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Keywords

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Socially Engaged Engineering: A Framework for K-8 Education

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Abstract

Socially engaged engineering provides for student learning of the design, analysis, and practices of engineering as well as the ways that engineering is situated in sociocultural contexts. This paper provides a conceptual framework regarding socially engaged engineering for K-8 educators, researchers, and curriculum designers. The framework identifies ways to support youth learning of engineering and considerations of technical, social, environmental, and ethical dimensions of engineering. As engineering enters K-8 educational settings, it is important to introduce the discipline in equity-oriented ways. We draw from the field of engineering for social justice to build this framework for examining engineering at the macro-, meso-, and microscales. Situating engineering in sociocultural contexts can be motivating to learners and provide perspectives on the nature of engineering. Our framework was concurrently designed with Youth Engineering Solutions (YES; https://YouthEngineeringSolutions.org) curricular units. To test the applicability of our principles, we applied them to K-8 YES curricula for school and out-of-school environments. Through the coevolution of principles and curricular materials, we developed age-appropriate learning objectives for three levels—lower elementary, upper elementary, and middle school. This paper shares the principles and progression, showing worked examples from curricula to demonstrate how the principles translate into curricular resources. We discuss constraints to the implementation of socially engaged engineering curricula, including those imposed in educational settings and the ideological assumptions about science, engineering, and STEM disciplines.

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Introduction

As engineering enters K-8 educational settings, it is important to introduce the discipline in equity-oriented ways (Cunningham & Kelly, 2022). Youth need to connect engineering to their lives and consider the impacts of engineering in the world. Engineering solutions can disproportionately impact—benefit or harm—certain populations. This differential impact cuts along class and race lines, raising important ethical questions for engineers as they address the criteria and constraints of stakeholders. As youth engage with engineering activities and curricula, it is important that they consider these elements. The emergent field of engineering for social justice urges that decision-making related to engineering designs and solutions consider technical, social, environmental, and ethical contexts (Claris & Riley, 2008; Leydens & Lucena, 2018; Lucena, 2013; Nieusma & Riley, 2010; Riley, 2008). Situating engineering in such contexts can motivate learners and provide perspectives on the nature of engineering. Thus, building a socially engaged engineering educational orientation both authentically frames the discipline and provides insights into the epistemic practices of the field.

Youth learn how engineering benefits or harms particular populations, local communities, and/or the environment as well as how to analyze possible impacts of design solutions.

This paper focuses on a conceptual framework for K-8 educators, researchers, and curriculum designers that offers guideposts for supporting students' considerations of technical, social, environmental, and ethical dimensions of engineering. Situating engineering in this way raises questions for educators: How can educators nurture such understandings in youth? How should K-8 engineering connect to issues of social justice? How can activities or curricula be structured to address these goals? These questions have driven our work, resulting in the articulation of a framework of design principles for equity-oriented engineering (Cunningham & Kelly, 2022). This paper builds upon the prior work, expanding and modifying the dimension focused on socially engaged engineering. Our conceptualization continually evolves as we learn more from others' scholarship and from our efforts to instantiate theory into practice by working with teachers to develop engineering curricula. Such work ensures our models are grounded in the realities of classroom life.

We also summarize the literature that informed our work. It demonstrates how scholarship has informed our current thinking about design principles related to socially engaged engineering. It describes how we have applied the principles to K-8 curricula in school and out-of-school environments and offers some reflections about what we have learned.

Engineering and Social Justice

The many fields of engineering construct cultures with ways of being, knowing, and communicating through the everyday work of engineering. These cultural practices are constructed by members of a specific discipline and also informed and influenced by interactions with broader cultural practices. Local engineering communities take up the cultural practices of the disciplinary fields (e.g., mechanical, electrical, biomedical engineering) along with ideological commitments associated with doing engineering. These ideologies inform narratives about the work of engineering, signal membership, and build cohesion within and across communities doing engineering work. Historically, engineering education has suffered from a dualism that separates technical knowledge from the social dimensions and applications engineering (Gravel et al., 2021; McGowan & Bell, 2020; Riley, 2008; Riley & Lambrinidou, 2015). This ideological commitment serves to facilitate efficiency in the putative work of engineering but may mask the social, environmental, and ethical dimensions of engineering.

