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# Outreach Design Education: Engineering Design Collaboration with Middle and High School Teachers (Evaluation of Program/Curriculum -or- Pre-college Resource/Curriculum Exchange)

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## INTRODUCTION

Since the release of the *Framework for K–12 Science Education* (NRC, 2012), engineering has become a central component of U.S. science education. When thoughtfully integrated, engineering design can deepen students' engagement with and understanding of core science ideas (Purzer & Quintana-Cifuentes, 2019; Siverling et al., 2019) and is positioned in the NGSS as a disciplinary practice on par with scientific inquiry (NGSS Lead States, 2013). With most states adopting the NGSS or NGSS-aligned standards (Neill & Paulson, 2023), K–12 science teachers are increasingly responsible for incorporating engineering design into their instruction.

Despite broad support for the NGSS, many teachers report limited preparation for implementing inquiry-driven, engineering-focused instruction and express a need for targeted professional development (Haag & Megowan, 2015; Harris et al., 2017; Margot & Kettler, 2019). Recent studies continue to highlight gaps in teachers' engineering knowledge, confidence, and pedagogical readiness, underscoring the need for sustained, high-quality PD to support engineering integration in STEM classrooms (Ozkizilcik & Cebesoy, 2024; Zhumabay et al., 2024; Christian, Kelly, & Bugallo, 2021; Crawford, Obenland, & Nichol, 2021.)

The Outreach Design Education (ODE) program addresses this need by providing an intensive professional development experience that helps middle and high school STEM teachers design and implement engaging engineering learning opportunities (Kyle et al., 2018; Kyle et al., 2022). ODE's summer program serves as a co-learning environment where teachers participate alongside students in engineering design challenges, learn an engineering-focused pedagogical model, and collaboratively develop curricular materials tailored to their contexts. Teachers then implement these materials during the subsequent academic year.

This paper presents two courses developed through ODE collaborations with one middle-school and one high-school STEM teacher. The first is a **content-integrated course** in which engineering design is used as a pedagogical framework to support science learning through inquiry-based, hands-on projects. The second, **pure design course**, is a stand-alone engineering design course focused on developing students' understanding and application of the engineering design process (EDP). Our goals are to:

I. Demonstrate how engineering design can be meaningfully integrated into secondary STEM curricula; and
II. Provide guidance for educators seeking to develop and implement high-school engineering design instruction.

## METHODS

### *Professional Development*

Four (4) local teachers took part in a five-week professional development program via the ODE Summer Design Camp. From 10am to 4pm on Monday through Thursday of each week, the teachers observed, supported, and learned alongside the high school students attending the summer design program (details of this process found in previous publication from this work, (Kyle et al., 2018). On Fridays, the teachers met with the program leaders to develop engineering design-centric educational content for their classes. During these semi-structured sessions, program leaders provided guidance and feedback that helped the teachers apply engineering design practices and ideas in ways that supported the needs of their individual courses. The Friday workshops typically followed the schedule:

1. ***Re-Visiting Engineering Design Concepts (30 – 60 minutes)***: We reviewed the engineering design content introduced in the preceding week of the ODE Summer Design Camp. These intro sessions were meant to examine the teachers' interpretation and understanding of the engineering design process (EDP.) We reviewed instructional materials and examined the summer camp students' work to enhance their understanding of how the EDP should be executed.
2. ***EDP Classroom Inclusion Considerations (30 – 60 minutes)***: During this time, we brainstorm with teachers on how the EDP can be included in their lessons. We consider how, when, where, and why the engineering design content should be taught in their classrooms.
3. ***EDP Instructional Material Development (60 – 120 minutes)***: Teachers develop engineering design instructional content for their classes. We largely defer to the teachers' expertise and instructional goals during this period; providing support where needed. Teachers are also encouraged to collaborate with each other, providing suggestions for content development. For example, this cohort had two high school chemistry teachers with similarities in their course goals and students. These two teachers worked with each other to refine their understanding of design and identifying spots in their existing curriculum where the EDP could be included: eventually leading both of them to adopt content-integrated EDP instruction. As the Summer Design Camp progresses, we introduce less engineering design instruction. This affords the teachers additional time during the week to develop materials along with the Friday efforts.

The major features of the summer PD intervention are:

1. **Duration**: Teachers participated in the PD for approximately 125 hours over 5 weeks.
2. **Active learning environment**: Teachers participated in the same activities as the summer students (Kyle et al., 2018; Kyle et al., 2022). This gave them opportunities to practice their new knowledge and skills and gain an appreciation for the student experience. For our high school teacher partners, it also afforded the opportunities to share prospective lessons and get feedback from students who might be comparable to those in their classes.
3. **Modeling**: Teachers observed engineering pedagogy from expert, university-level engineering instructors.
4. **Collaborative curriculum design**: While each teacher was tasked with creating their own engineering-based curricular materials, they had the opportunity to review each other's work, share ideas, collaborate on common materials, and provide each other support as they learned and applied engineering design.

These practices are in alignment with other effective models for engineering professional development and teacher self-efficacy in engineering instruction (Zhumabay et al., 2024; Crawford, Obenland & Nichol, 2021.) The courses' specific content is outlined in the **RESULTS** section.

