Student Agency Through Engineering

When students are given opportunities to address problems important to them, the engineering design process (EDP) helps show the way.

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"We use the term engineering in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems" (NRC 2012, p. 11).

As *A Framework for K–12 Science Education* (NRC 2012) reminds us in its definition of engineering, for those looking to make the world a better place, engineering has always played an integral role in supporting such pursuits. In particular, engineering has led the way in responding to the COVID-19 pandemic, including developing masks that reduce transmission, digital tools that allow contact tracing, and vaccines that show promise to put an end to the pandemic and allow a more normal way of life. Our society is not only "following the science," but we are also applying principles of engineering to human problems to create timely and needed solutions.

Teaching principles of engineering in our classrooms should involve more than simply working through preconceived design challenges. It should be a way to position our students with agency—that is, to offer them a chance to see themselves as capable of solving problems in their homes and communities.

In this article, we describe a unit that was implemented in second grade to demonstrate how the engineering design process (EDP) afforded agency to one teacher's elementary students (this unit was adapted for use with third-, fourth-, and fifth-grade students as well). The learning experiences allowed students to solve societally relevant problems, especially those they experienced during the COVID-19 pandemic. When students selected problems encountered during the pandemic, the teacher did not ask them to find a new, easier, or less contentious problem; instead, she took the opportunity to empower her students to respond to the pandemic in their own ways.

In outlining the unit, the sections below describe three disciplinary core ideas (DCIs) of engineering: defining an engineering problem (ETS1.A), developing possible solutions (ETS1.B), and optimizing design solutions (ETS1.C). We have linked these engineering DCIs to engage in the EDP, ending with student reflection and communication with others (see Figure 1). Reflection and communication have no clear analogs to the engineering DCIs but are pivotal for students because they mirror the actual work of engineers by giving students an opportunity to articulate the design process and have their work recognized and legitimized.

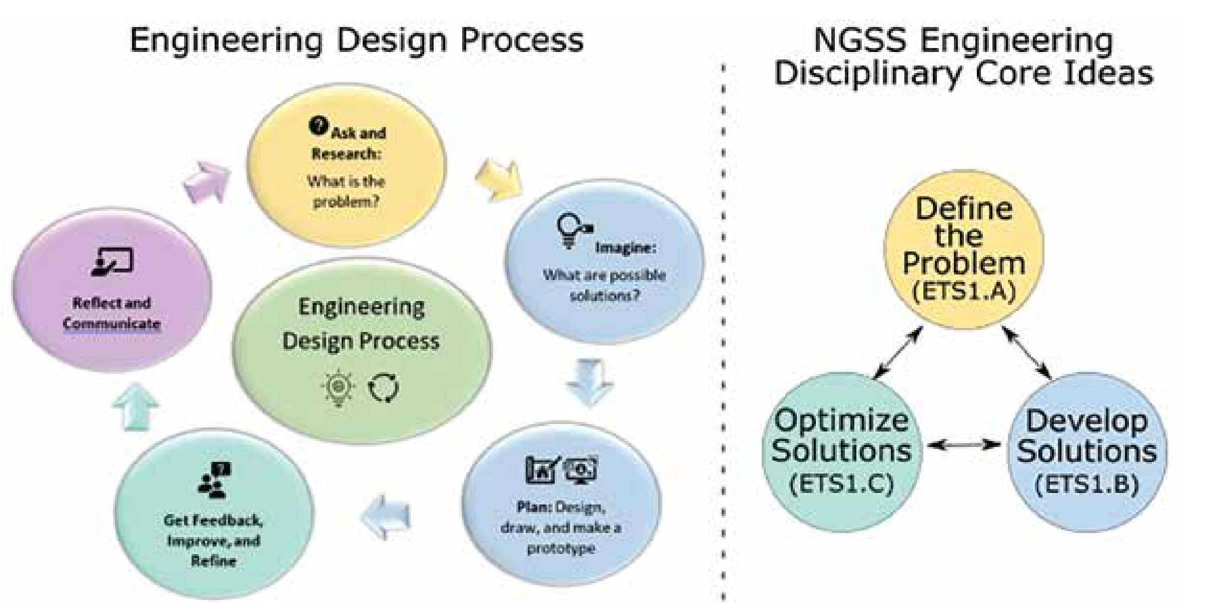
Formative and summative assessments were used to ensure students' understanding of the EDP. Self-assessments, peer feedback, and teacher assessment challenged students to continue to iterate their design solutions. Various assessment tools were used to monitor student engagement and inform instruction, including reflections in EDP journals, a self-assessment rubric, and exit tickets. This set of lessons was implemented while instruction was fully remote using online resources and materials that students could find and safely use at home (e.g., cardboard boxes, tape, and markers).