To create a more robust and accurate portrayal of engineering and introduce students to the nature of engineering as practiced in real-world settings, educators need to construct opportunities for youth to learn about the socially engaged nature of engineering. Educators can seek to create just and equitable classrooms by cultivating in teachers a critical consciousness of social justice and its role in engineering (Holly & Buford, 2022). This consciousness can be developed by tying the interactions of classroom life (i.e., talk, texts, technologies) to larger issues of engineering in society. This involves the recognition that engineering is mediated by ideologies and beliefs about learning and is encoded in representations, spaces, and social practices of the learning environment and of the broader societal context in which engineering is practiced (Gravel et al., 2021). Within our work, we leverage curricula that embed such principles of socially engaged engineering to aid teachers in creating equitable classrooms.

Equity in engineering education therefore requires a systems perspective that can connect micro-practices at the classroom level, including pedagogical practices and resistances within classroom settings, to the larger macrolevel structures of equity and social justice for engineering in institutions and society (Basile & Azevedo, 2022). There are multiple levels at which social justice and equity operate within engineering education. At the microlevel, equitable learning opportunities offer high-quality learning opportunities and instruction for students from all backgrounds including those from marginalized communities and identities in engineering. This requires intentionally and consciously designed spaces and experiences, and adjustments to educational environments, policies, and conceptualizations of what counts and is valued in education. Such work should create supportive educational experiences respecting the dignity of all learners by maintaining their sense of belonging within spaces that may have historically ignored them. We draw upon Burgess and Patterson Williams' (2022) description of equity as operating at macro-, meso-, and microlevels to organize our categorization of theoretical and empirical arguments and analyses related to socially engaged engineering and socially just engineering. As we synthesize the literature and our arguments across these levels, we also consider how equitable practices at any one level reinforce equitable practices at the others. Envisioning socially just engineering education requires thinking within and across all three of these levels.

Macrolevel Organization of Engineering for Equity

Engineering for equity and social justice involves a recognition of the ideologies shaping engineering and the orientations that engineering has towards society. Historically, science and engineering have been shaped by ideologies that are technocratic and exclusionary, often ideologically framed as rationalistic (Bazzul & Tolbert, 2019; Gunckel & Tolbert, 2018; Leydens & Lucena, 2018; Nieusma & Riley, 2010; Riley, 2008; Tolbert & Bazzul, 2017). Within this framework, engineering is seen as leading to unrelenting progress, where "progress" is viewed as fundamentally good for all of society (Gunckel & Tolbert, 2018; Riley, 2008) without pausing to considering important questions of who the progress affects, and the larger ecological and sociopolitical implications of that progress (Bazzul & Tolbert, 2019; Gunckel & Tolbert, 2018; Leydens & Lucena, 2018; Riley, 2008).

Social justice and equity efforts start from the recognition that ideologies are not static. Ideologies serve multiple purposes and are constructed by members operating within the community. Such ideologies come to define what counts as relevant knowledge and whose knowledge counts, as well as legitimizing ways of bringing about change in the field (Pawley, 2009, 2012). Education is a potential means to bring about social change and challenge dominant ideologies. Science and engineering can and should be tools to disrupt extant inequities and liberate students from oppression. This requires a fundamental ideological repositioning of the purposes and practices of science and engineering within our cultural systems. Such repositioning entails a critical examination of the ideologies and discourses around engineering in the social and institutional contributors to schooling. As Burgess and Patterson Williams (2022) summarize:

> …social contributors (e.g., racism) are informed by ideologies and discourses, while institutional contributors (e.g., curricula) are influenced by contextual factors such as politics. Taken together, these form the broad scope through which we engage macro-layer equity. (p. 1077)

At this scale, contesting dominant and exclusive ideologies has two related applications. The first of these is in recognizing the ways in which engineering education has not historically contested such exclusionary realities as inequitable. This results in injustices towards learners in the classroom. As Tolbert and Bazzul (2017), drawing on Gutiérrez (2013), argue, problems of equity in the classroom are too often taken up in the literature in ways that do not offer systematic or political challenges to "oppressive/hegemonic forces, institutions, modes of governance, discourses and ideology, and the cultural politics of education" (p. 324).