### *Course Implementation*

Participating teachers implemented the engineering education materials they created during the subsequent academic year. ODE provided financial and instructional support during implementation.

Each teacher received $1,000 to purchase materials for their course. These material purchases covered items such as small-scale electronic supplies, Arduino microcontrollers, textiles, low fidelity prototyping materials, 3-D printers and other items as needed. ODE also provided in-classroom instructional support throughout each course. For the teachers discussed in this paper, we hired a graduate student class assistant who regularly joined the engineering design classes to provide instructional and technical aid for the classes in progression.

### *Assessment and Evaluation*

We evaluated the impact of engineering design instruction on teachers who participated in the Summer Design Camp and their resultant courses. We propose that effective professional development efforts with teachers will result in high quality classroom instruction, increasing student learning. The teacher assessments focused on their engineering design process knowledge and their confidence in teaching it to students. The teachers were assessed through three interviews: a pre-program interview one week before the start of the Camp, a post-program interview at the conclusion of the Camp, and a post-course interview at the conclusion of the academic year. The first two interviews assessed their knowledge of engineering design and their confidence in teaching the engineering design process to students because of the summer PD. The post-course interviews allowed them to reflect on their experiences in learning the EDP, developing content for their classes, and how effective they were in teaching this novel content to their students. Participation in the research was voluntary for teachers; they could join the Camp without participating in the study.

The students were assessed through pre- and post-course surveys and informally assessed via regular observations of the course in progress. The surveys measured students' self-reported attitudes and beliefs about engineering. The survey items were adapted from the PEAR Institute's Common Instrument Suite tool (The PEAR Institute, 2017). Pre- and post-course responses were compared using a Wilcoxon Signed-Rank Test ($\alpha$ = 0.05). Participation in research was completely voluntary for students and students who elected not to participate in the studies were still able to receive engineering design instruction.

The surveys and interviews were administered by ODE's assessment and evaluation partner, Education Development Center. This study was done with approval from Durham Public Schools Office of Research and Accountability and EDC's IRB (Protocol #2242.)

### *Participants*

Four (4) teachers participated in this cohort of ODE-based engineering curriculum development. This article will focus on two of the teachers' experiences and resultant courses. One of the teachers is a middle school Physical Science teacher. The other is a high school chemistry teacher. Both teachers are at Title I high schools in Durham Public Schools (DPS), North Carolina. DPS is a majority-minority district with over 80% of students identifying as a racial minority. Thus, it is reasonable to assume that students underrepresented in STEM would receive unique instruction from the content that we co-developed. Both teachers had 10+ years of classroom experience and had previously participated in STEM professional development but had not had any engineering design training or experience. We also found that our program was unique for the participating teachers because they typically developed course materials alone, not in coordination with their colleagues. The teachers were motivated to participate in this program in large part to bring engineering design to their students, giving them more real-world appreciation for STEM and stimulating further pursuit of STEM topics. The teachers will be referred to as MST and HST from this point forward to preserve their anonymity and confidentiality.

## FINDINGS

### *Overview of Courses*

In both courses, teachers engaged students in core elements of the EDP: identifying and defining authentic problems, establishing criteria for successful solutions, and iteratively designing, building, and testing prototypes. Each curriculum emphasized hands-on investigation, student-driven inquiry, and collaborative problem solving. Although grounded in the same design principles, the two courses pursued different instructional goals, leading to distinct models of engineering design integration (Figure 1).

HST's **content-integrated course** incorporated engineering design concepts and practices into an existing advanced chemistry course. Students applied design thinking within a module titled *Pill Perfection*, in which teams created devices capable of performing measurements for a simulated drug-delivery system. Engineering served as a vehicle for deepening understanding of chemical principles while giving students structured opportunities to engage in design reasoning.

MST's **pure design course** embedded a stand-alone engineering design project within a physical science course. In the *Design a Hygiene Machine* challenge, students investigated user needs related to maintaining a nearby restroom and developed prototype solutions. As part of the project, students were required to build an Arduino-controlled device that addressed their identified problem. The course culminated in a prototype demonstration and a mini-poster presentation articulating each team's design rationale and solution.

