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An Instructional Framework for the Integration of Engineering into Middle School Science Classrooms

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An Instructional Framework for the Integration of Engineering into Middle School Science Classrooms

Introduction

A Framework for K-12 Science Education [1] describes three dimensions of science and engineering. These dimensions include core ideas from life science, physical science, earth and space science and engineering, a set of crosscutting concepts that span across these four disciplines, and eight practices that are used in science and engineering to develop and revise new knowledge about the natural or material world. This description of science and engineering is intended to convey a more realistic understanding of what science is and how science is done. The *Next Generation Science Standards* (NGSS) [2] were developed based on these three dimensions of science and engineering. The NGSS are a set of performance expectations that describe what all students should be able to do at the end of each grade level to guide the development of new curricula, instructional approaches, and assessments.

Many science teachers, who have backgrounds in science and are familiar with more traditional science pedagogy, are uncomfortable teaching engineering and shy away from the topic. In addition, many students do not understand what engineers actually do, holding inaccurate views of engineering as an isolating and sedentary job [3]. In response to these inadequacies, *Changing the Conversation* [3] calls for a change in the way engineering is taught and talked about, to include an understanding of engineering as a way to induce positive change and make a difference in the world. This emphasis on the benefits of engineering to society is hypothesized to make engineering appealing to students who are underrepresented in engineering, such as girls and minority students, in comparison to a more traditional perspective of engineering (e.g., engineering is a highly technical and profitable profession) [3]. Intentionally incorporating engineering into K-12 education can reduce misconceptions about engineers and engineering, and attract more diverse students into engineering later in their academic lives.

We developed a new instructional framework called Argument Driven Engineering (ADE) as a way to help address these issues. The purpose of ADE is to provide teachers with a tool that they can use to integrate engineering into science classrooms without neglecting the science. ADE is an eight-stage framework, which supports students through the design process and gives them an opportunity to use disciplinary core ideas, crosscutting concepts, and science and engineering practices to develop a solution to a meaningful problem. It also gives students opportunities to read, write, and talk about science and engineering. This framework, as a result, provides teachers with a way to also focus on the Common Core State Standards for English Language Arts (CCSS-ELA) [4]. In this paper, we describe the perspectives on learning and the research literature that we used to develop this new instructional framework. We also describe what happens during each stage of the framework and results of a pilot test of the approach inside a middle school classroom. The article concludes with a discussion of the potential implications of this work in terms of research and classroom practice.

Theoretical Foundation

Social constructivist learning theory has driven the development of ADE. Social constructivism suggests that knowledge is constructed through collaborative and cooperative social interactions [5-8]. Through these social interactions, students build upon prior knowledge by sharing ideas and coming to a consensus, thereby constructing knowledge and developing conceptual understanding. In addition, social interactions aid in the social-emotional development of early adolescent students [9, 10]. Igel and Urquhart [11] further emphasize the importance of social interactions for middle school students, specifically in encouraging engagement, developing collaborative skills, and encouraging deeper understanding. ADE is intended to engage students in a process of "probing one another's ideas, explaining one's own beliefs and ideas, and challenging weak ideas" [10, p. 16].

Social interactions are also important for development and refinement of knowledge in scientific and engineering communities, as "the concepts and models of conventional science embody practices, conventions, and modes of expression that are socially and institutionally agreed upon. Because scientific knowledge is the product of the scientific community, it cannot be learned through interactions with the material world alone" [8, p. 41]. Two important implications follow from this theoretical framework. The first is that students must have opportunities to engage in both personal and social processes of learning to understand disciplinary core ideas, crosscutting concepts, and the practices of science and engineering found in the NGSS, as well as important literacy skills. Second, students must understand the aspects of the engineering practices, what makes those aspects productive, and why.

