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Abstract

The broad case being made in this paper is that recognizing student assets—rather than focusing on deficits—is essential for making engineering education more equitable. The paper begins with our exploration of an epistemic practice of engineering, "making trade-offs," as enacted by kindergartners after experiencing design failure and during redesign. We then acknowledge through a reexamination of data that our understanding of children's grappling about a trade-off was incomplete without considering another asset that children brought to the design experience: "enacting empathy and an ethic of care." We argue for the inclusion of this asset as an epistemic practice of engineering. Doing so has implications for improving learning experiences, research, and equity in engineering education.

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Introduction

The purposes of schools include preparing individuals for employment, sustaining an informed citizenry, and acquainting students with society's cultural and historical roots. There is also the fundamental goal of educating children about subject matter. Learning about the academic disciplines increases employability, enriches decision-making, and advances a democratic society. The presence of educational standards is but a recent example of subject matter mastery as a learning goal with its associated push to generate student interest and motivation to learn. Valuing education does not translate into unified agreement about how it should be designed and implemented. Adults may view engineering education as a technical challenge to fix a mismatch between a child's ignorance and subject matter knowledge. This disciplinary focus has long influenced educational decision-making.

Progressivist philosophy takes issue with viewing children's innocence as flawed and in need of repair (Dewey, 1906). Instead of prioritizing transmission of disciplinary knowledge, progressivist educators see students arriving at school as carrying "past doings, thinkings, and sufferings" (p. 35). Student-centered views recognize utility in previous experiences among those who are not experts at engineering. The case made in this paper is that recognizing student assets, rather than focusing on deficits, is as important to kindergartners' engineering education as it is for college students. In addition to expanding engineering education to the very start of formalized schooling, this project extends the desire to improve students' engineering skills and knowledge to include Dewey's third category of "sufferings." Empathy as a learning resource emerged during this study—but only after the authors puzzled through the unexpected yet consistent ways children

interpreted the design challenge presented to them. During the activity itself, we came to recognize how children drew upon an ethic of care while engaged in an engineering design activity. Their caring not only influenced their designs but authentically mirrored advice about engineering education becoming more responsive to people, cultures, and society (Gunckel & Tolbert, 2018; Martin et al., 2018). In turn, the authors came to respect a more complex range of assets that students bring to the design process within engineering education (Bullough, 2012; Penuel & Furtak, 2019).

Underrepresentation with regard to gender, race, ethnicity, and other identities within engineering courses and careers has been a concern for many educators. Proposed causes of disparities range from school policies that produce uneven opportunities to participate in high-quality learning experiences (Sattin-Bajaj & Roda, 2020) to suggestions as to whether role models are necessary to increase gender, racial, and ethnic diversity (Bettinger & Long, 2005). Often missing from proposals for diversifying engineering education is consideration about the resources inherent within the students, their families, and communities (e.g., Brophy et al., 2008). Instead of recognizing how human assets could be leveraged to improve engineering education, too often the focus has centered on teacher knowledge, technology affordances, and curricular innovations. While scholars consider ways to reduce educational disengagement from engineering, the consideration of race, class, and gender is very tentative (Adams et al., 2011). Rarely do such discussions reveal with confidence that students have backgrounds that could promote stronger engagement. Given the challenges of racial and ethnic diversity among professional engineers as well as educators, it seems likely that differences in identities between the adults and the students is not perceived as an opening for growth but rather a hole that impedes learning. Innocence or ignorance about the potential educational affordances with students, families, and communities all too often translates into educators seeing deficiencies rather than untapped resources. We suggest that those committed to infusing engineering education into pre-K-12 education should adopt greater curiosity about the manner in which students navigate engineering design challenges. Our own puzzlement over students' design choices was rooted in a failure to be sufficiently attuned to ways that students leveraged previous experiences to solve the engineering challenges we placed before them. In retrospect, we may have been too tied to a narrow set of factors that might inform reasonable engineering design possibilities. A little curiosity about students' thinking processes might have kept us from being inattentive to students' unique assets.

More than making engineering relevant, forging substantive connections between formal engineering education and the lived experiences of those being educated is captured by the phrase "funds of knowledge" (Moll & González, 2004). Heightened regard for the resources embedded within students, along with their families and communities, is vital to those who seek increased engagement by students who are typically not seen as "engineering types" because of gender, ethnicity/race, physical abilities, English fluency, family structures, social class, etc. In effect, the stereotypes about engineers create a sense about normalcy. Engineering's historical gender imbalances perpetuate implicit biases against females (Eberhardt, 2020) and, by association, traits seen as feminine (Amy Sue, 2013; Capobianco & Yu, 2014). Similarly, racial biases foster disparate performance between Black and White student populations across a host of educational outcomes (Shores et al., 2020). Despite expressed desires to diversify engineering, there is a self-perpetuating cycle where unawareness of students' assets translates into beliefs about deficiencies which in turn exacerbates inequities and decreases opportunities for academic success. Breaking this cycle becomes possible when students' backgrounds are viewed by engineering educators as resources that foster and "fund" learning.

McGowan and Bell (2020) remind us that these intellectual assets, albeit in less sophisticated forms, are woven into professional engineers' work. But beyond bits of knowledge, engineers rely on epistemic resources—or "ways of knowing" (e.g., Moore, 1993)—that even young learners will draw upon as they engage in engineering sensemaking and solve design challenges. Science education standards proposed a set of engineering practices for K-12 students; these practices have been enhanced by engineering education researchers and their list is empirical and enlightening. Such engineering epistemic practices describe the work of practicing engineers within their professional communities. We contend that such practices are refinements of natural intellectual practices. In other words, the ambition of diversifying participation within engineering would benefit from seeking within students the nascent foundations of these more sophisticated practices. To believe students are too young or too naïve to hold ideas that could be developed into engineering knowledge, practices, or dispositions risks continued disenfranchisement. As an alternative, we propose presuming that students (and their communities) offer funds of knowledge as resources to support authentic engagement in order to move closer to the ideal of equitable educational opportunities for all students.

Background

Epistemic Practices

Epistemic practices are the means by which knowledge claims are developed, applied, analyzed, and evaluated within communities. Cunningham and Kelly (2017) proposed sixteen epistemic practices of engineering "to make visible the ways of knowing that should ground students' experiences in engineering" (p. 489). These practices are listed in Figure 1.

Developing processes to solve problems
Considering problems in context
Envisioning multiple solutions
Innovating processes, methods, and designs
Making trade-offs between criteria and constraints
Using systems thinking
Applying math knowledge to problem-solving
Applying science knowledge to problem-solving
Investigating properties and uses of materials
Constructing models and prototypes
Making evidence-based decisions
Persisting and learning from failure
Assessing implications of solutions
Working effectively in teams
Communicating effectively
Seeing themselves as engineers

Figure 1. Engineering education's epistemic practices (Cunningham & Kelly, 2017).

Cunningham and Kelly's (2017) epistemic practices represent goals for students as they come to know and do engineering. Together, these offer a guiding framework for engineering education to support learners from pre-kindergarten (pre-K) through graduate studies.

Making Trade-offs

Initially, this study's focus was on kindergartners' engagement in one epistemic practice: making trade-offs between constraints and criteria (hereafter, "making trade-offs"). This epistemic practice has been advanced as an important practice within engineering education (American Board for Engineering and Technology, 2019; Crismond & Adams, 2012; Moore et al., 2014; Strimel et al., 2020). Making trade-offs is about compromising or prioritizing during the engineering design process among constraints and/or criteria. For example, if an engineer wants to use a particular material because of its specific properties, they must also consider the material costs or manufacturability. The most ideal material with respect to material properties may be too expensive or difficult to manufacture. This illustrates the practice of trade-offs where the desired material must be balanced against the price that would be paid to use it.

Making trade-offs is an act of agency by engineers and students-as-engineers as they consider and balance constraints and criteria to optimize their solutions. Citing Kelly et al. (2001) and Stroupe (2014), Kelly and Cunningham (2019) offered: "Balancing…trade-offs and creating viable solutions…positions students as epistemic agents contributing to the direction of inquiry and type of knowledge and practice constructed in the local setting" (p. 1094). Such agency is manifested by students "bringing in disciplinary knowledge with their own lived experiences and unique ways of being" (p. 1081). Prior work by the first author and colleague—about trade-offs within the same design challenge for kindergartners reported in the present study—promoted centralizing this epistemic practice (Lottero-Perdue & Tomayko, 2020b). Among the epistemic practices for engineering education appearing in Figure 1, not as much has been reported about making trade-offs. Below we summarize specific investigations of younger students.

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Research on Making Trade-offs in Early Childhood and Elementary School

Although researchers have explored middle school and older students' engagement in making trade-offs, few studies have examined early childhood or elementary school students' engaging with this epistemic practice. Broadly, middle and high school level studies revealed that while students can make trade-offs among constraints and criteria during the design process, they do so less adeptly than informed or experienced designers, and may benefit from teacher support (e.g., Goldstein et al., 2015; Purzer et al., 2015; Quintana-Cifuentes et al., 2019).

The elementary engineering education literature includes examples of students engaging in making trade-offs, but few have investigated student engagement in this practice in depth. Kelly and Cunningham (2019) described epistemic tools used within two Engineering is Elementary design challenges to support elementary (Grades 1–5) students' engagement in making trade-offs. One design challenge about locating a special kind of wire bridge within a village encouraged students to weigh trade-offs among scientific and cultural constraints and criteria; a map and student-written letter to the villagers were the epistemic tools used to scaffold student engagement in this practice. The other challenge involved designing parachutes and in so doing making trade-offs between rate of descent and parachute size. Hynes and Swenson (2013) include a vignette in their work about the humanistic side of engineering in which fourth-grade students considered trade-offs between material type and cost while engineering a periscope for characters in a book. Also, an article in the elementary teacher practitioner journal *Science and Children* shared how fourth-graders negotiated trade-offs between two competing criteria for an egg-package challenge: (1) material cost of the package and (2) effectiveness of the package at protecting the egg (Purzer et al., 2013).

Empathy and an Ethic of Care

The list of sixteen epistemic engineering practices (Figure 1) was not intended to provide an exhaustive account but rather to represent "features of engineering with most relevance to quality educational experiences for K-12 education" (Cunningham & Kelly, 2017, p. 491). This list was an effort to advance engineering education beyond overly simplified standards-based engineering practices (National Academy of Engineering & National Research Council, 2009; NGSS Lead States, 2013).