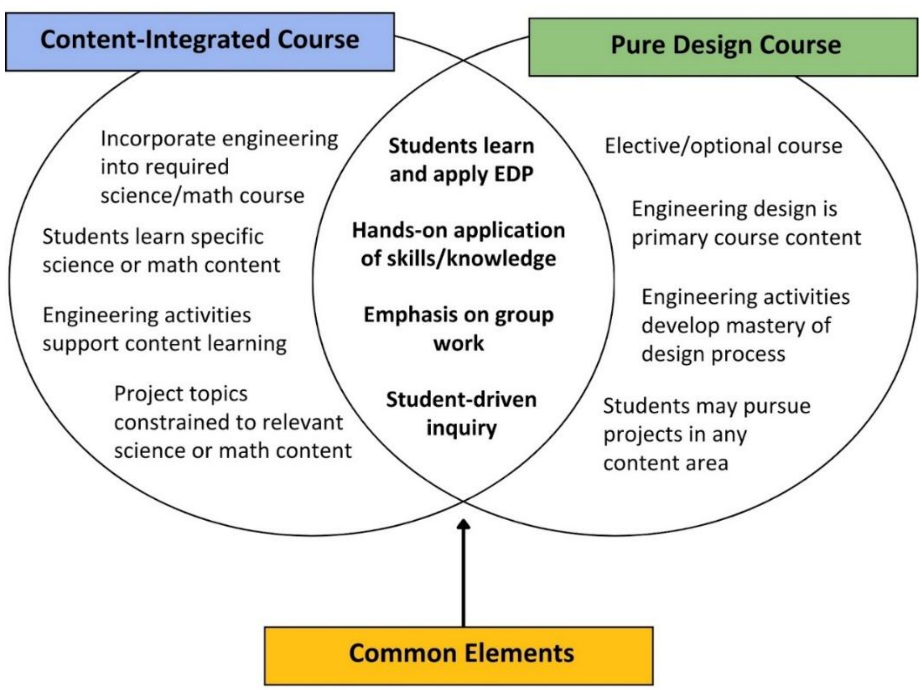


*Figure 1 Venn diagram of the common and unique aspects of the Content Integrated vs Pure Design Course models of EDP instruction in middle and high school classrooms.*

The utilization of the content-integrated vs. pure design model was informed by the teachers and their course goals. Pedagogically, both approaches introduce students to the EDP, ensuring that students in either model learn about design and apply the process, albeit in different contexts. The choice to incorporate design within existing instruction versus implementing a full design project was largely shaped by course constraints. HST had a more rigid schedule and set of expectations due to teaching a high-school-level chemistry course, making the content-integrated model the most feasible option for embedding engineering design within an existing unit. MST, by contrast, had a more open-ended project in mind and wanted to use the EDP to provide structure for students' work. This informed their adoption of the pure design course model.

Although the two teachers implemented engineering design in different ways, their courses highlight complementary pathways for integrating the EDP into secondary STEM instruction. The content-integrated model demonstrates how engineering design can deepen disciplinary learning within a tightly structured course, while the pure design model shows how the EDP can provide coherence and purpose within a more flexible project-based environment. These contrasting implementations illustrate how course constraints, teacher goals, and curricular structures shape the choice of design-integration strategy.

### *Content-Integrated Course – Structure and Content*

HST implemented engineering design through a novel module focused on hydrogel-based drug delivery, using the context of pill and capsule drug delivery through the digestive tract. The module introduced students to foundational concepts in pharmacokinetics and guided them in creating alginate hydrogel beads capable of diffusively releasing a model "drug" into a surrounding liquid environment. To support data-driven design iteration, the module also incorporated instruction in Arduino microcontrollers, which students used to automate measurements of temperature and pH conditions experienced by their hydrogel vehicles. In combination, the module integrated disciplinary science content, engineering design reasoning, and technical skill development in microcontroller programming. The objectives of the module are to:

1. Learn the principles of drug delivery systems and their importance for Crohn's disease patients.
2. Learn about material properties and their applications in pill coatings.
3. Apply the concept of acids and bases in simulating the digestive system environment.
4. Design an Arduino-based monitoring system to detect the temperature and pH of the hydrogel delivery system
5. Develop and refine engineering solutions based on experimental data.

In addition to adhering to North Carolina Standards for Chemistry education, the module was designed to align with the NGSS:

**HS-PS1-5**: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
**HS-ETS1-2**: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
**HS-ETS1-1**: Define a problem and use design thinking to solve it.

The Pill Perfection module was taught over the span of 11 fifty-five minute class periods as outlined in Table 1.

*Table 1 Pill Perfection Module Schedule*

| Days | Topic and Activities |
|---|---|
| 1 – 3 | • Introduction to the fundamental concepts of pharmacokinetics<br>• Overview of Crohn's disease, its symptoms, and why effective drug delivery is critical for treatment<br>• Case study of a Crohn's disease patient<br>• Problem definition and needs statement |
| 4 – 5 | • Hydrogel prototyping, using external gelation to create alginate vehicles<br>• Strategies for creating vehicles of varying size or release profiles |
| 6-8 | • Intro to Arduino, basic electronics and circuitry<br>• Arduino sensing: temperature & pH<br>• Feedback controls, creating alerts from sensors |
| 9-10 | • Expose hydrogel vehicles to temperature and pH conditions to simulate digestive tract<br>• Use developed instrumentation to measure conditions<br>• Quantify release from alginate vehicles |
| 11 | • Students present tests, data, and conclusions |

The engineering design challenges centered on two interconnected tasks: (1) developing an Arduino-based temperature and pH monitoring system capable of characterizing the hydrogel environment, and (2) engineering hydrogel vehicles that could withstand and perform effectively under varying digestive conditions. Together, these challenges required students to integrate scientific understanding, design iteration, and empirical testing, mirroring authentic engineering practice (Figure 2.)

