Sustainability in the Classroom: Using Real-World Anaerobic Digestion Data to Drive Place-based, Project-based STEM Teaching and Learning

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Her research interests lie at the intersection of sustainability, data science, and education. She has contributed to K–12 STEM engagement through professional development workshops for teachers, where real-time AD data is used to design lesson modules on environmental science, mathematics, and data literacy. As a Chartered Statistician, she is committed to advancing rigorous, data-driven approaches to renewable energy systems and community-centered learning.

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Abstract

This work-in-progress paper presents the development and initial classroom implementation of an interactive dashboard that transforms real-time anaerobic digestion (AD) data into classroom-ready visualizations for K-12 STEM education. Anaerobic digestion is a complex engineering process that converts organic waste into renewable biogas, yet its use as a data-rich instructional context remains limited. The dashboard is part of a multiphase project integrating sensor data pre-processing, teacher professional development, and collaborative lesson co-design. Initial classroom implementation included a digester site visit and dashboard-based activities in which 5th grade students analyzed real data on food waste and biogas production. Teacher feedback and classroom observations indicate strong student engagement, with learners generating questions, making comparisons, and reflecting on sustainability and engineering systems. Workshop feedback also informed improvements to data processing, enhancing the reliability and interpretability of dashboard data while preserving real-world variability. Co-developed lessons demonstrate how real-world engineering data can support data literacy, systems thinking, and sustainability learning across K-12 grade levels.

Sustainability in the Classroom: Using Real-World Anaerobic Digestion Data to Drive Place-based, Project-based STEM Teaching and Learning (Work In Progress)

1. Introduction and Background

Anaerobic digestion (AD) is an engineering process in which microorganisms break down organic materials such as food waste and/or animal manure under oxygen-free conditions to produce renewable biogas [1]. The AD process provides a real-world example of the circular economy, integrating topics that are relevant to K-12 learning such as food systems, energy systems and resource recovery. However, integration into K-12 STEM learning has been limited [2], possibly because AD processes are typically hidden from public view and are perceived as complex or inaccessible to non-expert audiences. To bridge this gap, Clarkson University's AD research team created an online dashboard that transforms live AD sensor generated data such as waste input (dairy manure and food waste [21]), temperature, biogas production and methane concentration into interactive, classroom-friendly visualizations that enable teachers and students to explore and extract real engineering data, identify trends, and learn about AD system behavior, while also using this dashboard to monitor their AD system performance.

1.1 Real-World Data in STEM Education

Wallman [3] advocated that K-12 education plays a critical role in the formation of data-literate citizens. Moreover, education research consistently shows that learning is strengthened when instruction is grounded in authentic, place-based contexts rather than abstract examples, as such approaches situate learning within locally relevant problems and promote student engagement, systems thinking, and deeper conceptual understanding [4,5]. The use of real-world data further supports the development of data literacy skills such as interpreting variability, identifying trends, and making evidence-based decisions, which are increasingly recognized as essential competencies for both students and educators [6,7]. Environmental and sustainability-focused datasets are particularly effective for interdisciplinary STEM instruction because they integrate concepts across science, mathematics, and engineering while addressing societally relevant challenges that many students are interested in. Prior studies indicate that sustainability grounded in real systems can also foster positive attitudes toward environmental stewardship [8].

1.2 Anaerobic Digestion as a Teaching Tool

AD links biology, chemistry, engineering, and environmental science, providing a theoretically rich context for engineering education. It exemplifies a complex socio-technical system in which biological, chemical, and physical processes are integrated through engineered control and monitoring [9,1]. As such, AD supports instruction in systems thinking, process optimization, and trade-off analysis, all core epistemic practices of engineering [10]. Teachers can use AD systems to address climate literacy, waste management, and renewable energy topics. Grounding instruction in authentic energy systems addresses persistent gaps in energy and climate literacy by requiring learners to reason with real operational data rather than simplified representations, thereby supporting the development of competencies associated with engineering judgment and sustainability-oriented decision making [8,11,12].