In revisiting the investigations of epistemic practices among kindergarten engineers in the present study and our other work (Lottero-Perdue & Tomayko, 2020a, 2020b), we have come to understand that another practice—*enacting empathy and an ethic of care*—is worth including as a relevant and important epistemic practice of engineering. We advocate for recognizing and valuing this practice as an asset held by children to support their engagement in engineering. Beyond our concern that its exclusion as a key epistemic practice ignores an asset held by many children *and* an asset that is important within engineering, we are concerned that excluding and devaluing empathy and care may further disadvantage girls and women within engineering (Capobianco & Yu, 2014). Although girls and women are not the exclusive implementers of empathy and care, these traits have been traditionally assigned to women and girls (Fisher & Tronto, 1990; Tronto, 1993). After clarifying our view about enacting empathy and care, we elaborate on the justifications for elevating the status as a practice and feature of effective engineering education.

Defining Empathy and Care

Within and beyond the engineering education literature, there are multiple definitions and categories of empathy and care; it is beyond the scope of this paper to consider them all. Rather, we will focus sharing the operating definitions that we will use here that others have put forth both within the empathy and care literature in general and with respect to engineering.

Empathy. According to Decety and Jackson (2006), empathy "refers to the capacity to understand and respond to the unique affective experiences of another person" (p. 54). In addition to this individualistic understanding of empathy, we also wish to build on the idea of social empathy, defined by Segal (2011) and emphasized in the work of engineering education and social work researchers Walther et al. (2017). Social empathy is:

> The ability to understand people by perceiving or experiencing their life situations and as a result gain insight into structural inequalities and disparities…[which] can lead to actions that effect positive change, social and economic justice, and general well-being. (Segal, 2011, p. 267 as cited in Walther et al., 2017, p. 127)

In both of these individualistic and social forms of empathy, there is not only perspective taking and understanding but also a resulting responsiveness and action.

Care. In supporting care as a guiding practice within engineering education, both Capobianco and Yu (2014) and Gunckel and Tolbert (2018) drew upon Fisher and Tronto (1990) who defined caring as:

> a species activity that includes everything that we do to maintain, continue, and repair our "world" so that we can live in it as well as possible. That world includes our bodies, our selves, and our environment, all of which we seek to interweave in a complex, life-sustaining web. This effort to keep life going does not assume that certain people (women rather than men) have a special ability to sustain our world or that some efforts (healing rather than house-building) make a more important contribution to sustaining life on Earth. (p. 40)

We included not only the first sentence's definition, but also the subsequent two sentences to show the feminist underpinnings of their work, which resist stereotypical ideas that caring is "only" women's work and as such, is devalued.

Similar to how social empathy encourages thinking beyond the individual to the social/political, Gunckel and Torbert (2017) referenced de la Bellacasa (2011) to argue for the importance of "contextualized caring practice" (p. 953). de la Bellacasa (2011) warned that caring was relative: "a way of caring over here could kill over there" (p. 100). Like social empathy, care is "an ethically and politically charged practice…at the forefront of feminist concern with devalued labors…and signifies: an affective state, a material vital doing, and an ethico-political obligation" (p. 90).

Empathy and Care Together. Ultimately, we employ the idea of Hess et al. (2017) to combine these closely related concepts of empathy and care in the context of engineering. Together, the constructs of empathy and care "represent both understanding and feeling for others through a variety of techniques and, generally, acting on that understanding or internalization" (Hess et al., 2017, p. 1132). Their combined definition arose from their work of exploring ideas about care and empathy among practicing engineers (Hess et al., 2016). We add to this idea the dimensions of empathy and care for purposes of empowerment and social justice. In what follows, we will continue to address empathy and care similarly.

Empathy and Care in Engineering and Engineering Education

Hess and colleagues (2017) conducted an extensive analysis of practicing engineers' perspectives on empathy and care in their work. One major conclusion was that with more years of work experience, engineers were more likely to recognize the existence and importance of the practices of empathy and care within their profession. Although participants reported that their collegiate experiences did not increase their empathy or caring, they "suggested a greater inclusion of empathy and care within the culture of engineering has the potential to improve engineering practice along multiple facets" (Hess et al., 2017, p. 1145). Walther et al. (2017) examined alignment between engineering and social work fields, arguing that empathy is "concurrently and inseparably, a teachable skill, practice orientation, and professional way of being" (p. 124). Fore and Hess (2020) have included care among five components of "ethical becoming…[which can] be thought of as a process of reflective inquiry and caring practice" (p. 1366).

Empathy and care in engineering education continue to garner more attention. For example, scholars in the engineering education community have investigated empathy in the context of service learning courses for engineers (e.g., Hess & Fila, 2016). A search of annual conference proceedings papers for the American Society for Engineering Education over the last 20 years shows that the number of papers mentioning empathy increased by 26.2 times between 2000 and 2020; the total number of papers increased during this time by 2.4 times.[1] In other words, about 1% of papers mentioned empathy in 2000 whereas 7% did so in 2020. Use of the term "caring" increased between 2000 (128 papers; 18% of all papers) and 2020 (398 papers; 22%). By comparison, "trade-offs" or "tradeoffs" increased from 26 publications in 2000 to 67 in 2020 at about the same rate as did the total number of papers, making up 4% of the annual conference papers in both 2000 and 2020.

Including Empathy and Care in Engineering for Equity and Social Justice

Because they are key features of engineering, we are championing empathy and an ethic of care as an engineering epistemic practice (Hess et al., 2017; Walther et al., 2017). Additionally, we recommend using this practice within efforts to promote equity and social justice. Citing Walther et al. (2017), Gunckel and Tolbert (2018) claimed that there has been "little attention to developing social empathy and care as essential aspects of engineering education and practice" (p. 939). This is fundamentally problematic because engineers shape the problems being addressed and the ways in which those are solved. Gunckel and Tolbert (2018) argued for developing student engineers' social empathy to help them:

> understand and deconstruct contexts of power and inequality in classrooms, in the workplace, in the engineering design context, and in relationships between engineering and society…[and] develop more in-depth understandings of the

[1]Note that this was not a title search, but a simple search for terms.

> structural inequalities that play a role [in] how the problem is defined and delimited, as well as what solutions might be beneficial, relevant, and accessible, to whom and form whom. (p. 952)

Capobianco and Yu (2014) advocate for explicitly infusing care throughout the design process because it "provide[s] a useable means of re-representing engineering as a caring profession" (p. 30). This juxtaposes with the more common "technocratic, utilitarian framing of engineering in the science curriculum" (Gunckel & Tolbert, 2018, p. 940) that privileges some populations while discouraging and excluding others. Capobianco and Yu (2014) drew upon Fisher and Tronto's (1990) four components of caring: caring about (i.e., recognizing that care is needed); taking care of something/someone (i.e., initiating and supervising care); caregiving (i.e., actually doing the work of caring); and receiving care (i.e., responding to the care being given). Capobianco and Yu (2014) aligned these aspects of care with analogous features of the engineering design process to re-represent engineering as a caring profession. In particular, this elevates caring by engineers during problem scoping and information gathering where the problems faced by others and help that may be needed are prioritized. Further, taking care occurs during the generation of design solutions.

Empathy and Care as a Means to Value Student Assets and Equitize Engineering Education

Another reason to elevate empathy and an ethic of care to the status of an epistemic practice of engineering is to place value on what students bring to the learning experience. Consider a conceptual "backpack" of epistemic practices that children might bring with them to the learning experience from Cunningham and Kelly's (2017) list. We want children to strengthen their capacities to apply science concepts, make decisions using evidence, persist, and work on a team. During engineering design challenge experiences, these resources can be routinely taken out of the backpack, attended to, developed, and refined. Even young children bring with them the propensity to engage in empathy and demonstrate care (Decety et al., 2018; Howe et al., 2008). However, if we do not make explicit the importance of empathy and care during engineering design experiences, that practice will stay in the backpack. It will not be used, developed, or improved in the context of engineering—its value decreased—and the message to the child will be that this particular asset is not important for engineering. This devalues the practice, which is indeed important to engineering. Further, such neglect devalues the child's assets, likely distancing them from schooling.

In the financial sphere, "equity" describes assets held by an individual, group of individuals, or organization. To equitize is to divide assets among multiple investors. Although still asset-focused, we use "equitize" here a bit differently. By equitizing engineering education, we suggest that educators attend to the multiple assets that students bring with them and develop those assets within engineering education. We equitize engineering education by placing more value on the multiple assets that students bring with them to engineering learning experiences that support students' epistemic agency.

From a teaching perspective, identifying students' initial ideas has long been recognized as vital to teaching success (Larkin, 2012). Over the decades of science education research, there has been an evolution in both theory and practice about making effective use of children's ideas. In the post-Sputnik heyday, Piaget's developmental stages shaped views of students as on a continuum from sensory motor to formal operations (Bliss, 1995). Curricula were created to accommodate these ideas (Bruner, 1960). Two decades later, alternative conceptions or naïve theories were treated as important preexisting student ideas that needed to be accounted for in preparing for instruction (Driver & Easley, 1978; Posner et al., 1982).

More recently, science and engineering educators have become more attuned to the cultural and linguistic background that students possess that can be viewed as instructional resources rather than impediments (Martin et al., 2018; Moll & González, 2004; Rosebery et al., 2010; Suárez, 2020; Tan et al., 2019). Across the years, it has been recognized that the knowledge students already have is instrumental in influencing their cognitive responses to new material. What has changed over these years has been an expanding regard for the knowledge resources educators should not ignore. Currently, pre-K-12 teachers are encouraged to seek connections to students' personal experiences as well as from their familial, cultural, and community knowledge bases (Bang & Medin, 2010; Bell, 2019). This is where an assets-based approach to engineering education addresses the goal of advancing educational equity.

Research Questions

Our purpose in this paper is to reveal what we found and what we missed when we excluded—and then learned to include—the epistemic practice of empathy and an ethic of care in our focus on how kindergartners grappled with trade-offs after design failure. Specifically, we ask:

1. How did kindergarten participants negotiate a key trade-off after design failure and during redesign?
2. What evidence is there that participants may have also employed empathy and an ethic of care as they negotiated this trade-off?