*Figure 2 Students in HST Pill Perfection module working on (l) Arduino-based sensing of pH and temperature and (r) fabricating alginate vehicles for drug delivery*

### ***Content-Integrated Course – Results***

Sixteen (16) students in grades 10–12 from HST's class completed both the pre- and post-surveys. The sample reflected substantial demographic diversity: 50% identified as female, 37.5% as male, and 12.5% as non-binary or preferred not to say. Racial and ethnic identifications were not mutually exclusive; 69% of students identified as African American/Black, 44% as Hispanic/Latino, and 12.5% each as Asian/Asian American and White/Caucasian. Smaller proportions (6.25%) identified as American Indian/Native American, Caribbean Islander, Middle Eastern/Arab, or Native Hawaiian/Pacific Islander. One quarter of students reported speaking a language other than English at home. Most students had taken honors-level science courses—particularly chemistry—prior to the module, though only 25% reported prior experience with a science or engineering project, and only two students had taken an engineering design course.

Across survey subscales, students demonstrated modest increases in their self-reported understanding of engineering and the engineering design process. The most notable gains occurred in students' perceptions of what engineers do, with statistically significant improvement in recognizing engineering as varied, creative, and collaborative. Changes in engineering interest, enjoyment, and academic intentions were smaller and more variable, with some items increasing and others remaining stable or decreasing slightly (Figure 3.) These patterns suggest that while the module effectively expanded students' conceptual understanding of engineering, its influence on longer-term interest or career intentions was less consistent.

Post-course feedback indicated generally positive perceptions of the instructional experience. A slight majority of students (53.3%) reported being totally or somewhat satisfied with the unit, describing the hands-on experiments as engaging and informative (Figure 4.) These students highlighted opportunities to participate actively in the engineering design process and reported gaining new knowledge throughout the project. Students who were neutral or only somewhat satisfied often cited challenges in understanding the underlying science, feeling that they were following procedures without fully grasping the concepts. Some also noted frustrations with group dynamics or the pacing of the activities. Despite these concerns, most students still described the experience as informative and appreciated the practical engagement the unit provided.

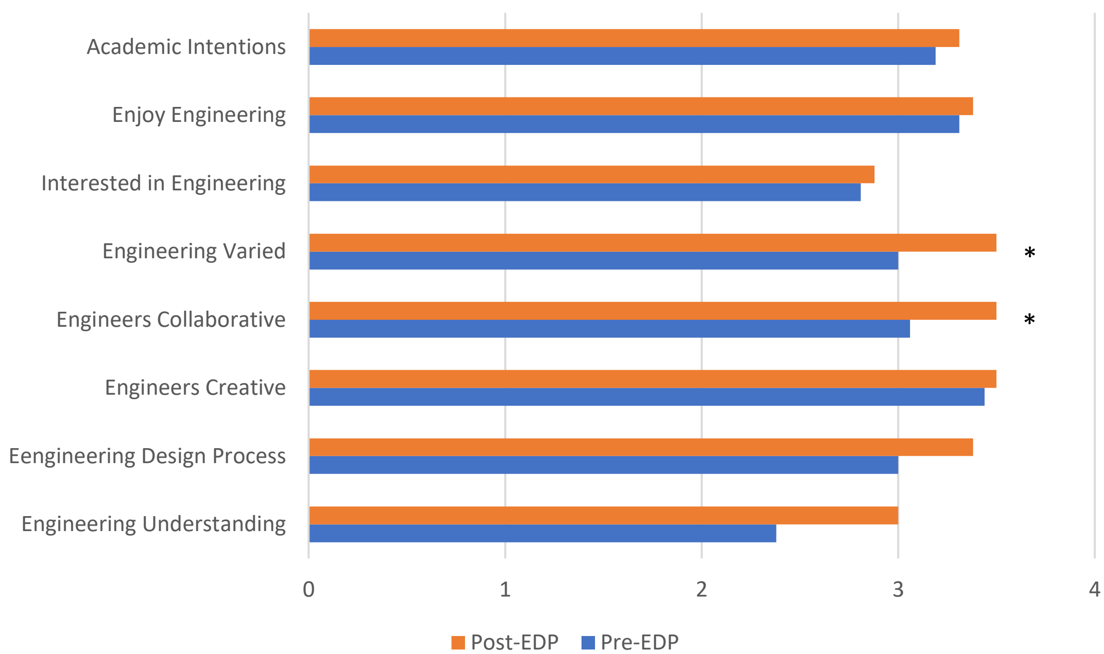


*Figure 3 . Comparison of average pre- and post-course student responses to the Engineering Attitudes and Beliefs survey in HST's class. Response key: "strongly disagree" (1), "disagree" (2), "agree" (3), and "strongly agree"(4). p<.05; n = 16.*

Students' reflections on learning gains relative to other course units were similarly mixed but leaned positively. A majority (57.1%) reported learning more than in other units, while 35.7% reported learning about the same amount (Figure 4.) Students who felt they learned more emphasized the clarity of instruction and the value of integrating coding, chemistry, and applying these concepts in the hydrogel project. Those who felt they learned the same or less noted that the unit focused more on experimental procedures than on deeper conceptual explanations. Overall, the survey results indicate that the module supported meaningful learning for many students while also revealing areas where additional instructional support may enhance future iterations.