1.3 Dashboards as Instructional Tools in Engineering Education

Interactive dashboards have been used in STEM education to support data exploration and sensemaking by scaffolding learners' engagement with complex datasets through multiple representations and visual cues [13,14]. These affordances align with core engineering practices such as interpreting data from real systems and reasoning under uncertainty. Dashboards have also been shown to support teachers' own data literacy and professional learning [6]. However, most educational dashboards rely on static or curated datasets, limiting learners' exposure to authentic situations such as sensor failures, missing values, and system variability that are central to professional engineering practice. Similarly, despite growing recognition of the value of real-world data and dashboard-based instruction, instructional materials often rely on simplified datasets and idealized system representations, limiting learners' engagement with uncertainty, variability, and complexity inherent in engineered systems [15,16].

This paper describes a project that addresses these gaps by leveraging a campus-scale AD system that processes up to 600 lb./day of food waste as a living laboratory for exploring a range of scientific and mathematical concepts. The dashboard provides teachers and students access to continuously updated operational data. The overall goal of the project is to engage K-12 students in educational activities that will improve their data literacy skills while simultaneously broadening their awareness of AD as a resource recovery technology. Our multiphase project is guided by the following objectives:

1. Develop a robust, interactive dashboard that displays AD data in real time and stores historic data in a format accessible for exploration and manipulation.
2. Educate teachers, to: (1) Improve their understanding of the AD processes, particularly in the context of eliminating food waste and producing renewable energy; and (2) Introduce them to the interactive dashboard.
3. Develop, implement, and assess classroom instructional modules that use the interactive dashboard and associated data files.

By integrating authentic engineering data, a robust data integrity pipeline, and teacher collaboration, the project offers a replicable model for translating engineering research into classroom-ready resources while preserving features central to professional engineering practice. This work contributes a classroom-ready data pipeline, a teacher-centered co-design model, and early evidence that real-world engineering data supports data literacy and systems thinking.

2 Dashboard Development

We developed an online interactive data visualization dashboard using Microsoft Power Business Intelligence (Power BI) software to transform digester (sensor) data into real-time visuals. The dashboard feeds from **two data sources**: (1) AD sensor records (methane concentration, feeding input, temperature, and biogas output) are stored in **MySQL database**; (2) mass of food waste, chemical oxygen demand (COD), and volatile/total suspended solids (VSS/TSS) are manually entered into a **Google Sheet** that is equipped with data validation rules for quality assurance/quality control (QA/QC) to prevent entry errors.

Dashboard refinement has been iterative. Data glitches caused by power outages and sensor malfunctions highlighted the need to develop a robust data integrity framework. A data processing pipeline was developed to ensure reliable, automated data processing for educational use. The system architecture (Figure 1) enables automated seamless data flow from collection to visualization, producing an up-to-date dashboard without manual handling as follows:

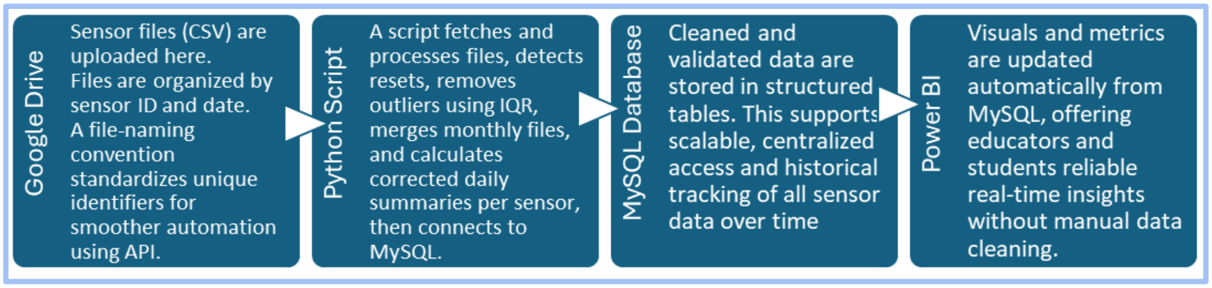

Figure 1: Automated Python–MySQL–Power BI pipeline for processing AD sensor data and updating classroom-ready dashboard visualizations.

Technical outcomes of the pipeline include: (1) automated cleaning and ***outlier removal*** caused by sensor failures; (2) corrected ***power-outage resets*** for cumulative data; and (3) ***daily averages*** for all sensor data.

(1) Daily average (AD) temperatures before and after outlier removal are shown in Figure 2. Spikes caused by sensor failures obscure underlying system behavior (Fig. 2a). Removing the outlier (Fig. 2b) reveals stable and realistic temperature trends.