By shifting ideologies about who is allowed to do engineering and what counts as engineering in the classroom, engineering education becomes a means for engaging in equitable social transformation by countering dominant exclusionary forces and making space for the heterogeneous ways in which engineering can be used (Burgess & Patterson Williams, 2022; Gravel et al., 2021). This contestation is critically important if pedagogies are to become asset-based where educational materials, structures, and practices value and support heterogeneous ways of knowing and being (Gravel et al., 2021). Therefore, equity work at the macrolevel of contesting ideologies and dominant ways of knowing and being acknowledges barriers that foster inequities in engineering participation at the microlevel, making way for all students to rightfully participate (Calabrese Barton & Tan, 2018, 2019).

The second application of this contestation concerns conceptualizing epistemologies of engineering for learning. For this orientation towards engineering and practice, engineering in education can be leveraged to engage in social justice work. Morales-Doyle (2019) argues that curricula constitute spaces that can invite students to interrogate and critique macrolevel systems, increase their knowledge and understanding of the relevant issues, and enact change. Bazzul and Tolbert (2019) frame such contestations as central to empowering education communities to politically engage. This change is perhaps best captured by the turn from critical thinking *in* engineering to critical thinking *about* engineering (Baillie & Levine, 2013; Claris & Riley, 2008; Riley, 2008). This aspect of educating for socially engaged engineering, often also studied under the domain of engineering ethics education, concerns what Riley (2008) termed a problem of macroethics, involving collective action of engineers in and for society.

The definition of Leydens and Lucena (2018) offers a good starting point for conceptualizing engineering for social justice as:

> …engineering practices that strive to enhance human capabilities (ends) through an equitable distribution of opportunities and resources while reducing imposed risks and harms (means) among agentic citizens of a specific community or communities. (pp.169–170)

Engineering for social justice requires educating engineers to consider engineering problems and solutions from the perspectives of the people impacted by the consequences of such solutions (Cardella et al., 2012; Leydens & Lucena, 2018; Nieusma & Riley, 2010) as all engineering decisions contain ethical positions (Baillie, 2006; Baillie & Levine, 2013; Downey et al., 2007; Leydens & Lucena, 2018). Ethical considerations run through all aspects of engineering from problem solving to critical examinations of who gets to define the problem (Downey, 2005; Leydens & Lucena, 2018). Although there are significant agreements and disagreements about what values should underly ethic codes in engineering (Baillie &

Levine, 2013), nearly all approaches agree about the need to be critical about engineering and emphasize the ethical positions available within engineering. This requires rejecting the dualism elucidated earlier and rejecting the culture of socioethic disengagement among engineering students that this creates (Douglas & Holbrook, 2020). Depoliticization resulting from this dualism, combined with a social privileging of flawed notions of decontextualized meritocracy as central to technocracy, is central to breeding an engineering culture of disengagement with public welfare concerns (Cech, 2014; Leydens & Lucena, 2018; Riley, 2008).

Mesolevel Organization of Engineering and Education for Equity

At the mesolevel, contestations from the macrolevel are taken up in conceptualizing and framing the kinds of learning experiences, environments, and curricula that are designed for socially engaged engineering. This is critically important as defining and legitimizing what counts as engineering in our learning environments have lasting consequences for participation and opportunity (Gravel et al., 2021; Pawley, 2009; Slaton & Pawley, 2018). However, learning has been historically understood against a stable, normative background. Different ways of knowing and being must be included in the framing of engineering practices, allowing for a diversity of approaches to problem solving. This view of equity opens up new perspectives in engineering and redefines what counts as legitimate engineering education (Baillie & Levine, 2013; Slaton & Pawley, 2018). This is important to empower communities whose ways of knowing and being have been historically excluded. Continued politicization of who and what counts can intensify social and political struggles (Cardella et al., 2012; Tolbert & Bazzul, 2017) in the macrolayer.