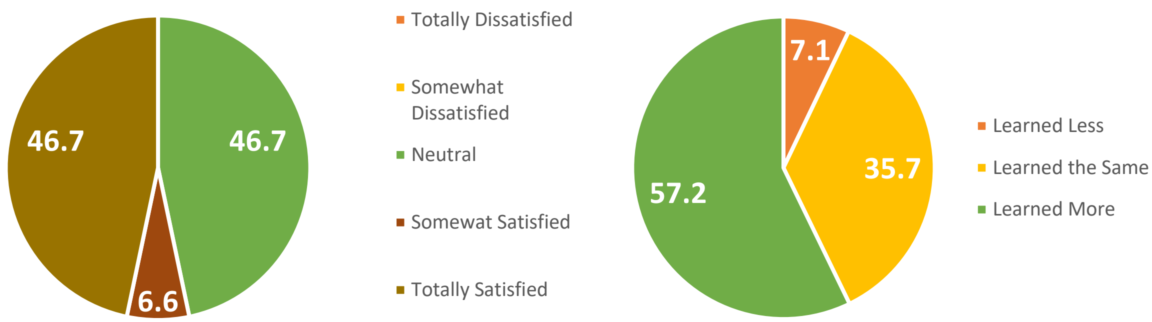


*Figure 4 (l) Student satisfaction with HST's course and (r) student perceived amount learned compared to other courses*

### *Pure Design Course – Structure and Content*

MST created a design project within their physical science course. They wanted to use engineering design to provide a framework for students to uncover project needs, giving them more ownership over the projects and guidance as they developed solutions. The students were working on a unit focused on basic mechanics and simple and compound machines. To reinforce these concepts, the students had to solve a problem related to the hygiene and maintenance of a restroom near their classroom using a simple mechanical design. The students were also introduced to Arduino microcontrollers for the sensing and actuation of machines.

The objectives for the bathroom hygiene project were to:

1. Introduce students to the EDP and have them use it to uncover and solve bathroom hygiene problems,
2. Apply compound machine concepts,
3. Understand the importance of accessible hygiene products in public schools,
4. Demonstrate how engineering design can be used to develop real world solutions

MST developed these lessons to align with the NC Department of Public Instruction standards related to understanding energy transfer and investigations into simple machines. The lessons meet NGSS middle school standards:

**MS-ETS1-1**: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

**MS-ETS1-2**: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MST lessons were administered to a broad set of students: three (3) sections of 7$^{th}$ graders with 24 – 30 students per section. The project was administered over 16 fifty-five-minute lessons as outlined in

Table 2.

*Table 2 Design a Hygiene Machine Module Schedule*

| DAY(S) | TOPICS AND ACTIVITIES |
|---|---|
| 1-2 | • Introduction to simple and compound machines |
| 2-3 | • Introduction to the EDP<br>• Conduct bathroom tours to observe the conditions and identify specific problems |
| 4-6 | • Define problems based on observations<br>• Arduino training (basic programming, acquisition of signals from sensors, feedback controls.) MST used a version of the lessons that were developed with HST. |
| 7 - 8 | • Select a problem. Students work in teams of two on projects.<br>• Learn more about the problem, mostly through Google-based research |
| 9 – 11 | • Ideate solutions through brainstorming<br>• Collate ideas and begin searching for a machine that can do what they propose |
| 11 - 15 | • Plan and design a machine to address the problem. Plans involve the creation of an idea sketch, detailing the parts and processes of the machine.<br>• Build and test Arduino-based solutions to problems. |
| 16 | • Students present project outcomes with mini-posters, short talks and project demos |

MST asked their students to apply the design process to restroom-related challenges that typically involved over- or under-dispensing of products such as paper towels or toilet paper, alerting staff when hygiene supplies were depleted, easing or automating the refilling of supplies, or improving the accessibility and organization of hygiene products. These problem spaces were selected to align with needs identified during restroom observations and because the instructors had an *a priori* sense of how they could be addressed using Arduino-controlled mechanisms.

Once needs were identified, students moved into Arduino skills development and early-stage ideation to generate potential solutions. MST encouraged the class to sketch various ideas, forming initial visions of how their ideas might translate into solutions. They created prototype versions of their devices by integrating low-fidelity materials with Arduino controllers and sensor systems. The project culminated in a mini design symposium where student teams presented their identified needs and prototype solutions.

An example project outcome is displayed in Figure 5. This pair of students focused their project on the depletion of paper towels in the restroom. Because of the limited custodial staff at their school, paper towels could be exhausted without anyone noticing when the rolls needed replacement. After defining this need, the team devised an optical detection system to monitor roll depletion. In the Arduino lessons, MST showed them how a combination of an LED source and a photoresistor circuit could be used to detect changes in a light path. The students created a prototype that housed a roll of paper towels with the LED–photoresistor pair positioned so that, as the roll was depleted, light would strike the photoresistor and increase the voltage sensed by the Arduino. They produced control code that triggered video and audio alerts when the roll became low, notifying staff of the need for replacement. The author of this manuscript visited the students' final presentations and observed firsthand the successful execution of the projects and the students' ability to clearly convey their work.

