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”Living” Engineering Laboratory: Enhancing Undergraduate Learning Through Place-Based Education and Lab-Scale Engineering Models

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"Living" Engineering Laboratory: Enhancing Undergraduate Learning Through Place-Based Education and Lab-Scale Engineering Models

The engineering program at Juniata College, a private liberal arts institute, has witnessed a steady rise in applications and enrollment since its launch in Fall 2022. Beginning with a modest cohort of seven students in the inaugural year, the program has now grown to accommodate over 25 engineering students. While the upward trend in enrollment is promising, laboratories and facilities essential for hands-on learning must be expanded and improved, and thus, a "living" engineering laboratory was proposed. This project aims to integrate experiential learning into core engineering courses, aligning with ABET standards. The envisioned outcome is two-fold: first, to enhance the educational experience for students by providing them with practical and real-world learning opportunities within their core courses; second, this initiative aims to align Juniata's engineering program with criteria set by ABET. This paper will provide an overview of the living engineering laboratory and details of some recent projects.

Introduction

Hands-on experiences are essential in engineering education, serving as a bridge between theoretical knowledge and real-world application. Research consistently supports the integration of active learning strategies -- such as lab-scale models, project-based learning, and inquiry-driven approaches -- to enhance student engagement and learning outcomes. The National Research Council underscores the significance of such experiences and highlights the role of lab-scale models in connecting classroom concepts to practical challenges [1]. Kloser further explores how integrating lab-scale engineering models within place-based education can support inquiry-based learning and foster interdisciplinary problem-solving skills [2]. Similarly, other studies report that active learning methods, including lab-based and project-based activities, significantly improve student performance, retention, and conceptual understanding when compared to traditional lecture formats [3]. Additional research in engineering education emphasizes the value of project-based learning and contextualized problem framing in promoting deeper understanding and long-term retention [4] – [6]. These approaches not only strengthen technical knowledge but also cultivate vital skills such as creativity, problem-solving, communication, and teamwork -- competencies critical for success in engineering, research, and entrepreneurial careers.

Practical examples, such as the treatment wetlands set up at Rose-Hulman Institute, illustrate the value of integrating lab-scale projects into engineering curricula [7]. This setup, incorporated into courses like Water Quality and Environmental Engineering, provided students with technical knowledge while exposing them to complex, open-ended challenges. It fostered creativity, sustainability, and research experiences, with some students even pursuing careers inspired by these projects [7].

At Juniata College, the engineering program launched in Fall 2022 with a modest cohort of seven students and has since grown to over 25 students. This promising growth underscores the need to expand and improve laboratories and facilities essential for hands-on learning, a cornerstone of engineering education. The concept of a "living" engineering laboratory was thus proposed. This innovative initiative integrates experiential learning into core engineering courses, aligning with ABET standards. The project aims to achieve two key outcomes: enhancing the educational experience through real-world, hands-on opportunities and meeting the criteria outlined in ABET Criterion 5 (Curriculum) and Criterion 7 (Facilities). These criteria emphasize the importance of hands-on experiments, design processes, and access to modern tools and facilities to support student learning and outcomes. This paper introduces the living engineering laboratory initiative at Juniata College, discussing its framework, recent projects, and the potential to serve as a sustainable model for engineering education in small institutions. By leveraging student-designed and built laboratories, this initiative not only addresses current limitations but also lays a foundation for future cohorts, fostering innovation, sustainability, and practical learning.

A living engineering laboratory is defined as any space or activity that provides continuous learning opportunities for students. Unlike traditional laboratories confined within walls, a living laboratory can extend to community or local projects, emphasizing flexibility and real-world relevance. Two key features define a living engineering laboratory: 1) it must continuously evolve and grow over time and must serve multiple groups of students, and 2) it should be student-oriented, led and designed by students and must provide real-world experiences for students. Figure 1 presents a conceptual framework for the living engineering laboratory. The green circles represent elements of my teaching philosophy and the expected outcomes of this initiative: fostering innovation, enhancing student engagement, and providing practical learning experiences. The red circle highlights the alignment of this project with ABET standards, ensuring that it supports the program's academic rigor and professional relevance. This paper explores the living laboratory concept as a model of experiential learning and innovation in engineering education. It provides an overview of its framework and implementation, along with examples of recent student-driven projects that illustrate its potential to transform learning and address real-world challenges.