This epistemological shift necessarily incorporates a sociopolitical lens. This shift has begun in science education and has relevance to improving equity in engineering. Tolbert and Bazzul (2017) argue that science, and science teaching and learning, have largely been situated in masculine, white, heterosexist, Eurocentric, and middle-class contexts and the epistemologies that are valued and count in these contexts (Calabrese Barton & Tan, 2018; Carlone et al., 2021). Resistance to these narrow views of knowing can be constructed at the mesolevel, by building educational experiences tied to engineering practices that allow for multiple perspectives and solutions.

At the mesolevel, equity is served by alternative epistemologies that disrupt extant dominant epistemologies. Such alternatives conceptualize equity as dynamic, interactive, and influenced by context (Fortney & Atwood, 2019). Accounting for these heterogeneities serves two purposes. First, disrupting extant epistemologies allows for different kinds of discursive and epistemic practices, valuing what young people bring to learning (Calabrese Barton & Tan, 2019; Rosebery et al., 2010; Tan et al., 2019). Second, they disrupt and desettle expectations of the forms of knowledge and meaning making that can be used to engage in science and engineering, creating new possibilities and new forms of engagement and knowledge from historically underrepresented student populations (Bang et al., 2012; Leydens & Lucena, 2018; Riley, 2008). Youth experiences with engineering can and should be framed to provide understandings of multiple solutions to technological challenges, differential consequences for solutions, and ways of critically thinking about engineering.

Microlevel Organization of Engineering Education for Equity

Drawing from the epistemological shift to consider heterogeneities in ways of being and knowing helps to frame students as engineers in equitable ways. Empowering students with voice and agency requires a recognition of the ways in which identity is interactionally accomplished, dynamic, and intersectional (Brown et al., 2005; Burgess & Patterson Williams, 2022; Kelly et al., 2017). Fostering positive identities and affiliation with engineering requires both drawing from the practices, tools, and ideas that youth bring to the classroom (derived from their local communities) (Wilson-Lopez et al., 2016) as well as bridging to new ways of knowing informed by the disciplinary community (Kelly & Cunningham, 2019). The microlevel interactions in engineering classrooms are influenced by larger societal ideologies and assumptions related to race, gender, class, language, and other social and cultural identities (Leydens & Lucena, 2018). One way to introduce alternative pedagogies is to focus on students' assets and engineering or science capital to foster justice-focused engineering learning (Riley, 2008; Wilson-Lopez et al., 2016, 2018).

Wilson-Lopez and Acosta-Feliz (2022) provide an example of using students' assets to reform engineering instruction. In this example, the authors examined middle-school teachers' enactment of asset-based pedagogies in a technology and engineering classroom. The teachers leveraged students' existing funds of knowledge and encouraged translanguaging, readily allowing students to draw from multiple linguistic repertoires to focus on meaning making. The engineering design challenge involved gardening, which was familiar to local community members. The use of multilingualism allowed these community members to interact with the students by drawing from and enacting their funds of knowledge, thus becoming an asset for student learning. When asked to share their proposed solutions, students were also encouraged to use languages spoken by the audience of other students, teachers, and community members. This example demonstrates that effective engineering practices can be taught in ways that draw upon and facilitate students' identities as engineers and makers (Calabrese Barton & Tan, 2018, 2019; Carlone et al., 2021; Nixon et al., 2021).

A Framework for Science and Engineering Education

National frameworks documents such as *A Framework for K-12 Science Education* (National Research Council, 2012) call out some of the societal impacts of engineering. For example, the second core idea in the framework, ETS2: Links Among Engineering, Technology, Science, and Society, recognizes that:

> …all human activity…has had both short- and long-term consequences, positive as well as negative, for the health of both people and the natural environment… The results [of science and engineering] often entail deep impacts on society and the environment, including some that may not have been anticipated when they were introduce or may build up over time to levels that require attention. (p. 212)

Such frameworks introduce the possibilities that engineering may have negative consequences, but in general the treatment is fairly cursory and falls short of providing a structure for the types of critical lenses students might bring to their engineering activities to help them develop a more nuanced understanding of the relationships between engineering and society.