Study Context and Participants

Curriculum

The engineering design challenge that is the focus of this study occurred after students in participating classrooms engaged in two science lessons and were introduced to the challenge. By "students in participating classrooms," we mean classrooms from which students were invited to participate in the study.

Science Lessons

Students engaged in a lesson about force and motion followed by a lesson about inertia (Lottero-Perdue et al., 2017). The latter lesson involved students conducting an investigation to construct the idea that foam blocks are easier to move than wood blocks of the same size. This investigation provided experimental evidence that, when impacted by a toy car that had been released from the top of a ramp, the foam block would travel farther than the wood block.

Introduction to the Design Challenge

Each classroom of students was then introduced to the Hexbug Nano® robot, a device about size of a toothbrush head (Figure 2). It vibrates which causes it to move quickly on smooth surfaces and in a random pattern (arcs, circles, lines).

Students observed what the robot (which we named "Henrietta") looked and felt like, and how it moved. The problem was posed to the students as a question: "What would happen if we turned Henrietta on, put her on the [linoleum] floor, and left the classroom?" Students predicted that Henrietta would move enough to become lost or stuck under the cabinets. To elicit the idea of fences being used to surround an area, students were then asked what farmers or pet owners use to keep animals from wandering away but also give them space to walk or move around. Students were shown a small plastic model split rail fence, similar to one used on farms.[2] A plastic model horse named "Arlo" was placed inside to demonstrate the utility of the fence and then a final question was posed: "This is a good fence for Arlo. Would this be a good fence for Henrietta?" Students indicated no because Henrietta would easily escape by going under the fence.

To conclude the whole-class introduction of the design challenge, students were told that the goal of the design challenge was for students to create a fence suitable to contain Henrietta. Students could only use the same blocks they had previously worked with during the preceding science investigation—and they could only use up to 10 wooden and 10 foam blocks to make their fences. The fence would need to keep Henrietta from escaping from it for at least 30 seconds (Criterion 1, "containment") and provide Henrietta with as much room as possible to move (Criterion 2, "fence area"). Fence success or failure would be determined by whether Criterion 1 was met; Criterion 2 was a subjective criterion for children to consider, but was not formally measured. The science lessons and presentation of the robot and problem occurred over a period of two weeks and preceded data collection. As will be discussed in the methods section, data collection refers to where the participants independently engaged in the design challenge.

Key Trade-off in the Challenge

The key trade-off considered in the development of this design challenge is between block type and fence area. Block type related to the constraint of the types of blocks participants can use, and also related to Criterion 1. While Henrietta is able to easily push a foam block—and thus able to escape from a fence made with foam blocks—Henrietta is typically unable to do so with a heavier wood block. As mentioned above, the fence area is directly related to Criterion 2. To demonstrate the trade-off relationship between block type and fence area, we share two examples depicted in Figure 3:

- **Example 1: favoring block type** (Criterion 1). If a participant uses a continuous "loop" (a square, rectangle, circle, or some other shape) of wood blocks as the perimeter of the fence—in other words, to completely encompass the fence area—the fence is more likely to contain Henrietta. This favors block type (Criterion 1) over fence area. Since only 10 wood blocks can be used in the fence perimeter, the fence area is constrained to be smaller than that used by, for example, all 20 blocks (10 wood, 10 foam).
- **Example 2: favoring fence area** (Criterion 2). If a participant uses all 20 blocks to create a very large fence, they are favoring fence area over block type in the trade-off. In doing so, the participant uses foam blocks in their design that Henrietta can move and thus from which Henrietta can escape containment.

[2] Prior to this study, we introduced the model split rail fence to make the design challenge understandable to students regardless of background. Early testing of the challenge well before this study first occurred at a rural school where most children understood that a fence went completely around a field or other area. When the challenge then was taught at an urban school, the first author and colleagues learned that some children at the urban school had largely had experiences with fences in which they walked along side of fences. Thus, to make the challenge more inclusive we added the plastic model to help children understand that the fence they would create needed to go all the way around the area where Henrietta would be moving.

Figure 2. Henrietta, the robot.

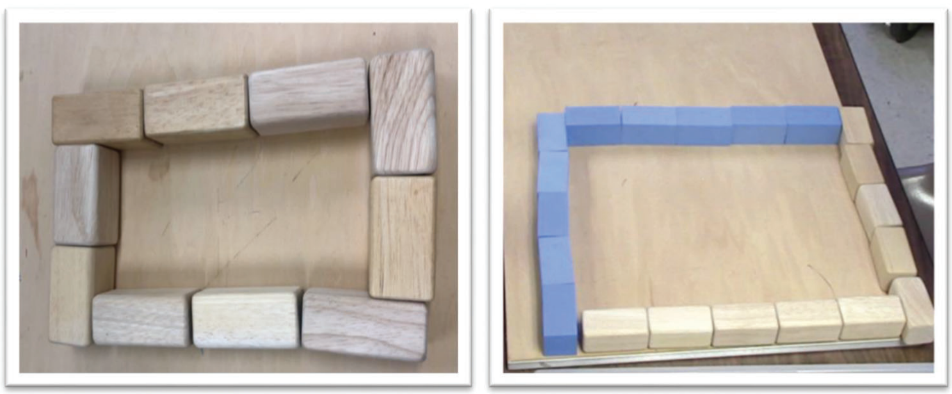

Figure 3. Contrasting fence construction favoring one constraint over the other.

In the development of this design challenge, Example 1 is the "ideal" in that it applies ideas learned about inertia from the science investigation and prevents Henrietta's escape (Lottero-Perdue et al., 2017).

Schools and Classrooms

Students from five classrooms in three elementary schools (i.e., grades pre-kindergarten or kindergarten through grade 5; ages 4 or 5 through 11) in a school system in the mid-Atlantic area were invited to participate in the study. The schools were Blakely Elementary, Adamsville Elementary and Kellerton Elementary. (Note that all school and student names used in this paper are pseudonyms.) These schools were purposefully selected based upon the first author's prior work at Blakely and Adamsville and with a recommendation from school system leadership to include Kellerton in the sample. Together, these three schools were representative of the diverse types of schools within the system.

Blakely enrolls about 100 students and is in a rural area. Blakely and the other schools in the study reported having approximately an equal number of male and female students. Blakely's website reported that the school had 85% White students along with other racial and ethnic categories too low to report. The percentage of students enrolled in the Free and Reduced Meals (FARMs) Program was about 36%. Only nine students were in a single kindergarten classroom during the year of the study. The science lessons and challenge introduction at Blakely were co-taught by the classroom teacher and the first author.

Adamsville is in an urban area with about 500 students. The race and ethnicity of students reported on the Adamsville website were: 45% African American, 30% White, 14% of two or more races, 10% Hispanic, and other categories too low to report. Nearly 83% of students were enrolled in the FARMs Program and the school is designated at Title 1 which infuses additional federal funding because of the high incidence of poverty. There were approximately 70 kindergartners across four classrooms at Adamsville during the year of the study. Two of those classrooms were led by teachers early in their career.

Because the principal preferred research activity be conducted in classrooms led by more experienced teachers, the classrooms of the two veteran teachers were where this study occurred. The science lessons at Adamsville were taught in all four classrooms by the first author's elementary science teaching interns under the first author's and each classroom teacher's supervision. The first author taught the introduction of the challenge.

Kellerton is located in a middle-class suburban area with about 400 students. Racial/ethnic statistics for this school were approximately: 5% African American, 85% White, 5% two or more races, 5% Hispanic, and other categories too low to report. Nearly 20% of Kellerton's students were enrolled in the FARMs Program. During the year of the study, approximately 65 kindergartners were distributed across three classrooms. Similar to the situation at Adamsville, the Kellerton principal preferred that we draw from just two of the three classrooms with somewhat more experienced classroom teachers. Similar to Blakely, the first author co-taught the science and challenge introduction lessons with all three Kellerton classroom teachers.

Participants

Students from five classrooms were invited to participate. Letters of consent were sent to parents explaining the data collection process, which included video-recording and assured confidentiality. Assent from students was verbally obtained. Rates of participation for participating classrooms were as follows: (1) Blakely (100%; 9 participants); Adamsville (36%; 13 participants); and (3) Kellerton (70%; 31 participants). The total number of participants in the study was 53. These participants were in the second half of their kindergarten year at the time of the study and ranged from 5.5 to nearly 7 years in age. The kindergarten classrooms from which we recruited participants were representative of the gender, ethnic, and racial make-up of their respective schools.

When the first author designed the study, demographic data about students were not collected. The primary goal of the initial study was to draw from a diverse set of schools to be as inclusive and representative as possible. On the other hand, there were perceived to be interpretive problems if gender, ethnicity/race, and other demographic descriptors of participating students were collected. Especially given what was likely to be a small sample size, this avoided the trap of making demographic subgroup comparisons. Such contrasts were not the focus of this investigation. Additionally, there were concerns about asking parents to indicate participants' demographic descriptions given that we were already asking them to consent to collecting video of their children. In retrospect, collecting demographic data would have helped to report participant demographics. That said, we were fortunate to include a range of students, reflective of the diversity within their schools.

Methods

Our study investigated how participants *individually* engaged in the engineering design process, and how they negotiated the key trade-off in the challenge and employed empathy and an ethic of care after design failure and during redesign. Figure 4 shows where data collection occurred (i.e., following whole-class science lessons and the introduction to the challenge, but before engaging in the challenge within teams).[3]

Data Collection

As suggested above, the first author designed data collection methods for the study. She conducted situated semi-structured cognitive clinical interviews to explore what the participants "do, say, and make" as they witnessed the first design testing process, explained what they observed, and created a new design (Kelly & Green, 2019, p. 8). These interviews were *situated* in that they directly related to classroom lessons leading up to the interview, used named and familiar artifacts, and were precursors to students doing a similar design challenge in teams in their classrooms. The interviews were *semi-structured*, utilizing a protocol but allowing for flexibility and follow-up (Saldaña & Omasta, 2018). These were *cognitive clinical* interviews, each involving a single researcher (the first author) and participant (kindergartner), and utilized a primarily inquiry-based frame in which students were constructing, narrating, and explaining their design ideas during the interview (Russ et al., 2012). These interviews took place at each school in a quiet room near each classroom, were video-recorded, and lasted about 20–30 minutes.