Introducing the Engineering Design Process to Students

Guided by instructional resources like those focused on managing student frustration during the EDP (Shouse and Lakhani 2016), the teacher (i.e., first author) addressed the

FIGURE 1

The engineering design process and its relationship to engineering disciplinary core ideas.



emotional aspect of the EDP early on. She started with a read-aloud (Spires 2014) over Zoom during which students were asked to notice and wonder about the main character's traits and actions that led to the creation of her "most magnificent thing" (you can also find readings of *The Most Magnificent Thing* on YouTube if you need to do this asynchronously). Students noticed that the main character was "persistent because she didn't give up" and "tried to follow her plan," although this plan didn't go the way she had planned.

Following the discussion of persistence despite things not going according to one's initial plan, the teacher introduced the EDP by showing a Brainpop video on her shared screen (see Online Resources). The teacher emphasized the importance of the process instead of the product because the product or prototype would evolve and change over time. As students made connections between the EDP and what they noticed during the read-aloud, they became more aware of and intentional about how they could regulate their emotions and learn from temporary failures during the iterative design process.

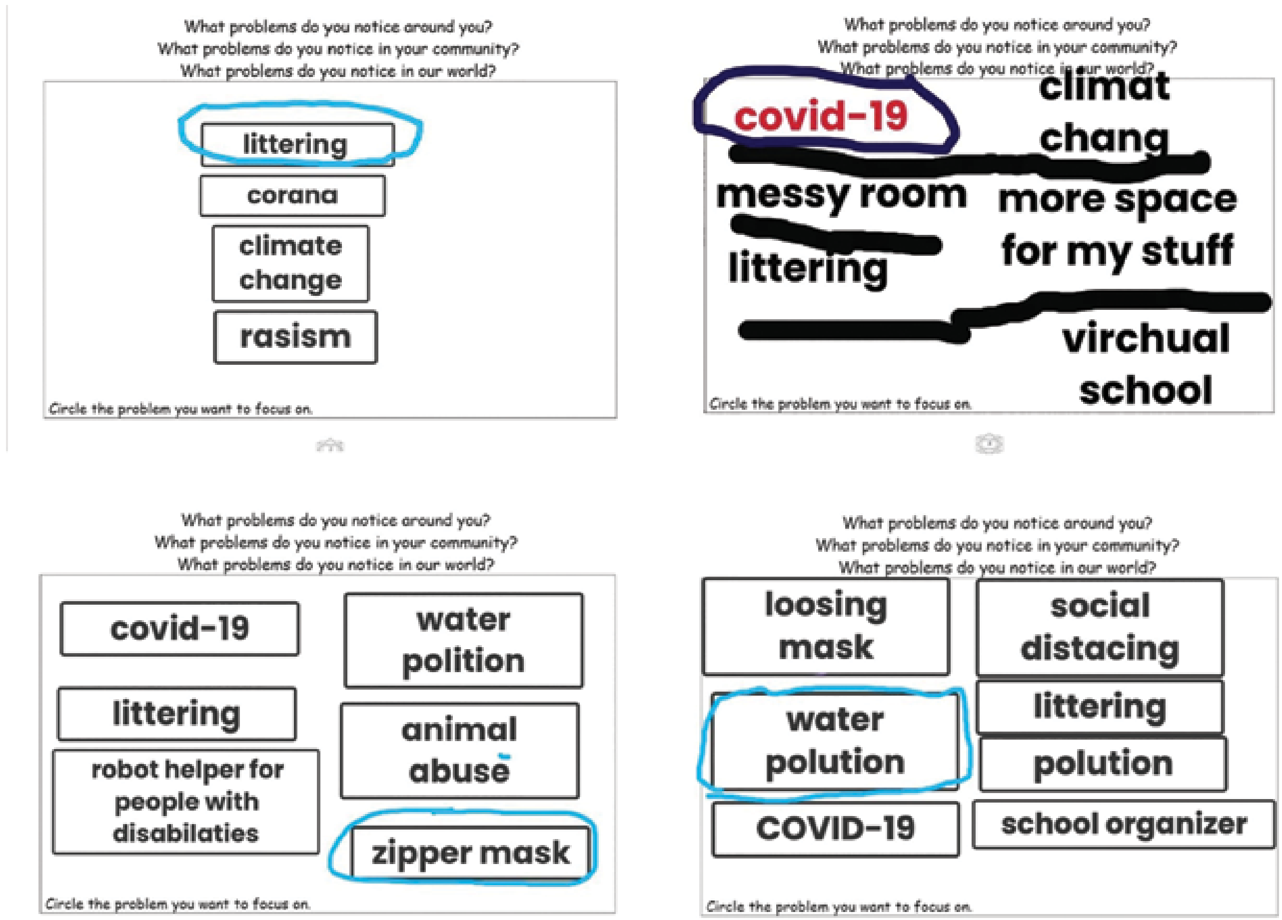
At this point, students were each assigned an EDP journal so that they could keep track of their ideas and designs throughout the process. The journals were shared using Seesaw, a learning platform that allows students to annotate and even submit audio comments, pictures, and presentations using templates that a teacher can share with the class. By using Seesaw, the teacher was able to formatively assess from her computer how students were doing in their EDP journals and could assist students individually in breakout rooms.

Defining the Problem Space Through Asking and Researching

After the in-class discussion, the teacher posed the following questions to students:

FIGURE 2

Some problems that third graders noticed around them, their community, and their world through Asking.



- What problems do you notice around you?
- What problems do you notice in your community?
- What problems do you notice in our world?