From our reviews, a set of themes emerged that we honed through discussions with experts from engineering, K-12 education, and social justice in education. We distilled these themes into principles that can inform curricula, instruction, and assessment. The principles provide agency for youth to engage with the disciplinary practices of engineering in a socially engaged manner. We next share the principles and progression, showing examples from classroom-tested curricula to demonstrate how the principles translate into curricular resources.

Socially Engaged Engineering

We have previously described socially engaged engineering as situating engineering in its larger societal context and helping students recognize how engineering can reproduce societal bias or seek to correct it (Cunningham & Kelly, 2022). We have continued to draw from the literature and our collaborations with teachers to pressure-test our ideas. This has led to further refinement of the socially engaged design principles that frame our work with K-8 students. These principles include:

- Situate the problem in a societal context.
- Consider the impacts of the problem on different individuals, groups, or systems.
- Think critically about the impacts of engineering solutions.

In this section, we ground each in scholarly literature, provide educator-friendly descriptions of each, and offer a learning trajectory of how these might manifest in materials in age-appropriate ways at the lower elementary, upper elementary, and middle school levels, illustrating each with examples.

Situate the Problem in a Societal Context

Engineering for social justice pays explicit attention to the ways in which engineering educational experiences frame the social contextualization of engineering. This requires a fundamental turn away from the technocratic worldview of conceptualizing engineering as a set of decontextualized problem-solving practices (Gravel et al., 2021; Leydens & Lucena, 2018; Nieusma & Riley, 2010; Riley & Lambrinidou, 2015; Tolbert & Bazzul, 2017). Forming connections by situating the engineering problem in students' lived experiences and their local communities is critical to rejecting the culture of socioethic disengagement from public welfare concerns that is common among engineering students and professionals (Cech, 2014; Douglas & Holbrook, 2020). This conscious embedding of engineering problem solving within the social also defines and legitimizes engineering as a way of knowing and problem solving that is relevant within students' experiences and invites communities whose ways of knowing and being have been historically excluded (Cardella et al., 2012; Gravel et al., 2021; Tolbert & Bazzul, 2017). It empowers students who are historically positioned as outsiders, such as language-learners, to bring cultural assets and funds of knowledge to inform meaning making within familiar contexts, offering opportunities for them to be valued members of a learning community (Calabrese Barton & Tan, 2018, 2019).

K-12 teachers help students forge meaningful connections to their lives, their communities, and their society. Table 1 outlines how this principle might manifest across grade spans.

Table 1
Situating the problem (Youth Engineering Solutions [YES], 2023).

Situate the problem in a societal context. Students engage in real-world engineering challenges that expand their horizons while connecting to their lives, communities, and cultures. Activities begin with narratives that demonstrate how engineers shape our world by solving problems.	
Lower elementary	Students make personal connections to the problem
Upper elementary	AND think about how the problem impacts their own community
Middle school	AND connect the problem to a broader societal issue

Connecting the engineering challenge to children's personal lives or something they have experienced aligns well with how young children learn. For example, young children at the lower elementary grade levels often have strong preferences for how much light they sleep with at night. They can build upon these experiences to think about how they might design a nightlight that lets enough light through to meet their preferences.

Upper elementary students are generally able to move beyond their personal experiences to consider challenges that various members of their community might face. Eliciting or providing personal experience with a problem is still important. Additionally, students can situate the problem in a larger context. For example, students can think about safety at a local intersection. What technologies are present? Why is the intersection designed the way it is? Which sorts of users is the intersection designed to protect? Which sorts of users might be left out of the intersection's design?