Each interview began by the first author reviewing: the need for a fence for Henrietta; what they had learned about wood and foam blocks (e.g., how they were different, what they learned from the science investigation); the constraints (i.e., that only up to 10 wood and 10 foam blocks could be used); and the criteria (i.e., Criterion 1, containment; and Criterion 2, fence area). Students were asked to explain their Design 1 (D1) fence decisions, test the D1 fence, share what

[3]After data collection, every child from all seven classrooms across the three schools, including classrooms from which we did not draw participants, were able to engage in the design challenge in teams. These lessons were co-taught by the first author and classroom teachers.

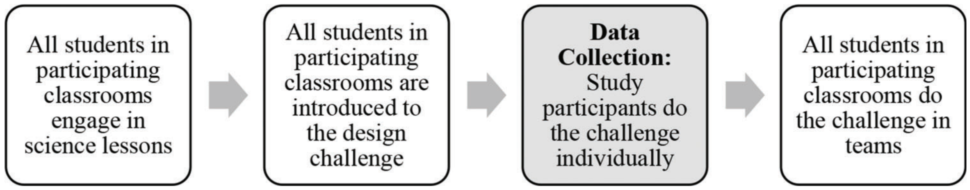

Figure 4. Instructional and data collection activities related to the study.

happened during the D1 test, and then create and explain their Design 2 (D2) fence. There was some variability across interviews with respect to the specific way that questions were posed. The following set of questions is representative and occurred after D1 creation:

1. How many wood blocks did you use? Foam blocks?
2. Can you show where Henrietta would go inside of your fence?
3. How will your fence keep Henrietta in?
4. What [else] do you want to tell me about your fence? [Ask about any additional features.]
   After D1 testing:
5. What happened? What did Henrietta do?
6. Which block(s) did Henrietta move?
7. Do you want to try again? or Do want to try to make your fence better?
   After D2 creation:
8. How is this different from your first fence?

The first part of the protocol explored how students described the foam and wood blocks, recalled the science investigation, and described the need to create a fence for Henrietta. The interview questions and the interaction between the interviewer and child served as epistemic tools, as did the physical materials (blocks, Henrietta), to support participants' opportunities to engage in making trade-offs and applying science (Kelly & Cunningham, 2019).

Researcher Roles Prior to and During Data Collection

By the time that students participated in the interview, the first author had spent about six hours in each classroom observing, volunteering, and teaching. The first author also collected all data for the project. Children likely saw the first author as part-teacher/classroom helper and part-researcher/adult who asks questions, consistent with an active membership role in the classroom community (Adler & Adler, 1987; Saldaña & Omasta, 2018).

Data Analysis

As part of a prior study, the first author and colleague generated transcripts of video files, adding information about what students were doing and how they were gesturing to those transcripts (Lottero-Perdue & Tomayko, 2020a). Pseudonyms were assigned to each participant. Qualitative data analysis through iterative coding was somewhat different for the trade-off research question than it was for the empathy and ethic of care research question.

Trade-off Analysis

Coding related to trade-offs was largely based on our (Lottero-Perdue and Tomayko's) "prior ideas of what is important" in the data (Maxwell, 2013, p. 107). Two of these were the *D1 description* and *D2 description* codes, with subcodes for the shape of the perimeter, number of foam blocks, number of wooden blocks, pattern of wood/foam blocks, orientation of the blocks, the presence of gaps, and whether or not blocks were stacked. Another broad code for the study was *D1 fail*, i.e., whether or not D1 failed. When the D1 fence failed, the attribution of this failure by the researcher, based on their observations, was coded as *researcher failure analysis* (RFA). RFA subcodes were that Henrietta: pushed a foam block, moved through a gap, or escaped by some other means. Student responses to interview prompts such as "What happened?"; "What did Henrietta do?"; and "Which block(s) did Henrietta move?" were coded for *student failure analysis* (SFA); these included that it was correct, partially correct, incorrect, unclear, or not performed.

These codes and subcodes were assigned to the transcripts by iteratively analyzing subsets of the 53 transcripts, referencing video excerpts and design images as needed (Saldaña & Omasta, 2018). We independently coded, compared, and came to consensus on codes, subcodes, and assignment of codes to the data, a form of intercoder agreement. In addition

to pulling quotes and observed behaviors from the data, we calculated percentages of participants who engaged in these practices; however, these are not meant to suggest statistical generalizability beyond our participants. We used Excel as our primary tool to code, analyze, and organize data. Additional analyses utilizing this Excel document were conducted by the first author to reorganize the data in preparation for the present study to focus in on how participants attended to the first criterion related to the ability of the fence to contain Henrietta (block type) and the second criterion related to providing space for Henrietta to move (fence area).

Empathy and an Ethic of Care Analysis

Coding related to empathy and an ethic of care is best described as "an inductive attempt to capture *new* insights" rather than our "prior ideas of what is important" in the data as for the trade-off analysis (Maxwell, 2013, p. 107). In other words, although our cognitive clinical interviews were not structured around empathy and care, the follow-up analyses of the data by the authors of the present study—Lottero-Perdue and Settlage—considered ways in which empathy and an ethic of care were present in the children's designs and the explanations they shared. This resulted in the following codes: *empathetic/caring response about the need for a fence*; *evidence of care for Henrietta in fence design*; and *evidence of care for Henrietta's owner in the fence design*.

Findings

We have organized the findings into three main sections. First, we describe how we narrowed the participant sample from 53 to 31 in order to focus on trade-offs between block type and fence area in the space between D1 testing and D2 creation. Second, we address findings related to the first research question about how participants negotiated the key trade-off between block type and fence area. Third, we share evidence for the ways in which the participants employed empathy and an ethic of care, which is related to the second research question.

Participants of Focus

The participants of focus for this study are those: (1) whose D1 fences failed, (2) whose D1 fences encompassed an area, (3) whose D1 fences failed because Henrietta was able to move a foam block and escape, and (4) who created a D2 fence. Specifically:

- Of the 53 study participants, 42 had D1 fences that failed; the remainder succeeded (9) or were not tested (2).
- Of the 42 participants whose D1 fences failed, 38 included an enclosed area; the remaining 4 designs resembled single one- or two-sided walls.
- Of the 38 participants whose D1 fences included an enclosed area and failed, 32 failed because Henrietta was able to push a foam block (27) or push a foam block simultaneously as Henrietta moved through a small gap between the foam and another block (5); one design failed due to Henrietta moving through a larger gap whereas five other designs failed as Henrietta pushed apart two wood blocks forming a corner (5).
- Of the 32 participants with D1 fences that failed due to a foam block being pushed and included and enclosed area, 31 chose to create a D2 fence. One participant declined the invitation to create a new design in response to the original failure.

Thus, we include 31 participants in our analysis regarding trade-offs between fence area and block type. These participants are from all three schools: Blakely (16%), Adamsville (29%), and Kellerton (55%); this is similar to the percentages for each school across the 53 participants in the entire study (17%, 25%, and 58%, respectively).

Negotiating Trade-offs between Block Type and Fence Area

As mentioned previously, the key trade-off within this design challenge was between block type and fence area. Table 1 summarizes the percentage of participants who reduced, maintained, or increased D2 fence area as compared to D1 fence area. For each of these fence area categories, we asked: What percentage of participants created a D2 fence in which wood blocks fully encompass the fence area (thus creating less of a likelihood that Henrietta will escape)? In what follows, we describe each of these categories in greater detail, incorporating examples of participants across the three school sites.

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Table 1
Fence area of D1 versus D2 and D2 block type (N = 31 participants).

Fence area comparison		D2 block type		
Area of D2 compared to area of D1	**Freq.**	**Do wood blocks completely encompass the fence area?**	**Freq.**	**Examples presented**
Reducing fence area D2 area < D1 area	55%	Yes[a]	32%	Charles
		No	23%	Chloe
Maintaining fence area D2 area = D1 area	42%	Yes	7%	Abigail
		No	35%	Hannah
Increasing fence area D2 area > D1 area	3%	No	3%	Aiden

[a]Or largely encompass the area but with one concentrated large stack of foam blocks.

Reducing Fence Area

Slightly more than half of the 31 participants (17 participants; 55%) created a D2 fence with a smaller fence area than their D1 fence. Most of these participants (10 of 31; 32%) created a D2 fence in which wood blocks completely encompassed the fence area.[4] The remaining 7 participants (23%) who reduced the fence area did not completely encompass their area in wood blocks, leaving D2 vulnerable to Henrietta escaping by pushing a foam block.

Reducing Fence Area and Encompassing with Wood: Charles. Figure 5 shows the progression of Charles constructing his D1 fence. When he realized he was out of blocks and the interviewer had no more to share, Charles adjusted his fence size to encompass a smaller area. Charles used foam blocks to finish a somewhat smaller D1 fence than he had initially envisioned, saying: "So it'll be a little bit smaller so Henrietta won't escape." However, he suspected Henrietta would escape when he said "I think she might push the foam blocks over." This prediction echoes his comment that foam blocks are "not strong enough" and that the wood block "didn't go as far" as the foam block in the science investigation.

During the D1 fence testing process, Henrietta pushed a corner made by a wooden and foam block (upper right-hand corner in Figure 6, left-hand picture). The foam block was pushed more than the wood block, but the wood block, pushed a little, toppled off the edge of the board. When asked what Henrietta did, Charles replied, smiling: "She pushed it, but can we do a redo?" The interviewer replied, "So tell me what happened?…Talk to me about what happened and then we'll change it." Charles explained that Henrietta "pushed—pushed the block over like [smiling]—choo choo choo choo choo choo [showing with his hand how Henrietta pushed the blocks]—like she's punching it." When the interviewer asked which block Henrietta pushed, Charles pointed to the wooden block. The interviewer asked, "Did she push the blue one at all or no?" Charles replied, "No. She only pushed the wooden block."

Despite Charles' diagnosis that the wooden block was at fault, his D2 fence suggested he understood the need to use wood blocks around the full perimeter of his fence (Figure 6). While he constructed this D2 fence, he said "And let me use the wooden piece, the blue pieces. So I'm not, I'm not gonna use—I just put these [foam blocks] all, put these on top so she won't escape like she did." In doing so, he created a fence that was smaller in area than the first fence. His D2 fence contained Henrietta for 28 seconds.