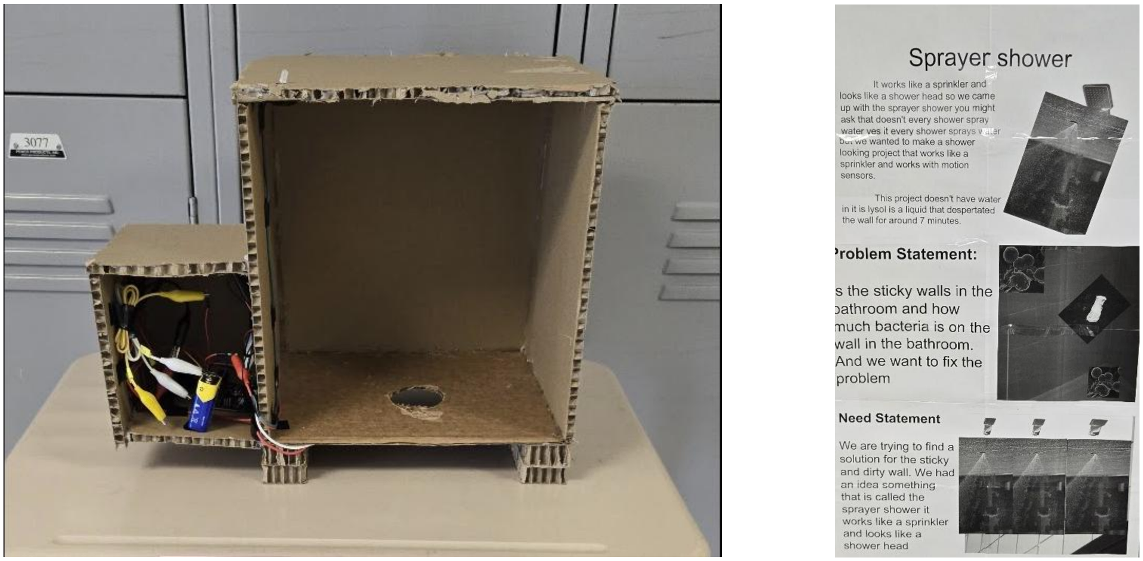


*Figure 5 (l) Paper towel depletion alert system and (r) sample poster from 7th grade students' "Design a Hygiene Machine"" projects*

### ***Pure Design Course – Results***

Twenty-five seventh-grade students from MST completed both the pre- and post-surveys. Nearly half of these students (46%) reported speaking a language other than English at home, and the gender distribution was 56% male and 44% female. Students entered the module with generally positive attitudes toward engineering, reflected in relatively high baseline scores across several subscales. Despite this relatively high baseline, selected items showed meaningful shifts in students' perceptions of engineering practices and the relevance of engineering knowledge.

Across the engineering knowledge items, students reported slight, not statistically significant, decreases in their self-assessed understanding of engineering and the engineering design process. Given the high pre-survey means, these declines may reflect recalibration effects common in design-based learning contexts, where students' post-experience judgments are grounded in more concrete exposure rather than initial expectations.

Students' interest and enjoyment in engineering remained largely stable over the course of the module. Composite scores showed no statistically significant change, though one item, "I think engineering knowledge is important in the real world," increased significantly, suggesting that the project strengthened students' sense of engineering's societal relevance. This makes sense given the projects' focus on needs the students might regularly experience in the restroom. Overall, the fluctuating results in this subscale indicate that while the module did not substantially shift students' engineering identity or interest, it reinforced the perceived value of engineering knowledge.

Perceptions of engineering knowledge and skills also remained steady, with no significant changes across the subscale. Students began the module with relatively high confidence in their ability to engage in engineering practices such as testing designs, generating ideas, and collaborating with peers. Postsurvey responses showed small increases on some items and decreases on others, but none reached statistical significance.

Students’ academic intentions in STEM showed slight increases overall, though again without statistically significant changes. One item, interest in taking STEM classes in college, approached significance, suggesting that the module may have contributed to early curiosity about future STEM coursework. Other items remained stable, indicating that short-term exposure to engineering design experiences may influence students’ academic thinking but is unlikely to shift long-term intentions without sustained engagement.

The most notable changes occurred in students’ perceptions of what engineers do. Although the composite score did not change significantly, three individual items showed statistically significant shifts. Students reported increased agreement with the idea that engineers “use lots of ways to share ideas,” suggesting that the module effectively highlighted communication as a core engineering practice. Conversely, students showed decreased agreement with statements that engineers are “creative people” and that engineers “get to be the boss.” These declines may reflect a more realistic understanding of engineering roles after participating in structured design activities that emphasized iteration, constraints, and collaboration rather than autonomy or leadership. Together, these shifts suggest that the module helped refine students’ perceptions of engineering work, even when broader attitudinal measures remained stable.

Overall, the MST results portray a cohort that entered the module with positive engineering attitudes and maintained those attitudes throughout. While large-scale changes were not observed across most subscales, the module contributed to more nuanced understandings of engineering practices, particularly communication, and reinforced the real-world importance of engineering knowledge. At the same time, the findings highlight areas where additional scaffolding may strengthen future iterations, such as deepening conceptual understanding of engineering and supporting students in connecting hands-on activities to broader engineering identities and career pathways.