Middle school students can think about a problem in its larger societal or even global context. For example, students can consider how the shoes they wear impact the environment. Because of their personal experience wearing a variety of shoes and their increased ability to take a broader perspective, they can think about the tensions between the materials required for optimal shoe function and the harm those materials cause to the environment. They can consider how both companies and consumers (and they, themselves!) make decisions that affect society and the environment. In this way, their behavior as designers and also as consumers can be taken into consideration.

Consider the Impacts of the Problem on Different Individuals, Groups, or Systems

The technocratic framing of engineering as leading to progress ignores important sociopolitical considerations of who engineering is for and how it affects progress (Bazzul & Tolbert, 2019; Gunckel & Tolbert, 2018; Riley, 2008). Engineering for social justice involves using engineering as a tool to ameliorate existing inequities. In the classroom, this requires a repositioning of engineering within our systems (Burgess & Patterson Williams, 2022) to not just generate solutions to problems but consider the problem definition and solutions from the perspective of all the people impacted by it (Cardella et al., 2012; Downey, 2005; Leydens & Lucena, 2018). Engineering decisions always involve the adoption of ethical stances informed by the impact of engineering on individuals, groups, and systems, and as such this must be a component of engineering education (Baillie, 2006; Baillie & Levine, 2013).

To understand who is being differentially impacted by a problem, students need to consider how particular problems affect some people, groups of people, or systems (such as ecosystems) more than others. This design principle focuses on the problem that exists. Table 2 indicates age-appropriate instantiations of the principles.

Thinking empathetically and recognizing that people might have needs, preferences, or ideas that differ from theirs are skills that students are developing in early elementary grades and are key to understanding the concept of differential impacts. Young children can be asked to think about how people might experience a situation or problem differently and take others' perspectives to consider their needs and wants. Understanding that these might differ from their own is an important step. For example, students might be challenged to design a nightlight that meets the needs of two users with different preferences for light. One side of the nightlight needs to meet the needs of a child who likes a lot of light. The other side needs to meet the needs of a child who prefers a little light. As the students learn about the challenge, they can identify which preferences align with their own sleep preferences as they recognize that others view and are impacted by the problem differently.

Table 2
Considering the impacts of the problem (YES, 2023).

Consider the impacts of the problem on different individuals, groups, or systems. Students consider who or what is most affected by the problem and how. They use this knowledge to make design decisions.	
Lower elementary	Students identify needs or preferences of various users
Upper elementary	AND prioritize design criteria that help reduce harm for the most impacted groups
Middle school	AND make tradeoffs affecting how well they can meet these criteria and justify their decisions using what they understand about the various impacts of the problem

In upper elementary school, students can recognize that a problem impacts some groups more than others. Technologies at intersections have historically been designed for and privilege motorized vehicles. Students can think about other users that traverse intersections, including themselves, and consider problems that they face. For example, pedestrians, scooter users, and wheelchair users generally do not have technologies that allow them to signal to others, including motorized vehicles, how they will move at an intersection. Students can think which users are most impacted by problems moving through an intersection and choose to design a solution for that group. They can attend to design criteria that solve these users' problems. Such experiences begin to develop an awareness in students of the different ways that users may experience a problem and that design solutions can, and should, take these elements into account.

Middle schoolers can engage in design challenges in which there are more complex tensions between what various individuals, groups, or systems need. They may need to make tradeoffs that affect how well they can meet these needs, justifying their decisions based on what they understand about the differential impacts of the problem and what they value as an engineering team. For example, when designing an ecofriendly slipper, one middle school design team might decide to include some environmentally harmful materials in order to ensure the slipper has safe traction and is affordable for its users. Another design team might decide to prioritize the environment by leaving these materials out, while recognizing that their slipper might not be as safe or as affordable for all users.

Think Critically about the Impacts of Engineered Solutions

As the literature review evinced, a critical component of engineering for social justice is considering the benefits and harms of engineering for populations and ecological systems. Disrupting the view of engineering as leading to fundamentally good "progress" for all society (Gunckel & Tolbert, 2018; Riley, 2008) requires the adoption of critical stances about engineering practices and the solutions they generate (Baillie & Levine, 2013; Cardella et al., 2012; Claris & Riley, 2008; Riley, 2008). As youth engage in engineering, it is important to recognize the kinds of orientations they form towards the larger social impacts of engineering (Barak et al., 2022), especially because these orientations can influence how the next generation of engineers conceptualize engineering.