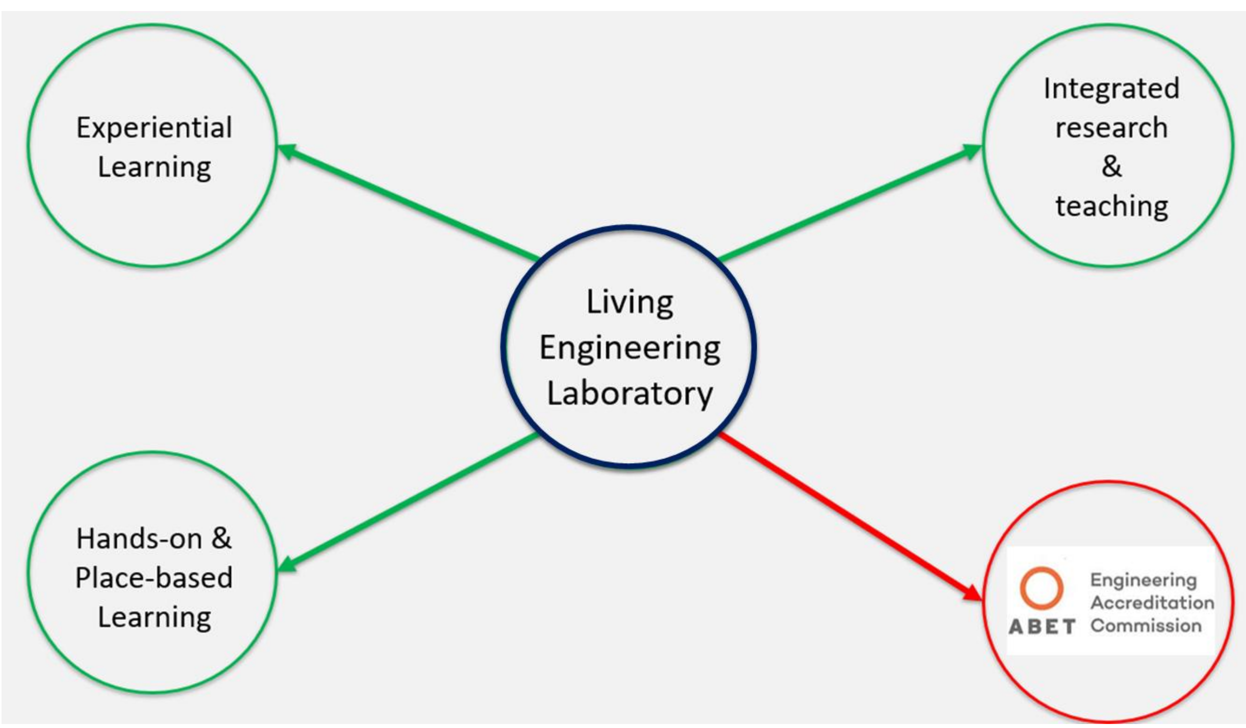

Figure 1: Conceptual framework for Living Engineering Laboratory

Implementation

The implementation of the living engineering laboratory builds on its core principles -- integrating local community projects and lab-scale models to provide hands-on, real-world learning experiences. This approach transforms traditional classroom learning into an interactive and practical experience, fostering deeper understanding and skill development. This section highlights some recent projects that exemplify the living engineering laboratory framework.

1) Community-based Projects

In my Environmental Water Quality class, the local stream "Muddy Run" was utilized as a “live” laboratory for understanding water quality parameters. Students engaged in hands-on activities such as collecting samples and performing field testing, which allowed them to apply theoretical knowledge to real-world problems. This experiential learning component was well-received, with students appreciating the opportunity to learn by doing. Figure 2 shows pictures of students collecting water samples and field-testing. One student further expanded this classwork into a summer research project, which has been accepted as a peer-reviewed conference paper [8]. The research focuses on assessing the water quality of Muddy Run, a local stream in Huntingdon, Pennsylvania. Sampling and analysis revealed significant findings, such as elevated nutrient concentrations and lower dissolved oxygen (DO) levels ($p<0.05$) as the stream emerged from underground, indicating point-source nutrient discharge. Higher total dissolved solids (TDS) and conductivity near impervious surfaces pointed to urban runoff contributions from streets and parking areas. These findings emphasize the impact of urbanization on water quality and the need for continuous monitoring and informed watershed management practices.

Figure 2: Student collecting water samples and field-testing of water quality parameters

Guided by the earlier project, students were tasked with identifying ways to address the runoff issues in Muddy Run as a project in Environmental Sustainability Design class. A notable outcome was a student-led research project on stormwater management using Low Impact Development (LID), which also culminated in a peer-reviewed conference paper [9]. The project investigated urban runoff management at Juniata College, a 110-acre campus through which the local creek, Muddy Run, flows. This creek receives runoff from parking lots and residence halls, presenting an opportunity for targeted interventions. Using site assessments, flood mapping, and the EPA Stormwater Calculator, the project identified areas prone to runoff issues and proposed LID solutions (Figure 3). Key recommendations included implementing a combination of green roofs and rain barrels for the campus's largest building, potentially reducing over 31,000 gallons of runoff for a 1-inch design storm. The harvested rainwater could also be reused, providing economic benefits. Additionally, a bioswale was proposed for a parking lot to mitigate runoff discharge into the creek, safeguarding local water quality. These LID not only offer practical benefits for the campus but also provide students with invaluable experiential learning through research and project involvement.

