zhou, X. Jiang, P. Polaczyk, R. Xiao, M. Zhang, and B. Huang. The Utilization of Waste Plastics in Asphalt Pavements: A Review. Cleaner Materials, Vol. 2, 2021, p. 100031. https://doi.org/10.1016/j.clema.2021.100031.
[28] The Recycling Partnership. State of Curbside Recycling Report (2020). https://recyclingpartnership.org/wp-content/uploads/dlm_uploads/2020/02/2020-State-of17 Curbside-Recycling.pdf. (Accessed 22 June 2023)
[29] Buruiana, D. L., P. L. Georgescu, G. B. Carp, and V. Ghisman. Recycling Micro Polypropylene in Modified Hot Asphalt Mixture. Scientific Reports, Vol. 13, No. 1, 2023. https://doi.org/10.1038/s41598-023-30857-9.
[30] Lastra-González, P., M. Á. Calzada-Pérez, D. Castro-Fresno, Á. Vega-Zamanillo, and I. Indacoechea Vega. Comparative Analysis of the Performance of Asphalt Concretes Modified by Dry Way with Polymeric Waste. Construction and Building Materials, Vol. 112, 2016, pp. 1133–1140. https://doi.org/10.1016/j.conbuildmat.2016.02.156.
[31] Mahdi, A. S., G. E. Milad, M. K. Mehmet, H. S. Mahdi, and S. Esfandiarpour. Production of Polypropylene-Reinforced Asphalt Concrete Mixtures Based on Dry Procedure and Superpave Gyratory Compactor. Iranian Polymer Journal, Vol. 20, No. 10136, 2011, pp. 813–823.
[32] Dalhat, M. A., and H. I. A.-A. Wahhab. Performance of Recycled Plastic Waste Modified Asphalt Binder in Saudi Arabia. International Journal of Pavement Engineering, Vol. 18, No. 4, 2015, pp. 349–357. https://doi.org/10.1080/10298436.2015.1088150.
[33] Dalhat, M. A., and H. I. A.-A. Wahhab. Cement-Less and Asphalt-Less Concrete Bounded by Recycled Plastic. Construction and Building Materials, Vol. 119, 2016, pp. 206–214. https://doi.org/10.1016/j.conbuildmat.2016.05.010.
[34] Wahhab, H. I. A.-A., M. A. Dalhat, and M. A. Habib. Storage Stability and High-Temperature Performance of Asphalt Binder Modified with Recycled Plastic. Road Materials and Pavement Design, Vol. 18, No. 5, 2016, pp. 1117–1134. https://doi.org/10.1080/14680629.2016.1207554.
[35] Chetan Yeole, V. U. Khanapure, V. P. Joshi, Abhaysinha Shelake. UTILIZATION OF INDUSTRIAL POLYPROPYLENE (PP) WASTE IN ASPHALT BINDER FOR FLEXIBLE PAVEMENTS. International Research Journal of Engineering and Technology (IRJET), Volume 04, Issue 06, 2017.
[36] Klinsky, L. M. G., K. Kaloush, V. C. De Faria, and V. S. S. Bardini. Performance Characteristics of Fiber Modified Hot Mix Asphalt. Construction and Building Materials, Vol. 176, 2018, pp. 747–752. https://doi.org/10.1016/j.conbuildmat.2018.04.221.
[37] Polypropylene Development: PP Resin & PP Blend Material Advances. https://omnexus.specialchem.com/tech-library/article/polypropylene-performance-developments move forward#:~:text=Polypropylene%20(PP)%20is%20the%20second,Growth%20Rate)%20of%205.85% 25.

[38] Tapkın, S. The Effect of Polypropylene Fibers on Asphalt Performance. Building and Environment, Vol. 43, No. 6, 2008, pp. 1065–1071. https://doi.org/10.1016/j.buildenv.2007.02.011.

[39] Brasileiro, L. L., F. Moreno-Navarro, R. Tauste, J. M. E. De Matos, and M. C. Rubio-Gámez. Reclaimed Polymers as Asphalt Binder Modifiers for More Sustainable Roads: A Review. Sustainability, Vol. 11, No. 3, 2019, p. 646. https://doi.org/10.3390/su11030646.

[40] Viscione, N., D. Lo Presti, R. Veropalumbo, C. Oreto, S. A. Biancardo, and F. Russo. Performance Based Characterization of Recycled Polymer Modified Asphalt Mixture. Construction and Building Materials, Vol. 310, 2021, p. 125243. https://doi.org/10.1016/j.conbuildmat.2021.125243.

[41] Asphalt Institute. 2014. Asphalt Mix Design Methods. Manual Series No. 02 (MS-2) 7th Ed.

[42] National Academies of Science, Engineering, and Medicine. (2017). Undergraduate research experiences for STEM students: Successes, challenges, and opportunities. The National Academies Press.

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