Engineering, and the technologies created through engineering, shape society and are shaped by society. Engineering has led to the creation of many technologies that make some people's lives healthier, safer, more efficient, and happier. However, such technologies can create new problems or exacerbate existing problems and inequities by benefiting or harming some populations more than others. Students can reflect upon how engineers can shape society and consider the various ethical, environmental, political, and cultural factors that may affect the creation and adoption of engineered products. Table 3 outlines how the principle might be translated for various grade levels.

Lower elementary students can start by asking themselves whether the technology they designed actually solves the problem. They can start to expand their view by considering impacts beyond their targeted users. For example, after students design their nightlights, they can identify ways in which their design meets the preferences of the two specified users. They can then think about their own light preferences and those of their peers. Would their technology work for others? Who might be left out of experiencing the benefits of this technology?

Upper elementary students start to grapple with the idea that, sometimes, a technology designed to solve a problem can cause or contribute to another problem. For example, when analyzing vehicle turn signals as a technology, students can identify ways in which its design solves some problems but creates others. Students might suggest that these signals solve a problem of dangerous interactions between vehicles at an intersection by allowing drivers to communicate with each other, but that the same signals might contribute to dangerous interactions between vehicles and pedestrians because pedestrians do not have the same ability to communicate their intentions using this signal system. This mismatch in communication abilities can lead to miscommunication and dangerous situations.

Middle school students can engage with problems that cannot be solved completely by technological solutions. They can start to view engineering in a broader social context by recognizing its successes and limitations when used to solve real-

Table 3
Thinking critically about the impacts of engineered solutions (YES, 2023).

Think critically about the impacts of engineered solutions. Students identify consequences, positive and negative, of engineered solutions. They consider the potential impacts of the technologies they design.	
Lower elementary	Students ask: How does the technology we designed help solve the problem?
Upper elementary	AND consider that sometimes a technology designed to solve one problem creates or contributes to another problem
Middle school	AND consider that technological innovation, on its own, is not often enough to solve complex societal problems

world problems. For example, middle school students might reflect on their ecofriendly slipper design and ask themselves: does this design solve the environmental problems caused by the increasing creation, use, and disposal of synthetic materials in footwear? What other solutions might need to be implemented to work alongside our own technology to better address this problem? Students might suggest that behavioral changes, such as consumers wearing footwear for longer before disposing of it, or companies setting up footwear recycling/reuse programs would help address the problem alongside changes in footwear design.

Allowing room for students' diverse viewpoints and experiences prompts students to recognize that there are multiple stakeholders impacted by an engineering problem and/or solution and that some stakeholders may be disproportionately impacted. In this way, topics for engineering are chosen to develop engagement among students and help them to understand how engineers shape the world they live in. Youth learn how engineering benefits or harms local communities and the environment as well as how to analyze possible impacts of design solutions.

Discussion: Opportunities and Tensions

Our perspective on socially engaged engineering has emerged from a review of relevant literature, commitments to equity in curriculum design, and listening to teachers who have participated in testing of curricula. We seek to develop curricula that prompt students to situate engineering in societal contexts, recognize the differential impacts of engineering, and think critically about the impacts of engineering solutions. We aim to do this, however, within the criteria and constraints of everyday classrooms. In this manner, we strive to work within the realities of schooling in everyday classrooms while also helping to catalyze change that improves the educational experiences of students and the supports that are available for teachers. In this discussion, we reflect on the opportunities of teaching and learning engineering and the accompanying tensions that arise in doing so. Two issues emerge as most salient to reforming engineering education: constraints on dedicated time to engineering in educational settings and limited views of science; science, technology, engineering, and mathematics (STEM); and engineering among teachers and students. We discuss these constraints and the need for evolutionary change committed to bringing about greater social justice through education.