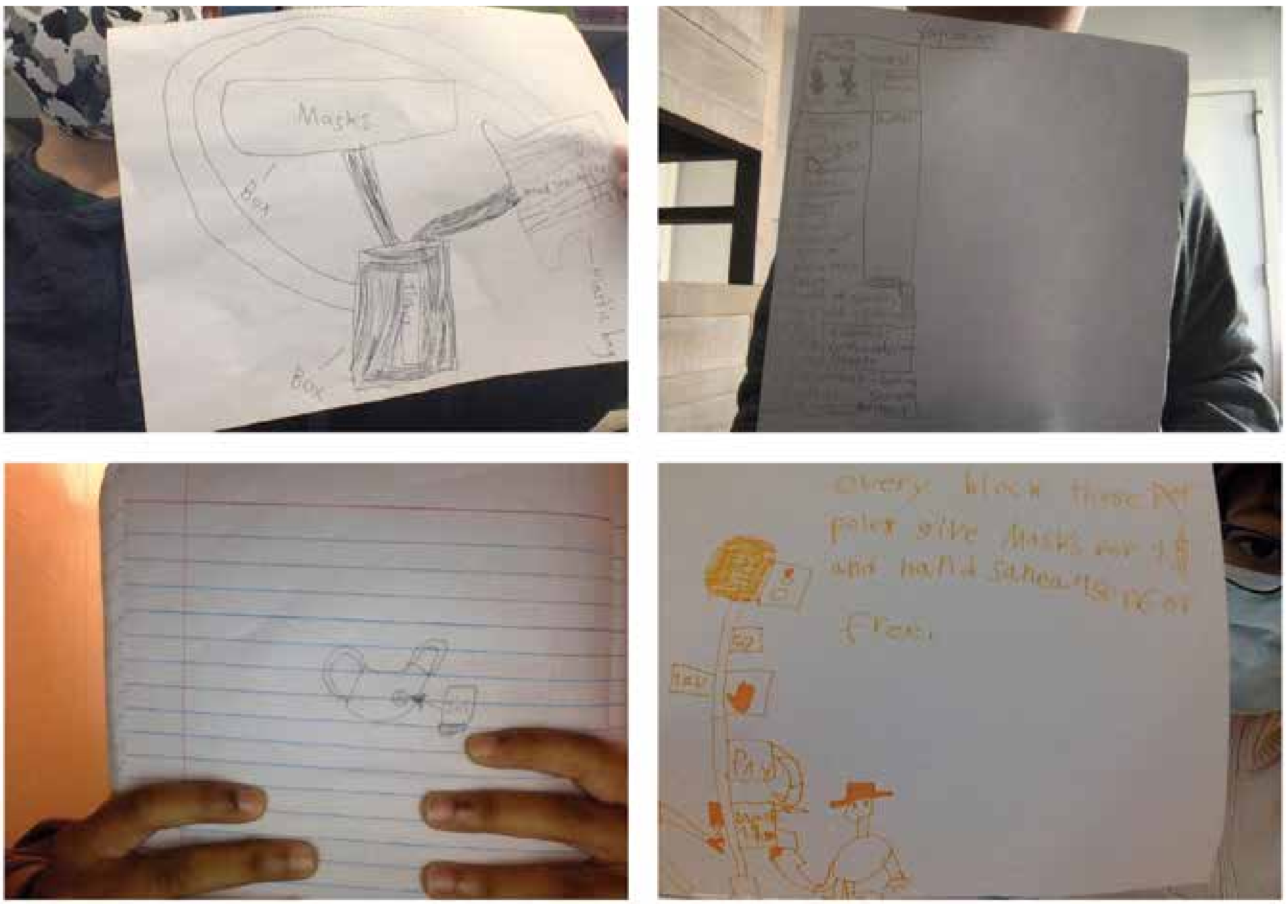
The teacher intentionally kept the questions open-ended because she wanted to let students lead with their own knowledge, experiences, interests, and passions or concerns for a particular problem. However, some students found brainstorming problems challenging because they either had difficulty selecting one topic from the multiple options they identified or believed they could not readily solve the topics they were interested in. To support these students, the class was divided into breakout groups so students who were uncertain about their topics could listen to peers describe their topics and share insights from their problems and potential solutions.

In response to the questions posed by the teacher, students wrote words or drew pictures of local or global problems in their EDP journals and considered whether they could figure out solutions to these problems (meeting NGSS K–2 DCI ETS1.A). Student responses included "climate change," "cutting down trees," "messy room," "people hunting tigers," "racism," "water pollution," and "COVID-19." COVID-19 ended up being the most frequently identified topic. In one class, almost half chose COVID-19 as a problem for which they wanted to contribute solutions. Figure 2 shows some of the topics that were chosen.

After students chose problems to focus on individually, they consulted nonfiction texts and used the Epic Digital Library, an online repository of grade-level texts, to do research before designing solutions to the problems that they raised (preparing students to eventually meet the NGSS 3–5 DCI

FIGURE 3

Examples of fourth-grade students' drawings for Imagining and Planning. Students' initial prototypes of designs related to COVID-19 included (clockwise from top left) a mask cleaner, a board game for "being lonely with no one to play with," a dispenser of masks and sanitizer, and a tracker to put on masks in case you lose them.



ETS1.B). The amount of instructional time can be shortened or lengthened depending on how much information students already have or still need to gather. The teacher emphasized how students would be returning to the research phase continually as they engaged in learning and building from what professionals had previously done in the science and engineering communities.