Reducing Fence Area and Not Fully Encompassing with Wood: Chloe. Like Charles, Chloe revealed an understanding that foam blocks are easier to move than wood blocks. She offered, "This one [holding the foam block] is more gentle and squishy and when something…crashes into it, it goes this way [bumping it with her hand and moving it about 8 inches]. And when it's crashed into this [wood block] it goes like this [moves it about an inch]."

Chloe began by creating a single wall of foam and wood blocks typically stacked three blocks high (see Figure 7, leftmost image). When she nearly ran out of blocks, she deconstructed the wall and started constructing what became her D1 fence (middle image). The interviewer asked: "So in the beginning, I saw you stacking blocks up…one, two, three, one, two, three. What were you thinking about then and why did you decide not to do that?" Chloe responded: "'Cause I thought maybe she wouldn't get out of three blocks standing up [reaches her arms up high and wide]. And then I almost ran out of it so I had the idea to make this."

[4]This also included two participants whose fences mostly used wood blocks but that also used one small section of fence perimeter with a concentrated stack of foam blocks.

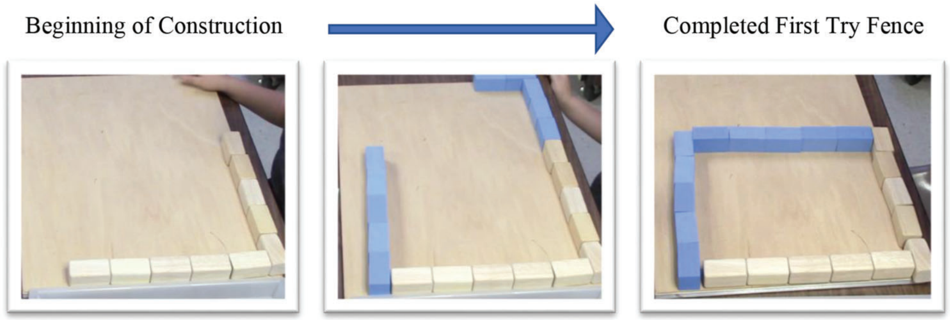


Figure 5. Charles' D1 fence construction process.

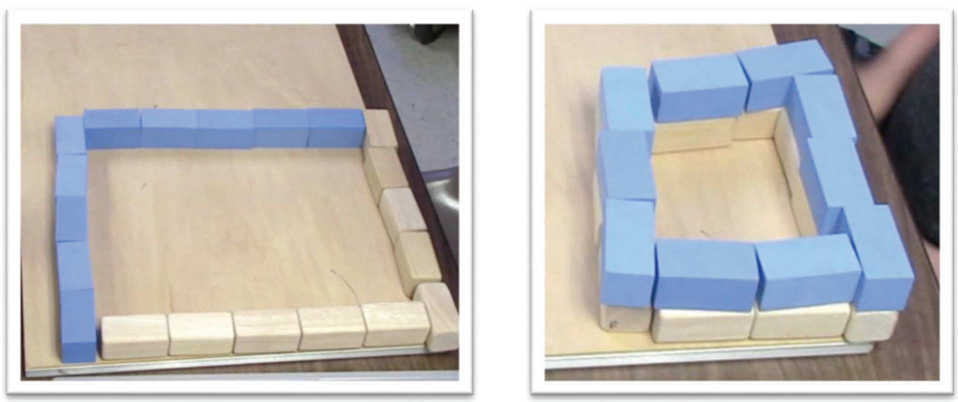


Figure 6. Charles' D1 and D2.

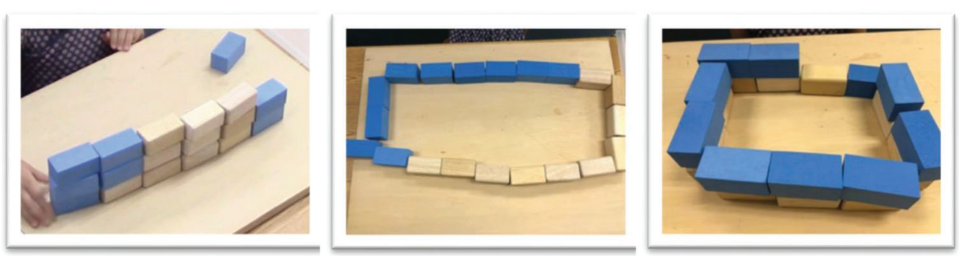
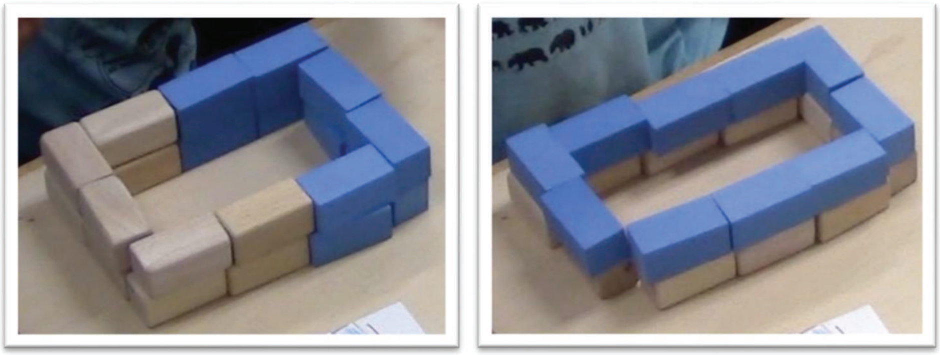


Figure 7. Chloe's untested attempt, D1 and D2 fences.

When Chloe's D1 fence was tested, Henrietta escaped in about 14 seconds, pushing through a corner made of two foam blocks. She reflected: "She digged [pushed repeatedly in the corner] and then it started to come out like digging and then a block fell over 'cause it was gentle." When Chloe constructed her D2 fence (Figure 8, rightmost image), she created a similar D2 fence to what Charles had constructed. She explained that this D2 fence had "wooden blocks down here [pointing to the bottom row] so Henrietta will bumped into it and then it wouldn't, like, fall over." However, there was one foam block that was on the bottom row that Henrietta could push. Prior to testing D2, the interviewer asked a final question: "So if you had one more wooden block, where would you put it?" Chloe pointed exactly to the foam block on the bottom row. When D2 was tested, Henrietta escaped after 15 seconds by pushing this foam block.



Abigail's D1 Fence   Abigail's D2 Fence

Figure 8. Abigail's D1 and D2 fences.

Maintaining Fence Area

Somewhat less than half of the 31 participants (13 participants; 42%) created a D2 fence that had the same area as their D1 fence. Two of these participants (6% of 31) created a D2 fence consisting of wood blocks that completely encompassed the fence area; they each stacked foam blocks on top of these wood blocks. The majority of participants in this same-area category, 11 participants (23% of 31), did not completely encompass their area in wood blocks. Thus, their fences included foam blocks that Henrietta could push.

Maintaining Fence Area and Encompassing with Wood: Abigail. When asked about what she learned about the different blocks in the science lesson the previous day, Abigail responded: "That one [holds onto the wood block] does not go far and this one does [holds foam block]." When asked why, Abigail replied: "Because this one is made out of foam and this one [wood] is heavier."

During construction, Abigail created stacks of blocks that were two blocks high with blocks laying down on their side forming a rectangular pattern. Each pair of blocks were either both wooden or both foam. Her process of construction was quite linear without any significant adjustments as she created D1 (see Figure 8, left-hand image). Reflecting on her design, Abigail said that she ran out of wood blocks, "so I needed to use these blocks [pointing to the foam blocks in her fence]." When asked how her fence would keep Henrietta from escaping, Abigail replied: "Because these are—won't move—but if he bumped into these ones [pointing to foam blocks], they may move. But these ones won't move as much [pointing to wood blocks]."

Henrietta stayed inside Abigail's D1 fence for about 20 seconds then pushed out of a corner made entirely out of foam blocks. Abigail identified where Henrietta escaped and said that it was "because he [Henrietta] moved these [foam blocks] over a little."

Abigail preserved the fence area and shape for D2 but reorganized the locations of foam versus wood blocks. As she described, "I changed it because I put the wooden ones on the bottom [pointing to those] and the soft [foam] ones on the top." When asked why, Abigail replied: "Because these [points to wood blocks] won't move and these ones [picks up a foam block] will." (Henrietta stayed inside of Abigail's D2 fence for over 30 seconds.)

Maintaining Fence Area and Not Fully Encompassing with Wood: Hannah. Asked about the preceding science investigation, Hannah recalled that the foam block "goes farther because, like, if the car pushes it, it would go far like that [moves the block about 5 inches], but if the car pushes this one [wood block] it would go like that [moves it about 1 inch]." The interviewer asked: "What is it about this one [the wood block] that makes it harder to push?" Hannah explained that the wood block was "heavier than [the foam block]" and that the foam block was "more squishy."

Hannah began constructing her fence using only wood blocks. But when she had used all 10 blocks, she started using foam blocks. Her process was somewhat linear as she created a rectangular fence, pausing occasionally to move blocks from one side to the other and to adjust the perimeter. See Figure 9 (left image) for Hannah's D1 fence.