Constraints on Dedicated Time for Engineering

Our engineering curricular units are designed to be integrated into science or STEM time in K-8 educational settings—both in school and out-of-school settings. Through our testing with teachers, we learned that setting engineering in broad societal issues offered an authentic vision for engineering in society, but also posed problems for teachers constrained by time. Engineering is not a core subject matter in K-8 education, so unlike science, mathematics, or language arts, there is not typically dedicated space in the curriculum exclusively for engineering. Engineering education is thus constrained by the limited time that school systems can spend outside of core subject matter. Engineering, when implemented, often occurs in time allocated for science, or STEM, or during less structured times of the school year, such as after state exams. The duration of engineering classes is also limited as most K-8 class periods are short, generally allowing between 30 and 45 minutes of instruction. Finally, the curriculum is packed—there are a limited number of lessons that teachers and schools can dedicate to engineering. Faced with these tensions, the approximately 100 educators who have collaborated with us, advised us that engineering units needed to be fairly short in duration (no more than two weeks) and that activities need to focus on core engineering practices.

Views of Science, STEM, and Engineering among Teachers and Students

Science teachers also stressed the need for engineering lessons that strengthened science understanding. Teachers valued the real-world connections, the emphasis on considering others' perspectives and the varied impacts on groups, and (for older children) the links to societal issues. However, although they found the lessons that explored societal, economic, and environmental issues in more depth quite interesting, they also suggested that most of these needed to be removed or made optional. This tension echoes that of the field. In some ways, this is to be expected, and this is also the primary motivation for conceptualizing and implementing socially engaged engineering. The curriculum units place emphasis on socially engaged engineering in an effort to help teachers and students reconceptualize the domains of science and engineering to include considerations of technical, social, environmental, and ethical dimensions of engineering.

The core commitments of socially engaged engineering are to set engineering in societal contexts, recognize the differential impacts of engineering, and think critically about the impacts of engineering solutions. These commitments portray engineering in ways that recognize the importance and relevance of the designed world for social justice. Yet, this view also runs against the technocratic view of engineering that only focuses on the technical and conceptual aspects of engineering design.

As engineering is often linked to science instruction, ideological views of science also permeate interpretations of the disciplines in schools. Our pilot and field test teachers indicated that they could not allocate "science" or "STEM" time to what they perceived as lessons on social issues. Interestingly, some teachers also reported that students viewed the societal aspects of engineering to be "social studies," and thus were resistant to doing such work in a science/STEM class. Finally, testing in classrooms revealed that students require additional scaffolding lessons to build the basic understandings that underlay lessons that asked students to consider the ways that engineering intersected with social, ethical, political, cultural, or environmental issues, which further exacerbates the constraints on time that can be dedicated to engineering.

Evolutionary Change of Educational Reform

The categorical separation of disciplines within STEM from social justice issues among some teachers and students is frustrating but is an undeniable reality facing educational reform. As curriculum developers, we needed to listen to teachers' voices, honor their perspectives and needs, and design for the realities of their world. If we wanted to introduce socially engaged engineering in a manner that would be taken up in classrooms across the country, we had to temper what we learned from the literature. Our lessons still address the socially engaged principles we distilled, but in a more limited manner. These experiences reminded us, again, that change in classrooms is often evolutionary and that new ideas are constrained by external factors. As we push for new approaches in classrooms, new disciplines, and new interdisciplinary work, such change might be incremental. The challenge for us is to value these complexities, be clear about our commitments to engineering and changing education for the better, while also knowing that what counts as engineering, and for whom, and under what conditions, is open for debate, discussion, and ongoing dialogue.

Our team will continue to work closely with educators to develop curricular materials. As these are "finalized," we will undertake research studies that investigate how teachers facilitate and students engage with socially engaged engineering. Observations and video analysis of teachers' and students' classroom discourse and engineering work as they engage in the lessons will illuminate how the ideas are taken up in classrooms. Further exploration about this take-up of ideas can inform improved versions of frameworks and resources.

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