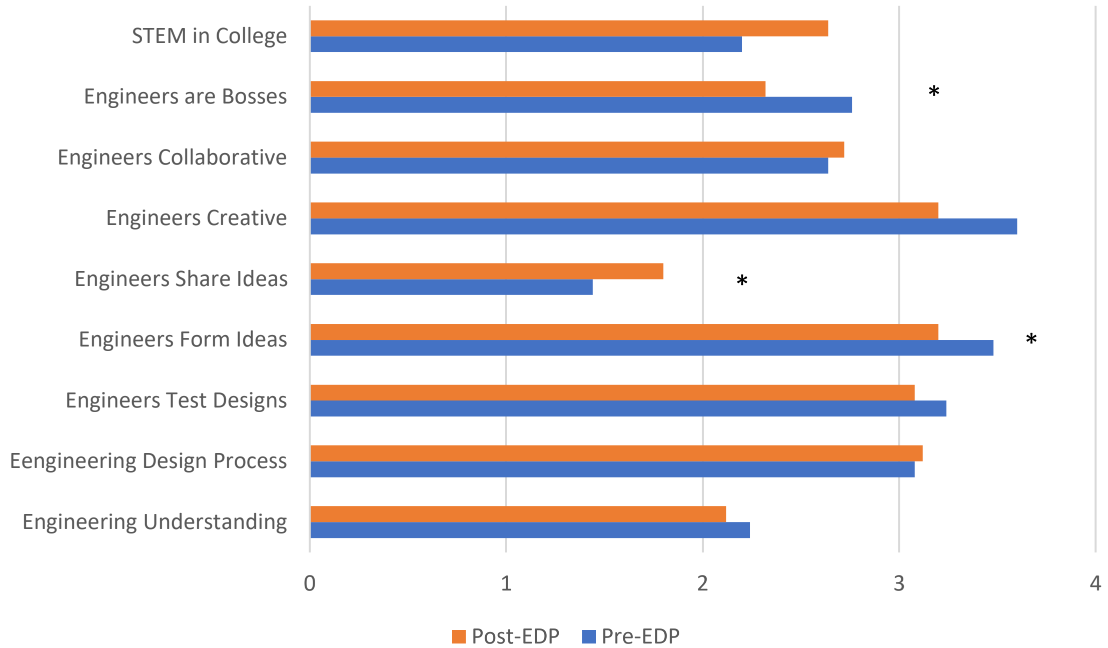


*Figure 6 Comparison of average pre- and post-course student responses to the Engineering Attitudes and Beliefs survey in MST's class. Response key: "strongly disagree" (1), "disagree" (2), "agree" (3), and "strongly agree" (4). p<.05; n = 25.*

### *Teachers' Experiences and Feedback*

We conducted pre- and post-Summer Design Camp and post-course implementation interviews with teachers to assess their prior knowledge and the self-perceived impact of the ODE collaboration and subsequent engineering course content implementation. The interview feedback was pooled and anonymized for the four teachers who participated in the 2024 ODE Summer Design Camp and implemented courses in the subsequent year, so we cannot directly highlight either MST's or HST's experiences. However, we present their broader perspectives here as an indication of the teachers' experiences, with the reasonable expectation that this pooled feedback encompasses both MST and HST.

Overall, the teachers were highly positive about the experience in the ODE Summer Design Camp, engineering course development, and subsequent implementation of this content. The teachers successfully integrated the EDP into their courses, utilizing either the content-integrated or pure design model. From their perspective, the teachers found the students to be enthusiastic about hands-on, inquiry-based project learning. They noted improved curiosity, innovation, and ownership, especially during the prototyping and testing phases of their engineering project work. Teachers agreed that the students gained knowledge in engineering-design aspects such as collaboration, communication, iteration, and critical thinking; however, they perceived the engineering design projects as enhancing conceptual knowledge, which is misaligned with the students' perceptions. The teachers reported greater confidence in teaching the EDP and enhanced technological literacy, especially with Arduino and programming. Based on this, they felt capable of both developing this instructional content and conveying it to students. HST's design choices reflected their increased confidence with engineering design practices developed during the Summer Design Camp, particularly in integrating Arduino-based sensing and iterative prototyping. MST's implementation similarly drew on PD experiences, using the EDP to structure an open-ended project and support students' problem definition and ideation. The EDP knowledge gains also enabled teachers to allow students more autonomy in class because of the inherent flexibility that must accompany the execution of design projects.

The teachers cited certain challenges, leading to suggestions for future improvements. Like the students, they reported issues with pacing and concerns about limited materials and time. It was challenging to balance engineering-design instruction with foundational concepts, especially in providing opportunities to reflect and revisit concepts throughout lessons. To help address these issues, they suggested more lesson planning, both during the ODE Summer Design Camp and during lesson implementation. Despite the challenges, all the teachers intend to continue teaching engineering design, as they feel confident in their abilities and believe this content enhances student learning.