FIGURE 4

A co-constructed chart on feedback.

As students were researching, they were also engaging with a number of DCIs associated with the problems that they had chosen. For instance, a student who was researching how to decrease COVID-19 transmission was finding out which materials made masks protective against the virus and impacted virus spread (DCI PS1.A), while another student was learning about human impacts on Earth as a means to combatting climate change (DCI ESS3.C).

Developing Solutions Through Imagining and Planning

After students had sufficiently researched their ideas, they were shown three iterations of an airplane: pictures of airplanes, a blueprint, and a 3D model. As students contrasted the different perspectives of airplanes, the teacher facilitated a conversation around the various ways that a design could be conveyed (preparing students for NGSS K–2 DCI ETS1.B). Building on the students' words describing the pictures and models, the teacher introduced the term *prototype* in the context of engineering. Students drew their initial prototypes as sketches to imagine possible solutions for the problems they chose (see Figure 3).

FIGURE 5

Iterative revisions in response to peer feedback. A second grader's first prototype, a mask holder, was transformed into a PPE station.

Students finished their drawings and reflections in their EDP journals in Seesaw, which were used as a formative assessment of their understanding of the EDP and a check for understanding before they could begin building their prototypes. For example, when students were writing summary statements of the research they conducted and barriers they encountered in building their prototypes, the teacher used students' summary statements as formative assessments.

Students were given a choice in the way that they wanted to represent their sketches as models that they could share with peers (giving students an opportunity to further grapple with NGSS K–2 DCI ETS1.B). Many students constructed their designs out of recyclable materials found at home, such as cardboard boxes, string, and duct tape. If scissors were used, it was under the supervision of a caregiver. For students who did not have access to the materials they needed to build their designs or were not able to use the materials safely, the teacher encouraged them to build digital models by creating free accounts on Tinkercad, a 3D modeling site. For lower grades or for students with fine motor difficulties working on a computer, teachers can also use the Toy Theater website for building. As a challenge for students, the teacher may extend this part of the process to include 3D modeling as they are designing and drawing their prototypes.

