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Engagement in Practice: Longitudinal Capstone Design Collaboration for Cleaner Brick Kilns in Bangladesh

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Abstract

The 2025–26 academic year marks the seventh consecutive year of collaboration between Stanford University's mechanical engineering capstone course sequence, the Stanford Woods Institute for the Environment, and Bangladesh University of Engineering and Technology to address the country's severe air pollution caused by coal-fired brick kilns. Brick kilns contribute approximately 11 percent of Bangladesh's annual $PM_{2.5}$ emissions and 17 percent of CO_2 emissions, making them one of the country's largest sources of air pollution [1]. The resulting health impacts are profound, including respiratory illness, increased rates of childhood pneumonia, and an estimated 6,000 premature adult deaths each year [2]. To mitigate these effects, successive student teams have developed and refined an automated coal feeder that allows continuous fuel deposition, improving combustion efficiency and reducing particulate emissions. The multi-year partnership enables continuity of learning and design iteration, as each cohort builds on prior work while addressing new technical and contextual challenges. Over seven years, project phases have included development of a feeder porthole attachment (Year 1), combustion efficiency improvements (Year 2), continuous coal feeding (Year 3), automated feeding (Year 4), reliability and multiport enhancements (Year 5), hopper and agitator redesign for manufacturability (Year 6), and scaling production using locally sourced materials (Year 7). This paper presents lessons learned from implementing a longitudinal capstone model that sustains community partnerships, deepens student engagement, and advances engineering solutions with measurable environmental and social impact.

Introduction

Community engaged learning (or service-learning) enhances student education by linking theory to practice and classrooms to communities [3]. Partnering with community organizations contextualizes engineering, broadens perspectives on who engineers can be and serve, and supports diverse student retention, particularly for those motivated to create impact [4]. Well-structured service-learning fosters deep learning and personal growth and is considered a powerful educational and social intervention tool. Instructors play a key role in developing partnerships in engineering community engaged courses. Eby acknowledges that "individual faculty often carry the additional workload and cost of incorporating community partners into courses," often with minimal institutional support [5]. Campus centers for public service can therefore provide essential resources to sustain these efforts.

Mechanical Engineering Design: Integrating Context with Engineering (ME 170) is the capstone for Stanford University's mechanical engineering BS program and immerses students in a team-based engineering design challenge working in teams of four. Projects tackle societal issues such as energy, food security, transportation, and health. Over two quarters, students iteratively define needs, establish design requirements, prototype, test, and refine solutions, gaining skills in design, teamwork, project management, and ethical evaluation [6]. Funding comes from industry affiliates and community-engaged learning grants provided through the Haas Center for Public Service, with each team guided by an experienced project coach.

Project background

Air pollution is a major contributor to global mortality, with fine particulate matter ($PM_{2.5}$) strongly associated with respiratory and cardiovascular disease [7]. These particles penetrate deep into the lungs and bloodstream, leading to chronic inflammation and increased risks of pneumonia, heart disease, stroke, premature birth, and early-onset respiratory illness [8]. In Bangladesh, exposure to $PM_{2.5}$ is particularly acute during the dry season, when atmospheric conditions and industrial activity combine to produce sustained periods of unhealthy air quality.

Greater Dhaka, a metropolitan region of over 10 million people and one of the most densely populated urban areas in the world, consistently experiences elevated particulate concentrations during the winter months. Air quality index values frequently exceed thresholds considered unhealthy for all populations between November and February. A significant fraction of this seasonal pollution is attributable to brick production, which intensifies during the dry season to meet construction demand [9].

Coal-fired brick kilns account for nearly 60% of black carbon emissions in Bangladesh, with approximately 8,500 kilns operating nationwide. The predominant zig-zag kiln design uses intermittent manual feeding of coal into a moving combustion zone, a practice that limits oxygen availability and leads to incomplete combustion. As a result, zig-zag kilns contribute an estimated 30–50% of ambient $PM_{2.5}$ concentrations in nearby urban areas during operation, while also consuming more coal than is required for efficient firing [10]. Although alternative kiln designs can reduce emissions, their higher capital costs and production constraints have limited widespread adoption [10].

Project partner background

Stanford Woods Institute for the Environment. The mission of the Woods Institute is to advance global sustainability through new knowledge and practical, fair solutions to pressing environmental challenges [11]. The Institute serves as the university's hub for interdisciplinary research about the environment, bringing together faculty, researchers and students to foster collaborations that can tackle challenges too complex for any one discipline to solve alone.