Review of the Literature

A major driver for science education reform has been to make learning science more authentic [2, 12, 13]. Authenticity is often defined as "transformative of students' views of themselves as knowers and doers of science and of the nature of science" [14, p. 1121]. While students are not expected to contribute to actual scientific research or engineering projects, they can participate in authentic learning experiences by building an identity of themselves as capable learners. Cunningham and Carlsen [15], for example, suggest that engaging students in engineering design can make classroom learning more authentic because "design encourages multiple solutions and there is rarely a single 'right' answer, so children can be successful in different ways" (p. 756). When allowed to construct their own solutions, students possess greater ownership of their ideas and become more deeply engaged in authentic engineering practices.

Given the benefits to incorporating engineering design into science education, it is no surprise that several excellent programs exist for this purpose. Engineering can be included in after school programs, dedicated engineering courses, or by incorporating engineering within science curricula. For example, Engineering is Elementary (EiE) from The Museum of Science, Boston, offers stand-alone curricular units for K-5 classrooms. EiE units can be implemented in any K-5 classroom, in any order, and can be adapted for higher or lower grade or ability levels. Similarly, The Museum of Science, Boston has also developed Engineering Everywhere (EE) for middle school-level after school programs. There is also a program for high school engineering, Project Lead the Way (PLTW) Engineering, which provides detailed curricula for whole courses in several engineering fields and topics.

However, these curricula do not meet the needs of all teachers. The EiE and EE units, for example, are lengthy and difficult to implement into science classrooms when teachers are required to focus on a great deal of content. The use of the PLTW Engineering curriculum requires a school to create a stand-alone course. In addition, a full curriculum can be restrictive in terms of wide spread adoption because it may or may not align with standards used in a specific state or the policies and goals of a district. Relevancy can also be lost as a curriculum ages or when it is implemented in different regions. In contrast, teachers can use an instructional framework to develop their own lessons to fit the unique needs of their students and learning goals. An example of a well-designed instructional framework is Learning by Design (LBD) [16]. This approach addresses "many practical issues in putting together a curriculum approach that can be broadly adopted" [16, p. 498] such as those described above. The LBD framework, however, was developed prior to the release of the *Framework* [1] and the development of the NGSS [2] so it does not focus on using disciplinary core ideas, crosscutting concepts, and science and engineering practices.

The development of new instructional materials also needs to be responsive to recent developments in educational research. *Changing the Conversation* [3] calls for Science, Technology, Engineering, and Mathematics (STEM) education to be more inclusive. Instructional materials, as a result, must address how engineers can positively affect the world and society by placing a greater focus on equity and social justice through engineering. This emphasis on equity and social justice has been shown to increase achievement for underrepresented minority students and leads to more interest and the development of an engineering identity [17-21].

In summary, while there are curricula and instructional frameworks that teachers can use to teach students about engineering, a modern instructional framework that is aligned with current research is needed. ADE is not an engineering curriculum, but a framework for integrating engineering into science curricula. ADE is more flexible than engineering curricula and frameworks and provides the added benefits of more equitable achievement and identity development, increased interest and motivation, and a focus on argumentation and writing.

The ADE Instructional Framework

ADE provides a way to give students an opportunity to use disciplinary core ideas, crosscutting concepts, and science and engineering practices to solve problems inside the classroom. ADE also emphasizes the importance of reading, writing, speaking, and listening when attempting to develop solutions to problems. For example, when students generate design concepts and then share these concepts with others, they must also develop important communication skills in order to explain and to justify design elements. Through iterations of the design process, scientific and mathematical principles are further used to improve the design and justify changes made, while engaging students in authentic engineering design practices.

Students are provided with multiple opportunities to give and receive feedback throughout the ADE framework. This feedback is intended to help improve design prototype iterations and arguments for the best design alternatives. Students learn to value feedback and critique as a way to improve future design solutions as well. By placing the students in such a critical role, ADE helps build a student-centered classroom, and is consistent with the core teaching practices of Ambitious Science Teaching: engagement with important science ideas and engineering problems, eliciting student ideas, supporting ongoing changes in thinking, and pressing for evidence-based explanations [22, 23]. These practices form a general framework for new and experienced teachers to improve their instruction and increase the role of their students in the learning environment as recommended by the NGSS [2].