Hannah described her D1 fence saying: "I used all of the blocks because I couldn't figure out how—because I knew these [foam blocks] slided more, so I kinda did want to just use the wooden blocks, but then I couldn't build enough room for Henrietta to…go around." The interviewer then asked: "Why didn't you want to use the foam ones at first?" Hannah responded: "Because…they're, um, more easier to push away." When asked to describe how her fence would work to

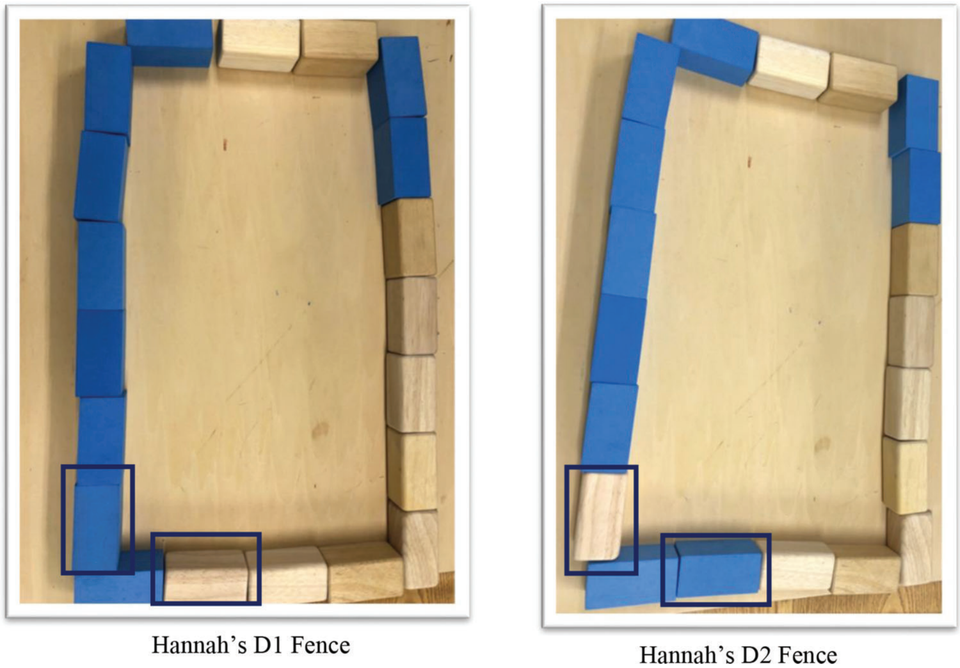


Figure 9. Hannah's D1 and D2 showing the two blocks that were swapped between D1 and D2.

contain Henrietta, Hannah explained that Henrietta would "bump into" [the inside walls of the fence] and "then she just scrapes against the wall an then she starts turning back."

Henrietta escaped from Hannah's D1 fence in about 22 seconds. When asked what happened, Hannah explained: "She, like, she got stuck over here [points to corner], and then she started pushing this block [points to foam block] away." The interviewer asked: "Now earlier you were telling me that you were thinking that these [foam] blocks would be easier for her to move. Was that true?" Hannah responded affirmatively.

Hannah's D2 creation process involved swapping two blocks. Those blocks are indicated with black frames in Figure 9. The foam block framed in the D1 image was the block Henrietta had pushed to escape. For D2, she swapped the framed wood and foam blocks (see Figure 9). When asked how D2 was different, Hannah explained her strategy: "So I switched places because this block did not get hit [touches the wood block] and—because it was right here…and so I switched spots and maybe it would—like she wouldn't hit this time either." Hannah was addressing the specific block's placement in which the D1 fence failed. However, she had not considered that there were other foam blocks that could be problematic. (Henrietta escaped Hannah's D2 fence in 3 seconds, pushing a different foam block.)

Increasing Fence Area

Aiden was the only participant who increased the size of his fence—slightly, yet noticeably. We will not spend time describing Aiden's design in detail. His D1 fence was similar to Hannah's D1 fence, albeit Aiden's used 8 foam and 10 wood blocks. During the test, Henrietta escaped in about 12 seconds by pushing through a foam–foam corner. Aiden accurately identified the location of the failure and that Henrietta had "been pushing this [points to foam blocks she pushed]—kind of too, like, fast." When asked which block Henrietta pushed, he said: "A foam." Early in the interview, Aiden described that the wood block was heavier and that the foam block moved further during the science investigation. Aiden did not adjust block type when creating D2. Instead, he fixed gaps in his fence (unrelated to the reason for failure). When the interviewer asked if there were other changes he would make, he replied: "Probably like kinda give her a bigger space like those two blocks [that he had not yet used]." He added those two blocks to a corner of the fence, which created a slight expansion of fence area. (Henrietta escaped the D2 fence in about 12 seconds by pushing past a foam block in that location.)

Summary

Nearly all participants (94%) indicated prior to creating D1 their basic science understanding of inertia and that foam blocks are easier to move than wood blocks. The remaining 6% (2 participants) either did not articulate this understanding when prompted or provided a somewhat unclear response. All 31 study participants observed during the test of their D1

fence test that Henrietta was able to escape by pushing on a single foam block or in some cases a stack of two foam blocks. Further, most participants (94%) included in their failure diagnosis that a foam block was to blame.

Despite participant understandings that foam blocks were easier to move, 19 of the 31 participants (61%; i.e., those with a "No" in the "D2 block type" column of Table 1) created D2 fences that (1) included a single foam block in the fence and (2) either maintained the D1 fence area or reduced the fence area only slightly. These D2 fences would have met Criterion 1 had they encompassed the fence area with wood blocks (and no single or double foam blocks), which would have required the reduction of fence area (Criterion 2).[5] Thus, comparing D1 and D2 designs, most of the study participants (61%) seemed fixated on a certain fence area or range of areas—perhaps not knowing how to or not being willing to reduce fence area further—rather than focusing on the need to contain Henrietta, which in a quantifiable way determined fence success or failure. Our data seemed to have limitations in what they could tell us about why fence area was not reduced more often, but we did suspect that it may have to do with students' desire to focus more on Criterion 2 (create space for Henrietta to move) rather than on Criterion 1 (contain Henrietta).

Evidence of Empathy and an Ethic of Care

The design of our study did not create intentional means to study children's thinking about empathy and care in the design process. However, the design challenge included "others" to whom care and empathy are directed relevant to each criterion as implied in the classroom introduction to the challenge and reinforced in the beginning of the clinical interview setting (Table 2). In the interview setting, participants were asked "why do we need to make a fence for Henrietta?"; told about the testing process where Henrietta needed to be contained for 30 or more seconds (Criterion 1); and told that they should try to make the fence so that Henrietta has as much room as possible to move" (Criterion 2).

In what follows, we share evidence that many participants were empathizing with or caring for Henrietta and/or Henrietta's owner(s) related to the need for a fence, room for Henrietta to move, and added elements of participants' designs.

Empathy and Care about the Need for a Fence

When asked about the importance of creating a fence for Henrietta, about one third of participants (32%) shared a comment that was indicative of empathy and care. Here, we did not include statements that a fence would prevent Henrietta's escape (related to Criterion 1) or that Henrietta "likes to move around" (related to Criterion 2). Participants offered that a fence would enable Henrietta to: "get food" (Natalie); be "safe" (Matthew and Jordan); not "get ran over by a car" (Matthew); not "go into the street (Arianna); not "get lost" (Kaylee); or not "be somewhere else, like off the table, you know, like hiding—maybe she would get stuck" (Noah). These indicate that the students were caring about Henrietta. Others suggested care for the owner because a fence would: "not let the animals go anywhere when they're not looking" (Sarah); make it so that "she [Henrietta] doesn't get away" (Eli); and prevent a situation in which "we wouldn't see her—we would be like, 'Henrietta, where are you?'" (Ryan). As a final, yet less direct, example of participants demonstrating empathy, in the discussion of the fence, Mia connected with the idea of the fence, saying: "I had an old fence in my yard." Although this is not an empathetic response per se, it is demonstrative of Mia connecting with the idea of what a fence is and, potentially, what it is like to have a fence.

Empathy and Care about Room to Move

After being presented with the idea that the participants should make the fence so Henrietta has as much room to move as possible, some participants (13%) shared additional caring and empathetic statements. This group included Natalie, Noah, and Ryan, who had also shared comments about the need for a fence as described in the previous section, and Madelyn, who had not.

Natalie explained: "so she can get some sleep and some fresh air." Ryan shared that he planned to make his fence as big as the board [a drafting board on which fences were built], using his arms to gesture his dimensional intent. The following exchange demonstrates Madelyn's empathetic concern with regard to space for Henrietta:

Interviewer: She likes to move around, doesn't she?

Madelyn: Yes, so she will be crying.

Interviewer: You think she might be crying if she doesn't have enough space?

Madelyn: [Nods yes.] She just be trying to move, crying [smiles as she says this].

Noah responded with empathy about how confining a small space would be. If you put blocks too close together "here and here and here…it would keep running over the blocks [and] you can't move that much" (Noah).

[5]Note that we are excluding four cases in which participants could have both removed foam and increased fence area by also altering the orientation of the wood blocks from standing upright to laying down flat; in three of these cases, D1 and D2 only utilized upright blocks.

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Table 2
Criteria and trade-off variables as they relate to empathy and care for others.

Criterion	Trade-off variable	Others to whom care and empathy are directed
Criterion 1: containment	Block type	Henrietta who might get "stuck under a cabinet" or lost Owner(s) of Henrietta who do not want to lose Henrietta
Criterion 2: space to move	Fence area	Henrietta who "likes to move around" Owner(s) who are considerate of Henrietta's needs

Empathy and Care in Participants' Designs

We found evidence of empathy and care with respect to the participants' intended designs, their created designs, and when reflecting on their designs. This evidence takes four forms: (1) a desire to make a large space for Henrietta, restated by participants in their own words during the interview (mentioned by 35% of the participants); (2) including features to serve Henrietta's needs (21%); (3) including doors for Henrietta and/or the owner(s) (6%); and (4) attending to the needs of Henrietta's owners (6%).

Many participants focused on creating a large space for Henrietta. Haily planned to create a fence that had a "big circle [of blocks] so she can like move all around." Madison's plan "made it look like she [Henrietta] has a lot of space." As mentioned previously, Ryan intended to make a fence that was as big as the board for Henrietta. Jordan said that in her plan, she "made a big fence." When creating her D1 fence, Evelyn shared that she was "just trying to make a big spot for Henrietta… I might not have enough blocks, but I'm going to try." Also during D1 creation, Michael said "It's gonna be really big for her." When reflecting on his finalized D1 fence, Michael said "I wanted to make it bigger so she can move it around." Mia said she made her D1 fence "so Henrietta had more room." Molly, when asked how her D1 fence would keep Henrietta inside, replied: "'Cause it's much room because it also is all the way closed." When asked to describe his D1 fence, the first thing that Riley said was "it's wide open." When asked to elaborate, he responded: "There's a lot of room for her to move around." When describing his D1 fence, David said that "it's actually kind of big for Henrietta to move around." When asked how he might change his D1 fence, Aiden said that he would "probably like kind a give her a bigger space."