Stephen Luby. Dr. Stephen Luby is a physician, researcher, and educator and a Senior Fellow at the Woods Institute. With a focus on brick kiln operations in Bangladesh, Dr. Luby's team has shown that relatively simple operational changes—such as improved brick stacking, airflow management, insulation, and more consistent fuel feeding practices—can significantly reduce coal consumption, particulate emissions, and greenhouse gases while improving brick quality and lowering costs for kiln owners. Dr. Luby has partnered with ME 170 faculty and students over the last seven years to advance the design of automated coal feeder (ACF) systems.

Bangladesh University of Engineering and Technology (BUET). The Woods Institute has engaged in sustained, interdisciplinary research on air pollution from brick kilns in Bangladesh, collaborating closely with BUET. As part of efforts to reduce emissions from traditional coal-fired brick production, Stanford engineers and BUET researchers have jointly developed and prototyped technical interventions—such as automated coal feeders designed to improve combustion efficiency and lower black carbon emissions. BUET engineers build and test these prototypes alongside Stanford teams in field trials on operational brick kilns, helping refine designs that address local operational challenges, collaborating closely with ME 170 students.

Project continuity

While continuity/longevity was not initially a designed instructional feature, intentional handoffs, documentation norms, and faculty stewardship across cohorts have proved to be valuable learning tools. Each capstone team develops specific parameters for future work as part of their final deliverables. In parallel, the teaching team works with the Woods Institute and the Haas Center for Public Service to identify opportunities for students to continue their work through independent projects and after graduation. This has resulted in concrete opportunities for students wishing to remain engaged and allowed the teaching team to remain in close contact with the Woods Institute, with visibility into project progress and opportunities for student teams in the next class cycle. Table 1 provides details of the project progression. Figure 1 shows the evolution of a specific feature, the coal agitator.

Table 1: Brick Kiln Project Evolution

Year/Project/Team	Project Summary
Year 1: Feeder Porthole Attachment (2019-20) *Team Name: Brick and Morty*	The Year 1 team sought to improve combustion efficiency and reduce emissions through a porthole attachment that integrates a funnel and diffuser to regulate the feed rate and promote more uniform coal dispersion, reducing overall coal consumption. Constructed from sheet metal, the attachment was designed to be simple to manufacture, durable under high kiln temperatures and repeated handling, and easy to retrofit onto existing kilns. The final design achieved improved spatial uniformity of coal distribution across the brick stacking formation.
Year 2: Automated Feeding Device (2020-21) [12] *Team Name: Kil'n It*	Extreme heat and physical demands limit the feasibility of continuous manual feeding. The Year 2 team addressed this challenge by developing an automated coal-feeding (ACF) system. The design repurposed a cut oil drum supported on stacked bricks, with a chain-driven wheel mounted to the underside. Coal enters the system through a hopper opening and fills discrete pockets in the rotating wheel; as the wheel turns, coal is released through an offset discharge hole. The system supported a range of feed rates, operating autonomously for 48 hours.
Year 3: Continuous Coal Feeding (2021-22) *Team Name: Kilnadegga Nights*	Intermittent porthole feeding leads to incomplete burning. Continuous feeding can improve combustion efficiency. Building on the Year 2 ACF, students focused on motor performance, reliability, and deployability. The team conducted motor characterization and testing to optimize power consumption and extend battery life. The team designed and evaluated an alternative rotary valve feeding mechanism, reducing material costs via a single custom-cast component, and developed a transport cart to move the feeder between kiln portholes.