Both of these projects demonstrate the potential of the living engineering laboratory to blend education, research, and community engagement, creating impactful learning opportunities while addressing real-world challenges.

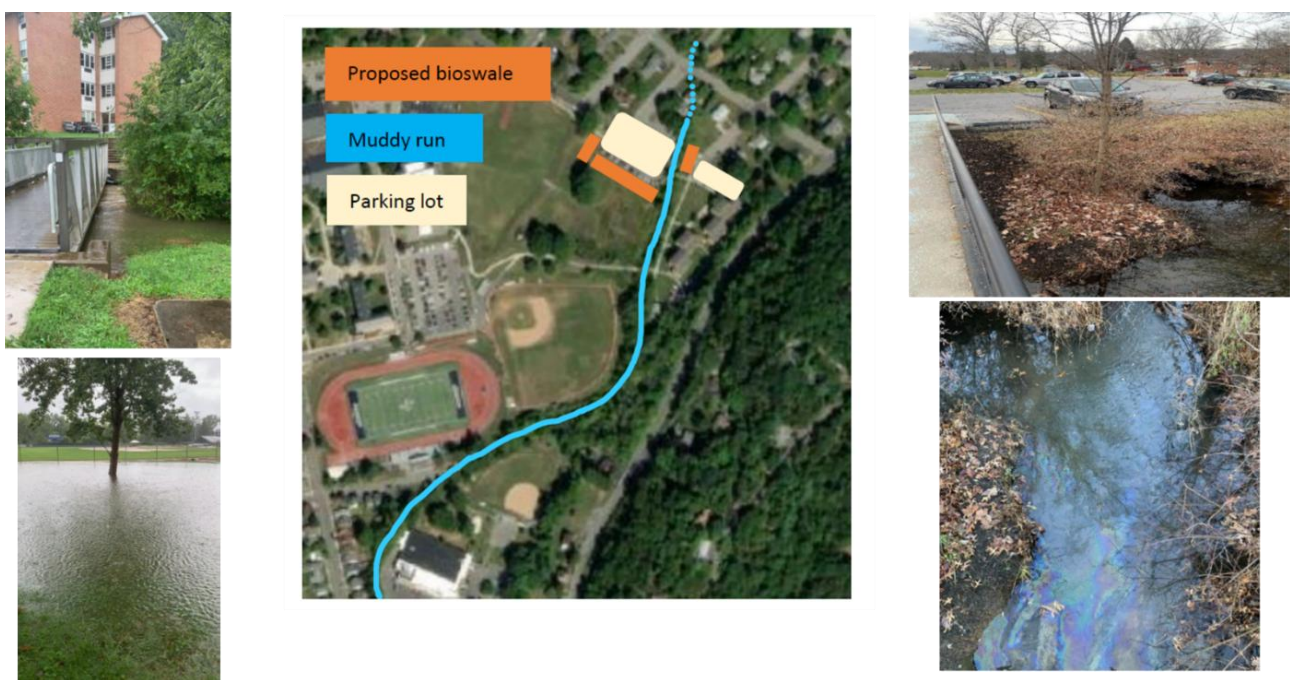

Figure 3: Pictures showing urban runoff issues along with proposed solution in the campus area

2) Lab-scale models

Another key aspect of the living laboratory is building lab-scale models to demonstrate various engineering processes. Some accomplished and ongoing projects include – 1) Lab-scale Green Stormwater Infrastructures: Integrating Research and Teaching [10]; 2) Lab-scale design for Pond-In-Pond: An alternative wastewater treatment system for reuse [11]; 3) Educational Lab Scale Model of a Surface Flow Wetland [12]; 4) Construction of a Laboratory-Scale Subsurface Wetland to Investigate Large-Scale Wetland Dynamics [13]; and 5) 3D Printing to Test Waterwheel Efficiency: A Practical Approach to Engineering and Sustainability [14]. By constructing these demonstration units, students gain practical skills in design, experimentation, and data interpretation while contributing to engineering practices. Figures 4 through 7 shows students actively engaged in these projects, showcasing their involvement in creating innovative solutions. These initiatives highlight the living engineering laboratory's role in bridging theoretical concepts with practical applications, fostering innovation, and equipping students with the skills necessary to address real-world engineering challenges. These projects will also enrich courses like Water Quality, Environmental Sustainability, and Water Treatment, improving educational experience for engineering and science students.