Some participants included creative features in their fences: an area "so she can play around" (Natalie); places to eat and drink "so she won't be hungry" (Natalie); places to sleep (Evelyn, Madelyn, and Sophia); obstacles for "if Henrietta wanted to, like, go around" (Evelyn); and trees (Sophia) (see Figure 10). When asked if the trees were "so that Henrietta could have some trees to look at," Sophia responded affirmatively; that said, this may have been a leading question regarding the purpose of the trees. We also include here as an aesthetic feature Molly's reflection on her D1 fence that she wanted to "make it pretty." Her square-shaped D1 fence included a two-foam, two-wood, two-foam, etc. pattern of blocks. She shared, "sometimes I make patterns and stuff," and described how she made patterns with beads.

Two participants included doors in their fence designs. Haily's door was a block along the fence she planned to include prior to fence creation. It is unclear if the door was intended to be included to care for Henrietta, Henrietta's owner(s), or both. Jordan said of her door: "I made a door for the farmer to let them out for a little bit…and then they'll go back in." As with Haily's door, Jordan's door was a part of the fence wall.

Finally, two participants attended to the needs of Henrietta's owner(s). Jordan was one of these, with the farmer's door. Additionally, when Jordan talked about her fence plan and where her wood blocks would be in it, she said: "For not escaping and then the farmer…let them out or they not be safe." Kaylee was also concerned about Henrietta's owners. After being asked how her D1 fence would keep Henrietta in, Kaylee replied:

> Because if you don't have a fence then you just have like, a field or a yard. And no fence around her, she might run away and then someone else will find her and just pick her up and bring her home. Then you won't have a pet anymore because if you want a pet then you have to keep it in a fence so she won't run away. 'Cause if she runs away then you won't see her no more. And then, then you have to get a new pet and then you—when you go to sleep you'll think about her. (Kaylee)

Here, she seems to empathize with the position of the owner of a pet who might lose the pet and be sad about that.

Discussion

The first author and colleague's prior work on making trade-offs and applying science in D1 designs (Lottero-Perdue & Tomayko, 2020b) and on D1 failure analysis and responses to D1 failure in D2 designs (Lottero-Perdue & Tomayko, 2020a) constituted the first steps in exploring trade-offs between block type and fence area. Similar to the present analysis in

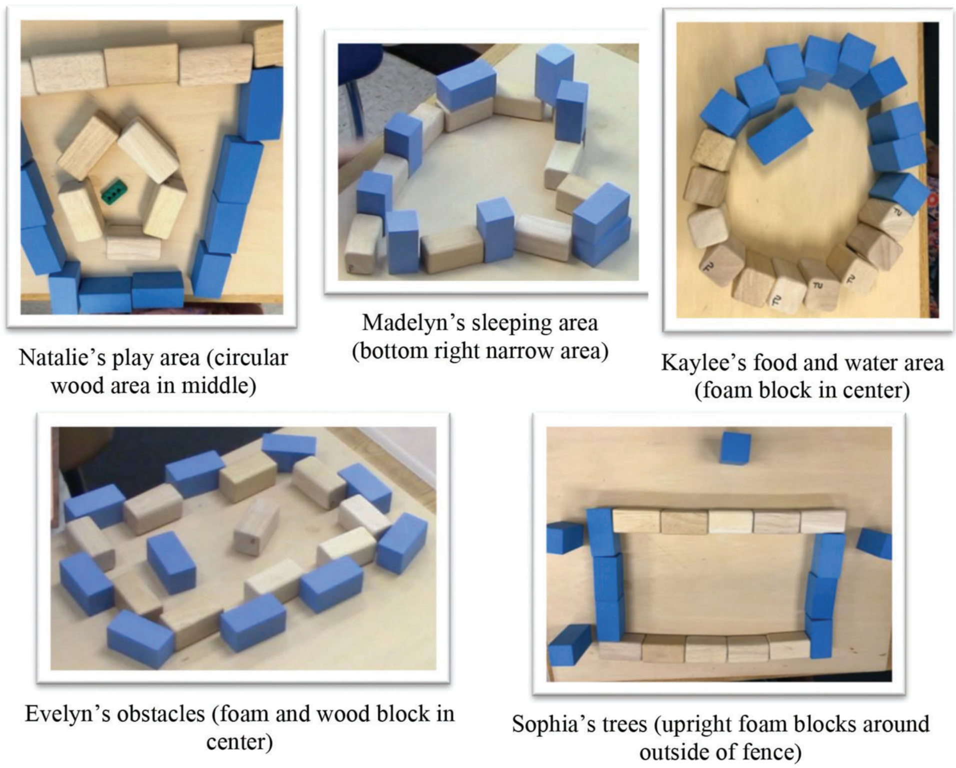

Figure 10. Additional features demonstrating care for Henrietta.

response to the first research question, both papers noted a "theory–practice gap" between students' understanding that Henrietta could push foam blocks and their use of those foam blocks in D1 (Lottero-Perdue & Tomayko, 2020b) or D2 (Lottero-Perdue & Tomayko, 2020a). While the students seemed to understand differences in inertia between the wood versus foam blocks (based upon the relative ease with which they could be moved), the concept was not necessarily translated into fence design decisions. In Lottero-Perdue & Tomayko (2020b), we shared that this gap "largely had to do with students' reluctance to shrink the area or perimeter of the fence; they preferred to keep the large size and use the foam blocks, even if they articulated that those foam blocks were unlikely to contain Henrietta" (p. 13). In Lottero-Perdue and Tomayko (2020a), we wrote again of the gap between understanding and application, this time with respect to D2:

> …many students knew what they needed to remedy in their first try [D1] designs but did not or could not implement this remediation in their second [D2] designs. A very significant reason for this…is that many participants had challenges with the trade-offs between the *fence perimeter size and the use of the foam blocks*…participants knew that foam blocks were easy to push and would not make for good fence walls but opted to use them anyway when they did not have enough wooden blocks to create a fence of a certain desired size. This trade-off between two criteria was a challenge for the kindergarten participants in this study. (p. 18, emphasis added)

Our conclusions focused on the epistemic practices asserting that many kindergartners in our study could "engage in making trade-offs…and may or may not apply science during engineering design" (Lottero-Perdue & Tomayko, 2020b), and "engage in failure analysis…persist, and…apply testing results and failure analysis in their next design attempts" (Lottero-Perdue & Tomayko, 2020a).

Within the present study, research questions 1 and 2 explored the same situation: kindergartners applying a science concept (i.e., inertia) in an engineering design challenge as they redesigned a fence to better contain Henrietta. However, Lottero-Perdue and Settlage together reexamined the data. From observing consistencies in the participants adjusting their fence designs between D1 and D2, it became apparent to us that the participants were drawing upon a resource not otherwise identified as an epistemic practice. There were indications that the participants recognized differences in how foam and wood blocks resisted repositioning. Each child accurately described and/or demonstrated how the two block types were easier or harder to displace. As educators, we anticipated that they would transfer this knowledge to the design challenge—and yet their designs failed to incorporate their knowledge that wood blocks had more inertia. With our

revisitation of the data, we realized the kindergartners may have relied on their sense of empathy and ethic of care during their designs and redesigns.

We acknowledge that we—and specifically, Lottero-Perdue in her prior work described earlier—missed resources the study participants drew upon during the fence design challenge in prior analyses (Lottero-Perdue & Tomayko, 2020a, 2020b). Martin et al. (2018) wisely identified this problem as a "pedagogical failure" in which we, generally speaking, ought to have recognized those "moments in which students do not do what is expected can be evidence of resources that those students have and that may be of value within a redesign" (p. 45). Curriculum developers tend to treat departures from planned lessons during classroom applications as failure of implementation fidelity (Earle et al., 2013; Rowan & Miller, 2007). Being invested in the activities and lessons makes it difficult for developers to recognize the value when teachers and students take materials into unanticipated directions (cf. Buxton et al., 2015). The irony is that field trials are meant to assess whether designs are sustainable outside the pristine conditions of curriculum developers' minds. As Martin et al. (2018) cautioned, those "failures" hold value for those who can suspend quick deficit-based judgements about where students fell short. In encouraging educational researchers to respect outliers and uncertainty, Bullough (2012) claimed that quality school-based research ought to be "characterized by humility in the face of the complexity of education, a complexity that is not yet fully or adequately appreciated and of *profound respect for those whose work researchers seek to understand*" (p. 343, emphasis added). Even though this study was originally conceived as an investigation of early childhood engineering design, this initial effort has evolved into a critique of viewing learners as a problem when instead the solution being sought is at the intersection of young learners and subject matter.

Our reanalysis of the data from an asset-based perspective has enabled us to appreciate how the participating students were drawing upon personal resources in the form of empathy and caring. Even though the activity was framed as a design challenge focused on trade-offs (i.e., balancing robot containment against maximizing space), we were misleading ourselves by the belief that the children included designs that ignored building walls with sufficient inertia. In a sense, their designs were better attuned to the constraints and criteria than we initially realized. Because those came from the children, we somehow failed to notice. It was as if the participants were venture capitalists willingly investing in the design challenge—and yet the assets they contributed were being dismissed. In an effort to speak against deficit views of young, diverse learners (e.g., Ladson-Billings, 2006), we propose including empathy and care as another student asset for equitizing engineering education. Rather than lament what is lacking in engineering education (e.g., enough time, funding, respect, materials, etc.), perhaps we should recognize children's resources which we have a tendency to ignore.

In much the same way that many White folks resist the call to become actively antiracist (Kendi, 2019), we were perhaps too comfortable in our socialized tendency to notice deficits in students' work. Our initial inclinations were to resist the possibility that we employed a deficit model about students' approaches to engineering design. Indeed, our work was centered on creating opportunities for diverse young students in a range of school settings to engage in engineering design, and look *for* the presence, not absence, of evidence of young children's engagement in epistemic practices. It is plausible that those participants who did not reduce fence area during their redesigns may not have had lack of understanding or an unwillingness to alter their design. Rather, students were exhibiting empathy and an ethic of care for Henrietta and using their regard for this "being" to shape their design decisions. Even though an ethic of care is receiving increased regard within collegiate engineering education (Hess et al., 2017; Walther et al., 2020), we now recognize that these traits represent an underappreciated asset with educational value within engineering design experiences.