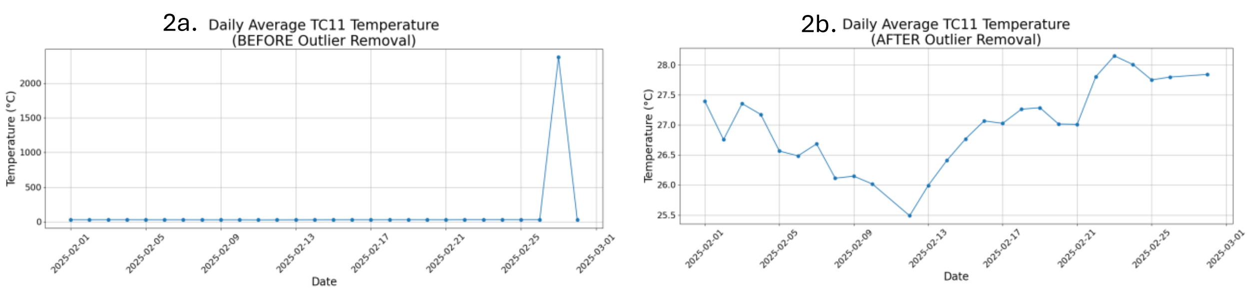

Figure 2: Average daily temperature before (Fig. 2a) and after (Fig. 2b) outlier removal.

(2) Power interruptions create discontinuities in sensor data, introducing artificial drops in data series (Fig. 3a). A code was incorporated to restore continuity by recognizing the artificial drop and resetting the data so the cumulative measures are accurately represented (Fig. 3b).

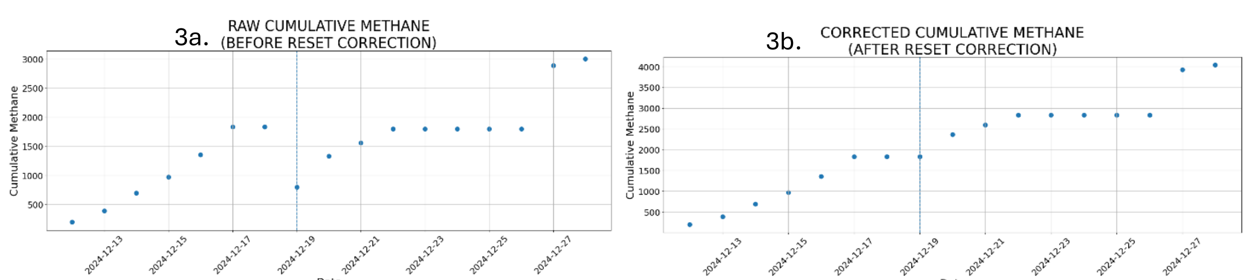

Figure 3: Cumulative methane data before (Fig. 3a) and after (Fig. 3b) reset correction for power outages.

(3) All system data are averaged over common time periods to provide a meaningful and reliable data set for analysis. Depending on the source and frequency of collection, data may be presented as a daily average or a rolling 7-day average for dashboard display. This ensures physical plausibility for the dashboard.

3 Teacher Workshop

The dashboard was introduced early to middle and high school teachers from various STEM disciplines in an all-day professional development workshop. Educators toured the university's campus food digester and learned about the AD system, used dashboard tools to analyze real-time AD data, and discussed curriculum integration opportunities. All participants reported that they intended to use workshop insights and 80% planned to use the dashboard in classrooms - with higher intentions among science and agriculture teachers compared to mathematics instructors. Some teachers indicated that some activities were overly complex for their younger students; as a result, subsequent project phases focused on engaging teachers in the co-development of grade-appropriate instructional materials. Pre-post survey results showed a 67% improvement overall in teachers' knowledge and attitudes toward waste management. Most importantly, the workshop fostered connections between K-12 teachers and the research team, providing opportunities for student field trips, curriculum advice, and continued collaboration.

4 Co-Development of Lessons

Lesson co-development follows a participatory, teacher-centered design approach. Workshop participants were invited to engage with an additional dashboard usage tutorial and provide feedback on dashboard usability, grade-level relevance, preferred activity formats, and barriers to classroom implementation. Two teachers – middle school life science and high school conservation – have fully drafted lessons that align with grade-appropriate learning goals, classroom constraints, and data literacy levels, as summarized in Table 1.