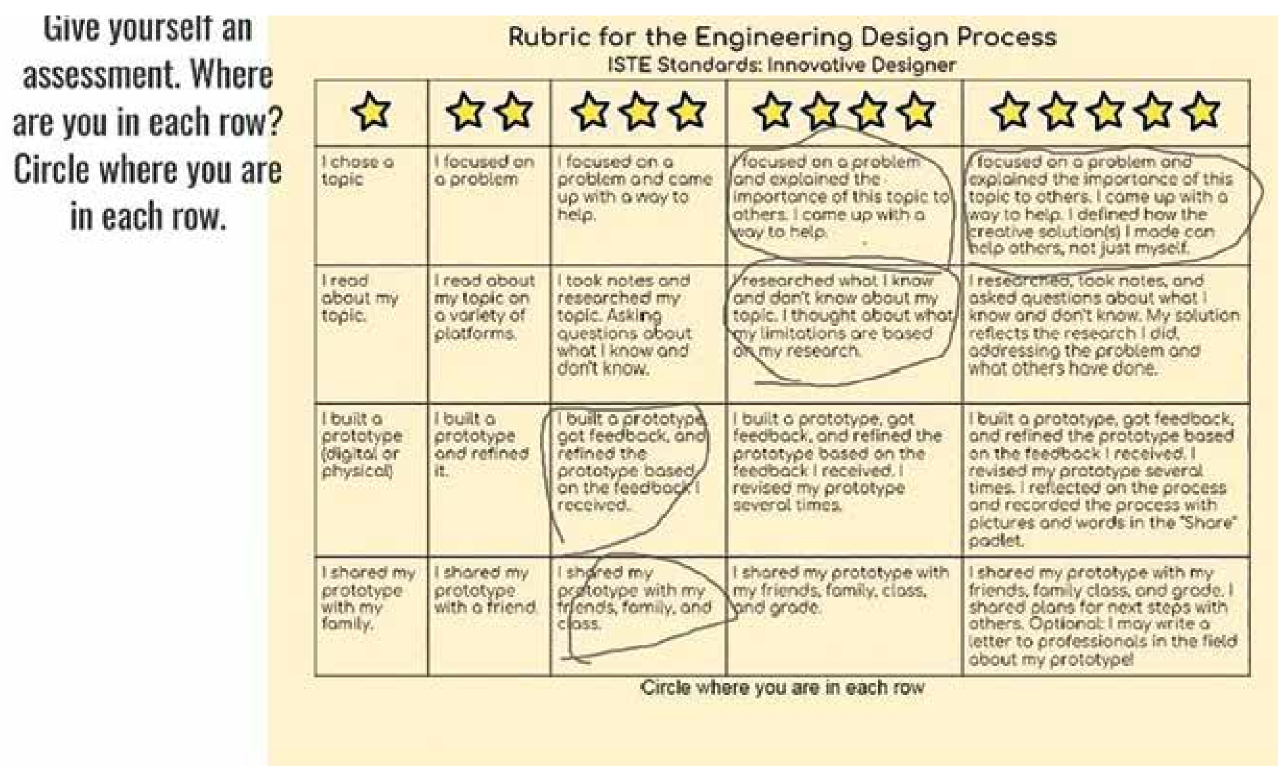
As students built their prototypes, they also came up with individual ways to test the strengths and weaknesses of their designs and refine their prototypes. These simple tests allowed students to gather evidence as to what was causing their designs to work as intended or what needed work in order to create the intended effect (a core part of how engineering relates to the CCC of Cause and Effect). In their EDP journals, students specifically documented what worked and what needed improvement as they ran trials and tested the durability of their prototypes. Students documented their trials and errors as they continued to refine their prototypes, which allowed for the teacher to review their work in SeeSaw.

Optimizing Through Getting Feedback, Improving, and Refining

After students had some time to build their prototypes and the teacher highlighted different students' products, the teacher paused the class and said, "I notice many of you are still building, and I'm finding it might be helpful to get some feedback on your prototype from your peers before you build

FIGURE 6

Self-assessment to determine next steps.


Give yourself an assessment. Where are you in each row? Circle where you are in each row.

Rubric for the Engineering Design Process
ISTE Standards: Innovative Designer

☆	☆☆	☆☆☆	☆☆☆☆	☆☆☆☆☆
I chose a topic	I focused on a problem	I focused on a problem and came up with a way to help.	I focused on a problem and explained the importance of this topic to others. I came up with a way to help.	I focused on a problem and explained the importance of this topic to others. I came up with a way to help. I defined how the creative solution(s) I made can help others, not just myself.
I read about my topic.	I read about my topic on a variety of platforms.	I took notes and researched my topic. Asking questions about what I know and don't know.	I researched what I know and don't know about my topic. I thought about what my limitations are based on my research.	I researched, took notes, and asked questions about what I know and don't know. My solution reflects the research I did, addressing the problem and what others have done.
I built a prototype (digital or physical)	I built a prototype and refined it.	I built a prototype, got feedback, and refined the prototype based on the feedback I received.	I built a prototype, got feedback, and refined the prototype based on the feedback I received. I revised my prototype several times.	I built a prototype, got feedback, and refined the prototype based on the feedback I received. I revised my prototype several times. I reflected on the process and recorded the process with pictures and words in the "Share" padlet.
I shared my prototype with my family.	I shared my prototype with a friend	I shared my prototype with my friends, family, and class.	I shared my prototype with my friends, family, class, and grade.	I shared my prototype with my friends, family class, and grade. I shared plans for next steps with others. Optional: I may write a letter to professionals in the field about my prototype!