Year 4: Integrated Coal Agitator (2022-23) [13] *Team Name: License to Kiln*	The Year 4 team addressed the fact that the ACF did not account for the use of damp coal, unavoidable in brick kilns. To ensure reliability under real-world conditions, the team integrated an internal rotation mechanism with the Year 3 team's rotary feed wheel, designed to agitate the coal and prevent clog formation. Testing demonstrated that the internal rotation system effectively disrupted clogs and maintained a consistent coal output without motor stalling.
Year 5 Team 1: ACF Reliability (2023-24) [14] *Team Name: Ace in the Coal*	The first Year 5 team designed structural and mechanical upgrades. A redesigned housing carried the coal load while protecting internal components and reducing stress on rotary elements. A modular "sandwich mechanism" housed the motor, wheels, and plates, with a six-hole feed wheel metering coal into the kiln. A funnel fan and tapered feed inserts enabled consistent declogging. Testing identified motor current variability and a possible negative correlation between coal moisture and feed rate as areas for future improvement.
Year 5 Team 2: Multiport Enhancements and Portability (2023-24) [15] *Team Name: Team Friendship*	The second Year 5 team advanced the feasibility of automatic coal feeding through two key innovations: enabling a single ACF to serve multiple portholes and enhancing ACF mobility so workers can easily reposition and deploy units as the firing zone migrates around the kiln. The design emphasized manufacturability and repairability, relying on simple fabrication methods and readily available material.
Year 6 Team 1: Hopper and Agitator Redesign for Manufacturability (2024-25) *Team Name: CLAir*	The first Year 6 team focused on manufacturability/durability barriers to large-scale ACF adoption. Key design modifications included redesigning the hopper to reduce weight and part count while preserving structural integrity, and developing fixtures to maintain shaft alignment and stabilize the sandwich mechanism despite material and process variability. The ACF delivered a consistent coal feed while keeping torque and power consumption within acceptable limits. The team produced detailed manufacturing and assembly documentation to support scalable production.
Year 6 Team 2: Clog Prevention (2024-25) [16] *Team Name: Coal-a-Bunga*	Coal contains up to 15% moisture. This "wet coal" causes inefficient combustion and harmful emissions. Previous ACF designs performed well with dry coal but clogged when using wet coal. The second Year 6 team addressed clogging in the hopper and sandwich mechanism through a redesigned agitator blade, enlarged inlet holes, and brass-drafted inserts to reduce adhesion. Testing eliminated clogging for the first time while successfully dispensing 15% moisture coal at targeted feed rates.
Year 7: Local Production at Sales (2025-26) *Team Name: Soot Sayers*	The Year 7 team was tasked with further DFM and cost improvements with the goal of manually building 100 ACF units in Bangladesh. Efforts focused on redesign of the motor mount and angled inserts in the bottom feed plate and transition from a sprocket to a square drive connection.

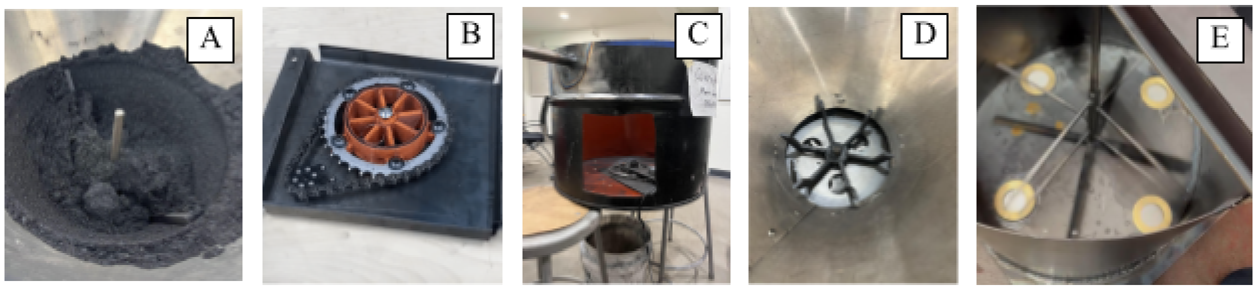

Figure 1: Evolution of the coal agitator design

A: Coal dampness causes buildup on the sides of the coal feeder

B: A sprocket-chain assembly is sandwiched between two steel plates. Coal is fed into an opening on the top plate, then through a rotary feed wheel before being dispensed through an exit hole on the bottom plate (Year 2)

C: Integration of an internal rotation mechanism with the rotary feed wheel, designed to agitate the coal and prevent clog formation (Year 4)

D: Agitator with fan blades extending along the edge of the feeder funnel (Year 5)

E: Angled brass inserts in the rotating plates and further agitator redesign (Year 6)

Example design approach: Year 4 Integrated Coal Agitator

ME 170 student teams follow a structured engineering design process that involves conducting a needs assessment with the partner liaison to understand functional requirements; brainstorming potential solutions, including sketches and concept models; prototyping and iterating on designs; and testing to ensure feasibility using simulated kiln and coal conditions. Student teams develop a set of high priority user requirements, which translate into associated engineering requirements. Table 2 shows a sample of these requirements from the Year 4 project.