Table 1: Classroom activities and learning outcomes by grade level

Grade	Activity Snapshot	Student Interaction with Data	Learning Outcome
Middle School	Students analyze daily food waste, relate to menus and biogas production to identify input–output relationships	Interpret time-series graphs; compare waste categories; construct simple visualizations	Foundational data literacy; cause–effect reasoning; introduction to renewable energy
High School	Students investigate relationships between waste input and biogas output through guided inquiry	Filter datasets; analyze trends; evaluate correlations using real operational data	Systems thinking; data-driven decision-making; evaluation of sustainability trade-offs

The middle school lessons frame the dashboard as a simplified engineering monitoring system, with students interpreting digestor data to reason about system inputs, outputs, and environmental impacts. The high school lessons extend dashboard use into a multi-day, inquiry-based unit on food waste and sustainability, emphasizing data analysis, interpretation of correlations, trend analysis, evaluation of engineering systems (AD) trade-offs, and connections between data-driven findings, environmental impact, and community awareness. Together the lessons demonstrate how teacher co-development supports grade-appropriate translation of real-time engineering data, enabling progressively deeper engagement with data analysis, systems thinking, and sustainability concepts.

Initial classroom implementation is underway. At the middle school level, approximately 80 students across four grade 5 classes participated in a two-day learning experience consisting of AD tour followed by data-driven classroom activities. Students used the dashboard to collect, analyze, and visualize real operational data from a nearby school's cafeteria food waste treatment program [19, 20, 21], constructing graphs and interpreting relationships between food waste input and biogas production. High school lessons are finalized for delivery later this Spring (2026). The proposed dashboard-based learning workflow summary is shown in Fig. 4.

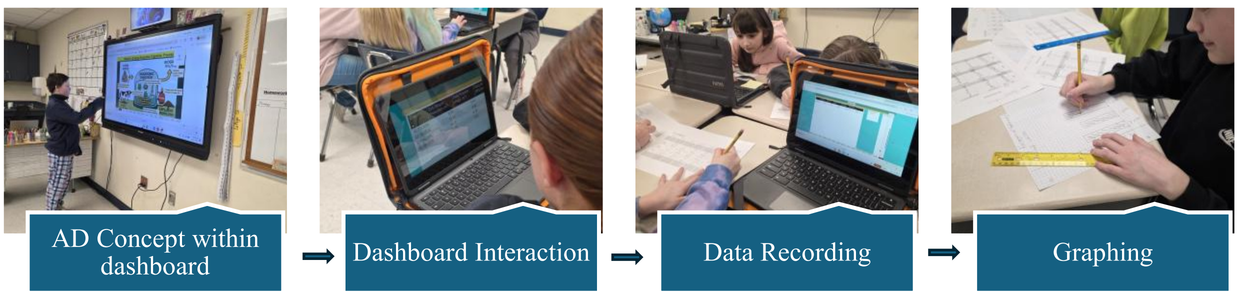

Figure 4. Co-developed lessons' classroom implementation workflow from real-system contextualization to data interpretation. Photos taken during middle school classroom implementation of dashboard-based learning.

Unlike traditional instructional materials that rely on simplified or synthesized datasets, the AD dashboard exposes learners to real-world data variability, encouraging critical interpretation and evidence-based reasoning. Preliminary findings indicate that the dashboard supports teachers' professional learning and classroom instruction by facilitating engagement with real-world engineering data and sustainability concepts. For students, access to real operational data, rare in K-12 contexts, bridges engineering research and classroom abstract learning while supporting the development of data literacy, problem solving, and decision-making skills required to work with complex, unstructured datasets [17]. From an engineering education perspective, the dashboard advances systems thinking and reasoning under real-world conditions by exposing learners to data variability and uncertainty, aligning with calls for authentic problem contexts and professional practices in engineering education alluded to by Huerta-Gómez-Merodio et al. [18].

5. Tentative Conclusions and Future Work

This work presents an ongoing effort to integrate real-world engineering data into K-12 STEM education through an instructional dashboard grounded in a campus-scale AD system. Initial classroom implementation and teacher feedback suggest the dashboard supports sustainability instruction, data literacy, and engineering systems thinking. The teacher-centered co-design process highlights the importance of engaging educators as collaborators to promote meaningful classroom integration and sustained use. The modular dashboard and data pipeline offer scalability to other digestion systems and sustainability-focused contexts. Our presentation will include lesson plan details and dashboard data access via QR code. Future work will expand teacher participation, support broader classroom implementation, and assess student learning outcomes to further evaluate educational impact.

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