The Privileged Criterion

Although there were two criteria in the challenge during implementation, we now see that one (Criterion 1, containing Henrietta) was privileged above the other (Criterion 2, providing space for Henrietta to move). The relative importance of Criterion 1 versus Criterion 2 was communicated by Lottero-Perdue during the problem presentation in the whole-class setting prior to data collection, as well as in the problem reintroduction in the clinical interview setting. As the fence problem was reintroduced, Lottero-Perdue asked the children to recall why it was that we needed a fence for Henrietta (Criterion 1). She mentioned Criterion 2 after the review of the block types and in the context of "two important things" that participants needed to know prior to starting to create their fence. These two things were (1) the constraint that they could only use up to 10 wood and 10 foam blocks and (2) Criterion 2.

As designing and testing got underway, assessing design success or failure exclusively focused on whether Henrietta would be kept within the fence enclosure for at least 30 seconds (Criterion 1). While the Lottero-Perdue-as-interviewer mentioned that the anthropomorphized Henrietta Hexbug robot "likes to have space to move around," Criterion 2 was not measured or interpreted. In the creation and implementation of the design challenge, the decision to test just one criterion, Criterion 1, and merely suggest the other came from a desire for simplicity, ease of testing, and because the key purpose of a fence is containment. That said, it further communicated increased importance of Criterion 1 over Criterion 2.

An Act of Agency, Demonstration of Asset

When students avoided creating too small a space for Henrietta they were exhibiting a degree of agency—prioritizing Criterion 2 above or at least on par with Criterion 1. The curriculum and interviewer asserted the importance of Criterion 1—but that emphasis was open to being challenged and questioned. Further, the children infused into their designs an asset that we had not fully considered. An ethic of care deserves to be included within engineering design as an epistemic practice of engineering, not a superfluous emotive disposition in an otherwise empirical pursuit.

Implications

This study has implications for research and practice within engineering education. As others have argued, having empathy and an ethic of care is an essential epistemic practice of engineers. It is also a practice that even young children, including the kindergartners in this study, can bring with them and employ in the engineering learning space. This connects to what we ask and expect them to bring: practices that employ analytical thinking, attend to scientific knowledge, etc. In our pursuit of educational equity, we must value, attend to, and encourage the assets children bring with them into the space, including their capacities to be empathetic and caring. By considering how the fence challenge problem and criteria could be more inclusive of empathy and care and how our interview protocol could be modified—and relatedly, the questions that teachers ask when facilitating the challenge—we can attend to their assets more thoroughly. We then expand to consider implications for P12 engineering education research and practice beyond this particular case.

Redesigning the Fence Challenge to become Empathy-Centered

During the classroom introduction and the interview, care for the owner was prioritized over care for Henrietta. A revised problem statement could be: We need to care for Henrietta by ensuring she: (a) has enough space to move around within the enclosure and (b) does not wander away and get lost or hurt. This would focus the problem explicitly on Henrietta's care. Further, we could clarify what it meant for a fenced enclosure to supply "enough space to move." This might be challenging to quantify since kindergartners would struggle with surface area. One way to quantify space in the fence area would be to count the number of "tiles"—such as pieces cut from foam board. The challenge might further incorporate empathy into the criteria by asking the children about living things and their need for space to move and also for boundaries. For example, students could be asked: Do you like to move around like Henrietta does? What do you like about being able to move around during recess? How do fences and walls around a play area protect us? How could fences limit us? Children could also be invited to propose other ways fencing might provide care beyond our two criteria. This could include asking children to empathize with Henrietta. For example, we could ask: If you were Henrietta, what might you want to have inside of your fence area? This would value the creative ideas that children bring—like those of Kaylee, Natalie, and Evelyn—to caring for Henrietta, rather than positioning them as irrelevant or unimportant.

Protocol (or Teacher-Posed) Questions during Design

The ethic of care has been advanced as a guide for developing accessible and authentic engineering educational experiences (Capobianco & Yu, 2014). Four phases of care are overlaid with engineering design process phases. The associated guiding questions would have strengthened the Henrietta fence design challenge. Similarly, the same phases of care could have been more explicitly infused into instruction. This would include the teacher's questions, the strategies used by the teacher while facilitating the design process, and support debriefing the activities for future design refinements or to encourage metacognitive awareness of the engineering design process. In Table 3, we propose refined prompts teachers could offer to students that draw upon the Capobianco and Yu (2014) framework. While this does not show all the protocol questions, it does identify major questions used with the participants of this study. In addition, we have provided supplemental questions that would more deliberately access students' empathy and care. Because we are advancing an additional epistemic practice into engineering education, these examples are meant to illustrate how those general notions would be enacted within an actual engineering curriculum.

Engineering Education More Broadly and Equitably

Classrooms can be places where students are marginalized. They might feel they are not valued by teachers and that their voices are not worth hearing. Under different conditions, those same students can exert agency by communicating ideas, leveraging experience, and participating in activities (Rosebery et al., 2010). The negative implications when educators fail to recognize and leverage learners' assets are much more likely when adults feel they have little in common with particular

Table 3
A revised set of prompts to guide the fence challenge to elicit student empathy and care.

Part of challenge	Protocol or teacher-posed prompts (new prompts in bold)
During presentation of problem, constraints, and criteria	**If you were Henrietta, what would you want your fence to be like? Why?**
	If you were taking care of Henrietta, what kind of fence would you want to make for Henrietta?
	We need to make a fence that keeps Henrietta inside of the fence. Do you think we should try to make a big or a small fence for Henrietta?
	Why might a big fence be good?
	Why might a small fence be good?
	You can use up to 10 foam and 10 wooden blocks to create a fence for Henrietta, but you do not have to use all of the blocks.
After D1 creation	How many wood blocks did you use? Foam blocks?
	Can you show where Henrietta would go inside of your fence?
	How did you decide how big to make your fence?
	How will your fence keep Henrietta in?
	What do you think Henrietta might like about your fence? Is there anything Henrietta might not like?
	What else do you want to tell me about your fence? [Ask about additional features.]
During testing	**How much room does Henrietta have to move? Is it enough space?**
	Does Henrietta stay inside for up to 30 seconds?
After D1 testing	What happened? What did Henrietta do? **Did she escape?** [If so, which block(s) did Henrietta move?]
	Do you think that Henrietta had enough space?
	Do you want to try to make your fence better?
	Will you try to make it so that Henrietta has more space, less space, or the same space to move?
	Will you try to make it so that Henrietta will not escape?
	Is there anything else you will change about your fence for Henrietta or for those who take care of Henrietta?
After D2 creation	How is this different from your first fence?
	(See also questions above for "After D1 creation.")

students. Educators can choose to be conscientious and deliberate about recognizing differences as assets to support engineering education efforts—or treat differences as deficits thereby reinforcing self-fulfilling prophesies about who can be successful in engineering (Martin et al., 2018). Disparate regard toward different groups of students aggravates the implicit biases that foster educational inequities.

"Making trade-offs" is not only a key practice within engineering education, it also describes the tensions educators experience as they negotiate between prescribed standards and the importance of attending to students' backgrounds (Penuel & Furtak, 2019). Too often, educators improperly ascribe constraints as the perceived limits of their students. In contrast to those who are open to the assets that students bring with them and can support their learning, educators instead treat unexpected responses by students as errors. As described at the outset, progressivist educators are deliberate about accessing children's prior experiences, their thought processes, and what Dewey (1906) called their "sufferings"—their challenges, their sensitives, their uncertainties, etc. In the context of engineering, students will connect activities to what they have previously done or considered: their technical and cognitive skills are foundations for performing and conceptually new experiences. An additional resource not always fully recognized with engineering education are the students' dispositions as platforms for supporting their sensations and sensibilities infused into doing engineering.

Recognizing children's out-of-school lives as offering in-school resources is a long-standing educational challenge. Misinterpreting those as deficits propagates educational inequities. The insidiousness of implicit biases concealed within the engineering activities we create is prone to neglecting backgrounds different from our own familiar experiences. We discovered this during our retrospective examination of this fence engineering design challenge. Now we realize our failures to appreciate how empathy and an ethic of care were being used by students. Perhaps the remedy is to elevate empathy and an ethic of care as a legitimate engineering education outcome. Returning to the epistemic practices of engineering education (Cunningham & Kelly, 2017), here we advocate for adding empathy and ethic of care to this list. For one, this practice is increasingly recognized as essential during engineer training and development (e.g., Fore & Hess, 2020; Walther et al., 2020). Another education benefit is that this practice would better attune educators to students' assets which promotes more equitable science, technology, engineering, and mathematics (STEM) education (Bang & Medin, 2010; Tan et al., 2019). Finally, specifying empathy and an ethic of care as among another epistemic practice alerts engineering educators to the need to intentionally incorporate this into curriculum, activities, outreach, and instruction (Capobianco & Yu, 2014; Gunckel & Tolbert, 2018; Hess & Fila, 2016).

We acknowledge the tensions between curriculum design and implementation. Within this study, the educator implementing the activities, Lottero-Perdue, was also the materials' creator. As such, there were implicit understandings

about the design challenges that could be adjusted during implementation. However, when engineering curricula are designed for others' use, it is necessary to specify the presence of certain features. Making the design decisions more explicit helps educators recognize the value of activity components that may not be obvious. That was our reason for offering prompts based on Capobianco and Yu (2014)—to make more evident how caring and empathy could be incorporated into the activities. However, these adjustments are descriptive rather than prescriptive.

We found the power of ethic of care framework once we realized how the original activity neglected empathy as a student asset. More than providing a template for teacher questioning, we advocate for the ongoing attentiveness to student ideas. As student populations become increasingly diverse and engineering education is more successful with expanding the participation of students from varied races and ethnicities, even as educators as a whole are not exhibiting equivalent demographic shifts, it becomes increasingly important to remain curious about children's sensemaking. Such curiosity by educators fosters a shift toward greater regard for the skills, knowledge, and dispositions students are likely to exhibit during engineering activities. This study illustrates much more than a need to elevate empathy and caring as an engineering epistemic practice. Perhaps more significantly, we wanted to use this forum to encourage educators to resist deficitized views of students, families, and communities. In its place, we advocate for equitizing engineering education by endorsing the educational benefits of seeking connections and creating resonance among the subject matter, its practices, and the wealth of assets that even young learners bring to table.

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