Table 2: High Priority User and Engineering Requirements, Year 4 Integrated Coal Agitator

User Requirement		Engineering Requirement	
UR 1-1	Device can be fabricated with one motor and local materials and processes	ER1-1	Use common parts that do not require special ordering. Most construction companies in Bangladesh use reinforcing steel, or MS rods, in major construction. Use batteries from motorcycles and gears which are readily available.
UR2-1	Mechanism should allow for variable power controls so that the firemen can dispense coal at a reliable rate.	ER2-1a	The device must maintain a steady coal feed rate within a tolerance of 15% of the expected rate.
		ER2-1b	The attainable feed rates of the device covers a range of least 0.5 g/s to 2 g/s.
UR3-1	Device should run a full day without requiring maintenance	UR3-1a	The device must have enough power to sustain at least six hours of run time

		UR3-1b	The device does not clog or need additional maintenance over six hours of continuous use
UR3-2	The device should function in high-temperature environments	ER3-2	The device must withstand temperatures of 200°C, which is above the expected temperature of 127°C at the kiln surface

Contributions to research

This longitudinal collaboration between the Woods Institute and ME 170 has enabled meaningful contributions to research on air pollution mitigation from brick kilns in Bangladesh, while simultaneously serving as a structured educational platform for mechanical engineering students. Through sustained partnership with the Woods Institute and BUET, capstone teams have produced design knowledge, experimental results, and manufacturable artifacts that extend beyond the scope of a single academic term and directly inform ongoing research efforts.

A primary research contribution lies in the progressive refinement of an automated coal feeder under real-world operating constraints. Successive student teams systematically addressed increasingly realistic challenges—including thermal exposure, limited power availability, variable coal size, and high moisture content—generating empirical insights into coal flow behavior, clogging mechanisms, and torque requirements that are difficult to obtain through short-term or laboratory-only studies. By testing prototypes under simulated and field-representative conditions, students produced validated design modifications that informed subsequent iterations and reduced technical risk for future field deployment.

Beyond individual design advances, the longitudinal structure of the capstone sequence enabled a shift from proof-of-concept engineering to questions of reliability, manufacturability, and scalability, which are central to translational research. Later cohorts focused on design-for-manufacturing, part count reduction, tolerance robustness, and alignment fixtures, producing detailed documentation and tooling concepts suitable for local fabrication in Bangladesh. These efforts contributed not only physical prototypes, but also process knowledge that supports scaling production using locally available materials and skills. In this way, the capstone partnership functions as a sustained R&D pipeline, advancing the Woods Institute's broader agenda to develop practical, low-cost interventions capable of reducing emissions from informal industrial systems.

Conclusion

Several insights have emerged from implementing a longitudinal, community-engaged capstone model focused on cleaner brick kiln technologies:

- *Continuity enables technical maturation*. Complex engineering challenges in informal, resource-constrained settings rarely yield deployable solutions within a single academic cycle. Multi-year continuity allowed student teams to move beyond conceptual performance toward reliability, manufacturability, and scaling considerations that mirror real-world engineering practice.

- *Explicit handoff structures are essential*. Design progress depended on clear documentation, test data archiving, and forward-looking recommendations from each cohort. Without intentional scaffolding for knowledge transfer, longitudinal gains would have been significantly diminished.
- *Local constraints must drive design priorities*. Engagement with partners in Bangladesh revealed that factors such as wet coal, fabrication variability, repairability, and worker practices were as critical as nominal performance metrics. Designs that ignore these constraints can perform well in theory, but fail under realistic conditions.
- *Educational timelines shape research pace*. While the cadence of capstone courses limits the speed of iteration, it also encourages deliberate design decisions, reflection, and validation. Aligning partner expectations with academic timelines was critical to maintaining trust and productive collaboration.
- *Institutional support sustains engagement*. Long-term success depended on coordination among course instructors, the Woods Institute, and campus service-learning infrastructure. This support reduced the burden on individual faculty and enabled partnerships to persist beyond single projects or personnel changes.

These insights suggest that longitudinal capstone partnerships can serve as effective vehicles for advancing applied engineering research—particularly when problems are persistent, partners are treated as co-designers, and institutional structures support continuity across student cohorts.

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