## Discussion

In this paper, we have shared experiences and outcomes from two of the four teachers with whom ODE collaborated in the 2024-25 academic year, demonstrating the development, implementation, and assessment of EDP instruction. The content-integrated course incorporated engineering design into an existing high school chemistry class. The pure design course focused specifically on learning and applying the engineering design process to provide structure to a middle school project. Although the two teachers implemented engineering design in different ways, their courses highlight complementary pathways for integrating the EDP into secondary STEM instruction. The content-integrated model demonstrates how engineering design can deepen disciplinary learning within a tightly structured course, while the pure design model shows how the EDP can provide coherence and purpose within a more flexible project-based environment. These contrasting implementations illustrate how course constraints, teacher goals, and curricular structures shape the choice of design-integration strategy.

The teachers received their engineering design training and subsequent translation to their classes positively, indicating overall success with the professional development for teachers that is part of this collaboration. Teachers felt that this instruction is ultimately beneficial and warrants continued development. However, the impact of the instruction on students' engineering identity indicates that ongoing refinement is necessary. Despite minor shifts in students' attitudes, they were able to successfully apply engineering design to develop solutions, creating devices that have real-world utility. Taken together, the content-integrated and pure design course models show that engineering design can be successfully taught across diverse secondary contexts and that teachers, when supported through sustained engagement, are able to translate design pedagogy into their own classrooms.

In the spirit of design, we treat the challenges that emerged in the course as opportunities for iteration and improvement. Our ongoing goal is to create engineering-design–centric experiences that strengthen students' engineering identities, especially for those who are traditionally underserved. In the HST class, the most prevalent concern was insufficient depth of understanding, which appears partly attributable to compressing too much content into an 11-day unit. Covering a disease context (Crohn's disease), alginate gelation for drug delivery, the engineering design process, and Arduino programming in a single short unit left some students feeling rushed, unprepared, or like they were merely following steps rather than developing conceptual understanding. To address these shortcomings, we will add targeted instructional supports: modular pre-lab lessons, short tutorial videos on core scientific concepts and Arduino basics, and embedded conceptual checkpoints during labs to prompt prediction and explanation. These changes will both bolster students' conceptual grasp and provide on-demand resources they can consult while conducting design-based procedures.

Students in the MST course reported generally positive, stable attitudes toward engineering, but several shortcomings emerged in the engineering design project. Pacing and scope were recurring concerns: covering many topics in a relatively condensed timeframe left some students feeling rushed and underprepared. Depth of understanding and incoming knowledge were also issues—students, like their high-school counterparts, wanted a clearer conceptual grasp of the science behind the project and of Arduino programming rather than simply following steps. A high proportion of students who speak languages other than English at home further complicated access to conceptual material. To address these gaps, the MST lessons would benefit from modular pre-unit instruction and short tutorial videos, more cyclical design practice (try, test, reflect, redesign), and deliberate supports for teamwork such as explicit team roles, communication prompts, and regular conceptual check-ins.

Despite modest attitudinal shifts across both classes, we argue that building teacher confidence to teach engineering design is itself an important outcome. Prior research shows that even brief exposure to engineering design can strengthen problem solving, iterative reasoning, and communication, sometimes without immediate changes in students' self-reported identities (Batdi, 2025; Kidd, 2025.) This is supported by the students attaining successful prototypes in response to design challenges across both the pure design and content integrated classes. Collaborating with teachers increases students' access to authentic design experiences and positions these units as entry points for continued exploration of engineering. Although students often describe these activities as engaging rather than deeply conceptual, offering what they find interesting can still seed formative engineering-identity development.

Teachers viewed their experiences in learning engineering design and bringing it into their classrooms as highly successful. Across the four teachers in this cohort, they reported meaningful changes in their instructional practices, emphasizing increased confidence in integrating engineering design within science curricula. The content-integrated and pure design frameworks promoted shifts toward more student-centered, inquiry-based lessons. They found their students were highly engaged in hands-on projects that encouraged creativity, problem-solving, and collaboration, while teachers observed stronger conceptual understanding of scientific and engineering principles. Participants identified areas for continued growth, including differentiated guidance for grade levels, additional time for planning and materials preparation, and expanded access to technical tools such as Arduino. The teachers indicated that ODE was successful in cultivating capacity to deliver authentic engineering experiences and indicated promising directions for sustaining and scaling this work.

From students' and teachers' feedback, we have identified the following recurrent positive themes:

1. Students were highly engaged with the hands-on nature of the engineering design lessons and projects. They appreciated the prototyping and testing that accompanied their project efforts.
2. There are evident gains in communication, collaboration, persistence, and iteration. These are inherent skills associated with engineering and design, essential design practices that support engineering identity formation.

3. Teachers developed competence and confidence in teaching engineering design and the associated technical concepts, i.e., Arduino microcontroller programming. The framework of engineering design allowed for more student-centered, inquiry-driven instruction.
4. Students saw the projects as real-world relevant, and reported that they would recommend the engineering design project classes to friends.

In conclusion, we have developed and implemented models that equip teachers with engineering design knowledge, empowering them to teach these concepts to their students. While improvement is needed to achieve the desired attitudinal shifts, the engineering design instruction is transferable into middle and high school courses. We are optimistic that as teachers continue to iterate and refine their EDP instructional practices, these collaborations will have a multiplier effect, impacting students and fellow educators well beyond our initial interaction. We will continue developing and sharing these approaches, promoting and supporting a community of learning that aims to make engineering design education more widely available to pre-college students to promote STEM interest and identity.

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