The ADE framework consists of eight stages (Fig. 1). These stages guide students through the design process to develop a solution to a relevant problem and argue for their solution. These stages are based on the eight-stage Argument Driven Inquiry framework [24, 25], but have been modified to be more consistent with the nature of engineering.

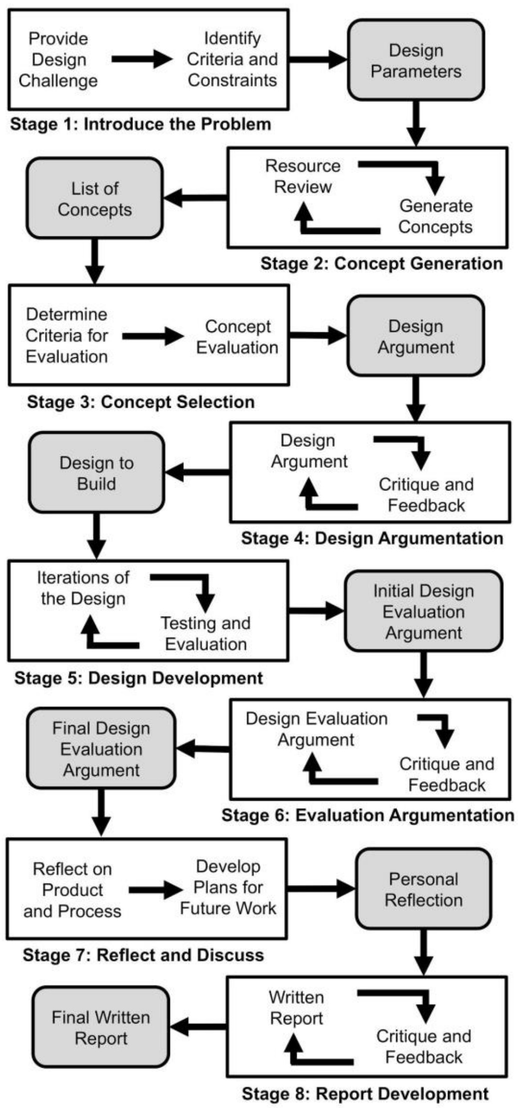

Fig. 1. The eight stages of the ADE framework. Student products are indicated in grey boxes.

Students progress through these eight stages over a period of one to two weeks to complete an Engineering Design Task (EDT). The EDTs are designed following guidelines recommended in *Changing the Conversation* [3] in order to emphasize how engineers change the world and make it a better place. For example, an EDT that we developed to help students learn about thermal energy transfer (Fig. 2) calls on students to design and build a prototype for a passive storage device to help solve current vaccine cold chain problems in developing countries. This EDT was inspired by a project sponsored by the Gates Foundation [26]. This EDT provides students with experiences that exemplify the way engineering can impact real change.

In the first stage of the ADE instructional framework, students are presented with an engineering design task (EDT) and introduced to the problem. Students work in small groups or teams to internalize the design task by identifying the specific need for the design. At this point students are not focusing on what they want to design, but instead are prompted to answer what problem or need the design will ultimately solve; identify the criteria, constraints, and target population for the design; and identify relevant mathematics or science principles that might be useful to the design task. In the example EDT, this includes identifying a need for a device that can keep vaccines cold without electricity and is easily transportable to rural areas, while identifying heat transfer as a relevant principle.

Introduction. Immunizations have become one of the greatest success stories in modern medicine, yet roughly 1.5 million children - or one every 20 seconds - still die each year from vaccine-preventable diseases. This is due in part to the sensitive nature of vaccines themselves, which spoil if they're not kept at precise temperatures from manufacture to use. Immunizations rates are lowest in rural areas, such as Sub-Saharan Africa, where poor infrastructure and unreliable electricity delivery make reliable, life-saving vaccines hard to come by. Public health officials have begun working on devices to keep vaccines cold by minimizing the heat transfer to the vaccine without using an electric power source.