Figure 4: Group of students building platform and tanks for wetland

Figure 5: Group of students working to establish vegetation in the wetlands

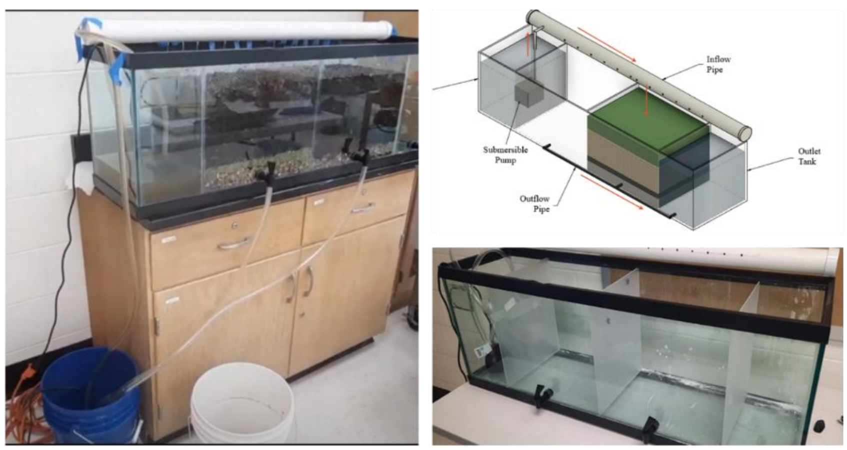

Figure 6: Pictures during the construction of lab-scale rain garden

Figure 7: Pictures during the construction of waterwheel using 3-D printer

Assessments and Outcomes:

Over the past two years, a mix of qualitative and quantitative methods have been adopted to assess the impacts of this initiative. Qualitative assessment includes feedback from students participating in activities within the living laboratory, either as part of coursework or for projects. Students' written and verbal feedback suggests positive feedback on the efforts. Quantitative assessment includes number of lab activities/modules developed, number of courses and students benefited from, independent research and projects utilizing the space, and tangible outcomes generated such as presentations or publications, and awards. In the past two years, multiple class cohorts and 9 individual students have engaged in this initiative leading to tangible academic outcomes. Students have travelled to multiple regional, national and international conferences to present their work as shown in Figure 8. Table 1 below provides a summary of accomplishments. As the project continues, more formal assessment will be conducted to measure the impact on student learning outcomes, the effectiveness of the new curriculum modules, and the utilization of the laboratory space.

Table 1: Direct outcomes from the living engineering laboratory initiative

Academic Outcome	**Number**
Undergraduate research project	9
No. of class involved	3
Conference Presentations	13 total presentations (across 4 different conferences)
Conference Proceedings	2 published, 1 accepted
Awards	1 (Best undergraduate technical paper in EWRI 2024)

Fig 8: Pictures of students presenting at various regional and international conferences.

Conclusions and next steps

The living laboratory provides hands-on learning experiences, bridging theory and practice. Students will tackle local challenges, design and build lab-scale models, and implement solutions, enhancing critical thinking and engineering design skills. Students will gain a deeper understanding of the interconnectedness between society, environmental issues, and sustainable development, fostering community engagement and empowering future environmental leaders. These projects will also enrich courses like Water Quality, Environmental Sustainability, and Water Treatment, improving educational experience for environmental engineering and science students. This student-led initiative benefits current and future cohorts. The project's interdisciplinary approach involves faculty and students from various other fields, including Environmental Science, Biology, Physics, and Chemistry. Additionally, the living laboratory's research and projects will serve as demonstration units and teaching modules for high school students, attracting them to engineering and STEM fields. As the project continues, an online repository will be created for the living laboratory. This will document all the work in the living laboratory with appropriate videos and images and will include the modules developed. These resources will help streamline courses for instructors and will be made accessible to all and will later be released as an Open Educational Resource.

Retrospective

What began as a response to a specific challenge for a class during my first semester of teaching eventually unfolded into a series of opportunities to integrate hands-on projects across multiple undergraduate courses. Each project came with its own set of difficulties, but a consistent highlight throughout was the enthusiasm and energy of working alongside undergraduate students.

We encountered challenges in various areas, including sourcing materials, designing functional systems, and troubleshooting implementation issues. One particularly memorable learning experience was the unexpected collapse of our subsurface wetland system immediately after adding the media and water. The room where the system was installed was not well-suited for such an experiment, highlighting the importance of carefully preparing the physical space for hazards or failures. Despite the setback, students responded with resilience and creative problem-solving, turning the situation into a valuable educational moment.

Another key takeaway from these projects is the importance of sustained faculty engagement. Student teams often face frustration when projects do not go as planned, and maintaining motivation can be difficult. In these moments, faculty guidance, encouragement, and a steady presence are crucial to help students persevere through challenges and turn setbacks into meaningful learning experiences.

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