Circle where you are in each row

some more." In this way, students could compare and test their designs with their peers (engaging students in grappling with NGSS K–2 DCI ETS1.C and NGSS K–2 CCC Cause and Effect). Up to this point in the school year, students had been working on effective feedback. To this end, the students and teacher co-constructed a chart on what feedback in the classroom should look like (see Figure 4).

The teacher displayed this feedback chart in the classroom and had a few students present their prototypes so other students could model giving feedback to the presenters. She used a fishbowl-style classroom arrangement in which a pair of students were showcased on Zoom (so that they were the spotlighted windows for the rest of the class) while the other students observed their interactions. This model of feedback is a remote adaptation of a typical fishbowl discussion in which a subset of students are seated in a circle in the middle of the classroom with the remaining students positioned outside of the circle so they can observe their classmates. After the students who were not spotlighted observed and verbalized how the students who modeled gave feedback, the teacher put students into pairs in breakout rooms. All students were expected to follow the protocol of deciding who would go first (Partner 1 presents the prototype, Partner 2 gives feedback) and then switch roles. The teacher gave students two to three rounds of different partners to get feedback on their prototypes over the course of one to two sessions.

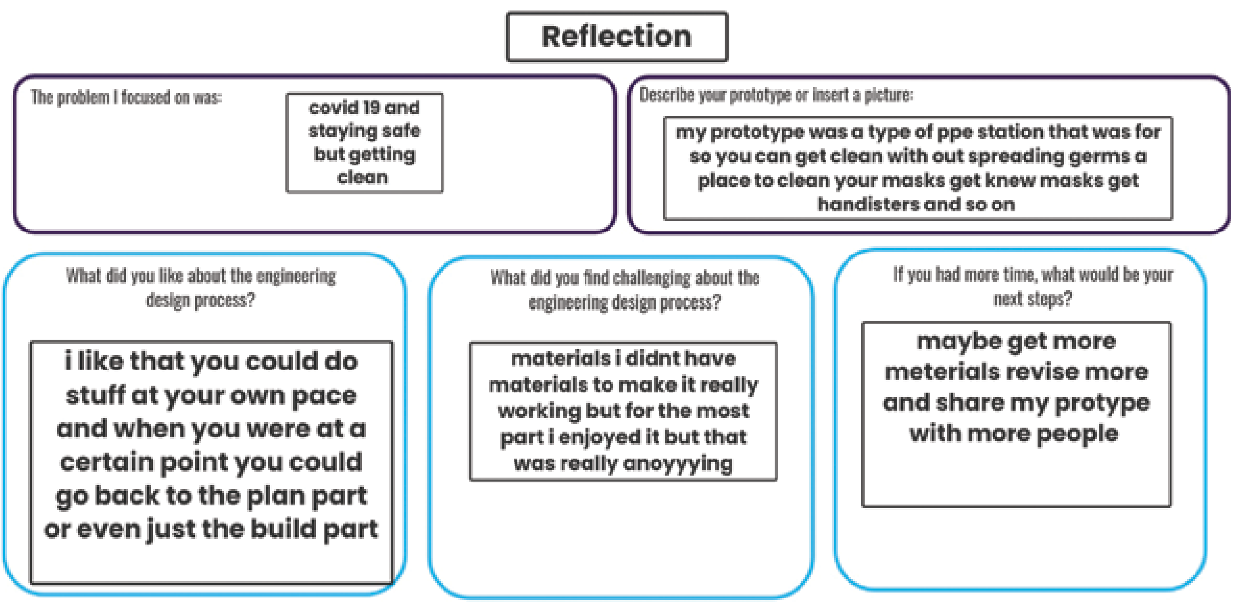
Students continued to build and iterate. Student feedback focused on the strengths and weaknesses of peers' designs, and students had opportunities to test their prototypes and improve their designs based on peer feedback. In each feedback session, students presented their prototypes and showed how they worked while their partners offered ideas about how to improve the designs. As students incorporated feedback from their peers in the designs of their prototypes, students documented the tests that they devised as well as the changes they made within their EDP journals. For instance, one student who was building a robot that picks up litter noticed that it did not work during testing because "the glue was not strong enough." Her peer suggested she use tape. As a result, she documented this change in her EDP journal as part of the test and revise process.

The iterative steps to improve their prototypes and then present their work to peers were the most engaging of the EDP process. For instance, when a student began to build a mask holder, a peer suggested she turn it into a "big station to clean." The student then realized it could be a "PPE station" for when her family members came home and needed to sanitize (see Figure 5). Some students found the iterative step helpful, for instance, "I liked the revision process because it allowed me to figure out the mistakes, which are really fun to correct!" Others found the iterative step challenging, for instance, "You must iterate your project even though you think it is perfect."

Formative assessment was conducted by reviewing students' designs within Seesaw. Through self-assessment (expanded in Figure 6), students were able to determine where they were in the EDP and the next steps they would take. For the teacher, students' self-assessment was informative in deciding whether and how to lengthen or shorten different

FIGURE 7

Reflections from an EDP journal.



parts of the EDP to support student learning. Peer feedback on the students' prototypes as well as teacher feedback on students' EDP journals provided insights to students about how to improve their prototypes.

Reflecting and Communicating

Reflecting upon and communicating the successes and failures of the iterative design process indicated how students had grown as engineers. As students neared the timeframe for completing their prototypes, they reflected on their design process (Figure 7). When the teacher asked students what they liked about the EDP, students wrote their reflections in their EDP journals. Some expressed how they enjoyed the creativity and openness of their projects, "I loved how you could come up with so many cool ideas and make them" and "I could go at my own pace." Others expressed their desire to help others, "It was nice thinking [about] how much people could be affected in a good way by what we are building" and "I love how I can make something useful." Still others expressed the challenges they went through, "You have to stay with something, even if it's really hard and you get feedback that you don't like sometimes."

As a part of the ongoing formative assessment, using a rubric within Seesaw, students would circle how well they were meeting the expectations of each part of the EDP (Figure 6). In addition, students created presentations either as videos or audio recordings within Seesaw as summative assessment. This allowed the teacher easy access to the presentations and recordings for grading. It also allowed these projects to be shared with other students and their families to celebrate the work that they did. Giving students this space to communicate their designs helped students to see themselves as engineers whose work was recognized and valued.

Conclusion

Engineering is a systemic practice of design to achieve solutions to problems. The EDP, combined with allowing students to find their own problems to solve, gave them authentic opportunities to build agency as engineers. In giving students the option to lean into the COVID-19 pandemic as well as other relevant issues to them, the teacher allowed students to orient themselves to real-world problems and use classroom space to make informed decisions and take responsible actions (Lee and Campbell 2020). Giving students agency reminds us that if the teacher always decides which problems students solve, students are not afforded the chance to see themselves as capable of improving their local community. Allowing students to select their own problems and related projects based on what they know about what is happening in the world around them is a powerful way to help students see themselves and be seen as engineers.

The teacher was impressed by the students' motivation and passion for their projects, and many students continued to iterate their designs even after the unit ended. While the teacher was initially hesitant and nervous about using varied and open-ended projects, the students showed such care and dedication as they engaged in their projects that they learned the EDP far better than if the topics were determined by the teacher ahead of time. In the end, giving agency to students and honoring their decision-making capacity reveals how students can become personally invested in the engineering process. ●

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ONLINE RESOURCES

Asking and Researching

Epic Digital Library
https://www.getepic.com

Imagining and Planning

Tinkercad
https://www.tinkercad.com

Toy Theater Build
https://toytheater.com/build

Introducing the EDP

BrainPop Video
https://www.brainpop.com/technology/scienceandindustry/engineeringdesignprocess

Reflecting and Communicating

EDP Journal
https://drive.google.com/file/d/1cDUFJBbvstYYxYhyLUlcWGOuiWFnKjuo/view?usp=sharing

Seesaw
https://app.seesaw.me

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