The Task. In this DESIGN DEVELOPMENT AND EVALUATION CHALLENGE you will use what you know about the transfer of thermal energy and the importance of tracking the flow of energy in systems to create a durable storage device that will keep a vaccine (falcon flask proxy) at a temperature range between 0℃ and 10℃ for at least 24 hours. Your device must allow the user to remove and replace the vaccine proxy. The device should be lightweight (must have a mass less than 5kg). It must be able to fit into a box with dimensions of 30cm x 30cm x 30cm. The client does not want to deal with water spills so it must be leak proof. The device must cost less than $25.00 to produce.

The fundamental scientific question related to this design is: *How can we slow the transfer of thermal energy into or out of the passive vaccine storage device?*

Fig. 2. The problem statement and design task from an EDT for NGSS Standard MS-PS3-3.

During stage two, which is called concept generation, student teams research the problem as appropriate. To reduce time and help guide student research, some information is provided to the students. This information might highlight existing designs, results from patent searches, existing codes, user interview data, and so on. Student teams generate as many concepts as possible through methods such as brainstorming, mind mapping [27], or C-Sketch [28]. In the example EDT, students are given a handout that presents relevant background about heat, temperature, and heat transfer. In groups of four, they use brainstorming methods to generate sketches of at least three possible storage devices that fit the parameters of the design challenge.

Once several concepts are generated, the best one is selected based on evaluation criteria. During stage three, teams use engineering techniques to select the best concept from the previous stage and construct an argument for their best design. The methods used during this stage encourage students to move from "tinkering" to authentic engineering and evidence-based design. Appropriate criteria for evaluation of the student team generated designs are determined through whole group discussion, led by the teacher. For the example EDT, the evaluation criteria are volume, mass, cost, and thermal resistance of the storage device. Each team then evaluates their design concepts based on these criteria. Each team creates a criteria matrix that compares criteria, one pair at a time. The values created from these criteria matrices are then plugged into a decision matrix to compare each of the design alternatives from stage two by score. This decision matrix informs the development of an argument for the best design. Students are engaged in critical argumentation when they are prompted to articulate a justification for each score and reach consensus as a team. At the end of this stage, each team creates a white board with the summary of their argument, including their generated concepts and their final design matrix, which is presented as their claim to their peers in the next stage.

Stage four is the design argumentation session during which student teams present their arguments for their design alternatives to their classmates. The students have an opportunity to both critique the arguments of their classmates and have their arguments in turn critiqued. During this stage, one student stays with the whiteboard created in the previous stage while the other team members conduct a gallery walk to view and critique all the other teams' design alternatives and matrices. Studies show that student learning improves when they are exposed to the ideas of others, when they respond to the questions and critique of peers, when they form more substantial justifications for their views, and when they evaluate competing ideas through argumentation [24, 25]. Following the gallery walk student teams are given time to reflect on critical feedback and revise their own work. Effective reflection includes keeping a record of changes made and justification of those changes.

During stage five, prototypes of the best designs – as determined through matrix scoring and argumentation in the previous stages – are built and tested (Fig. 3). Importantly, this is a fluid, iterative process; iterative design is reflective of authentic engineering and aligns with NGSS science and engineering practices such as Developing and Using Models, Analyzing and Interpreting Data, Using Mathematics and Computational Thinking, and Constructing Explanations and Designing Solutions [2]. Student teams build and test at least two prototypes using given metrics. In the example EDT, students test mass and volume of the container, and 24-hour temperature difference of the vaccine proxy (Fig. 4). Based on data collected through testing, improved designs are built and tested. During this process,

Fig. 3. A student discusses their prototype vaccine storage device (Stage 5).

teams are required to provide explicit evidence and justification for their selection of the best prototype.

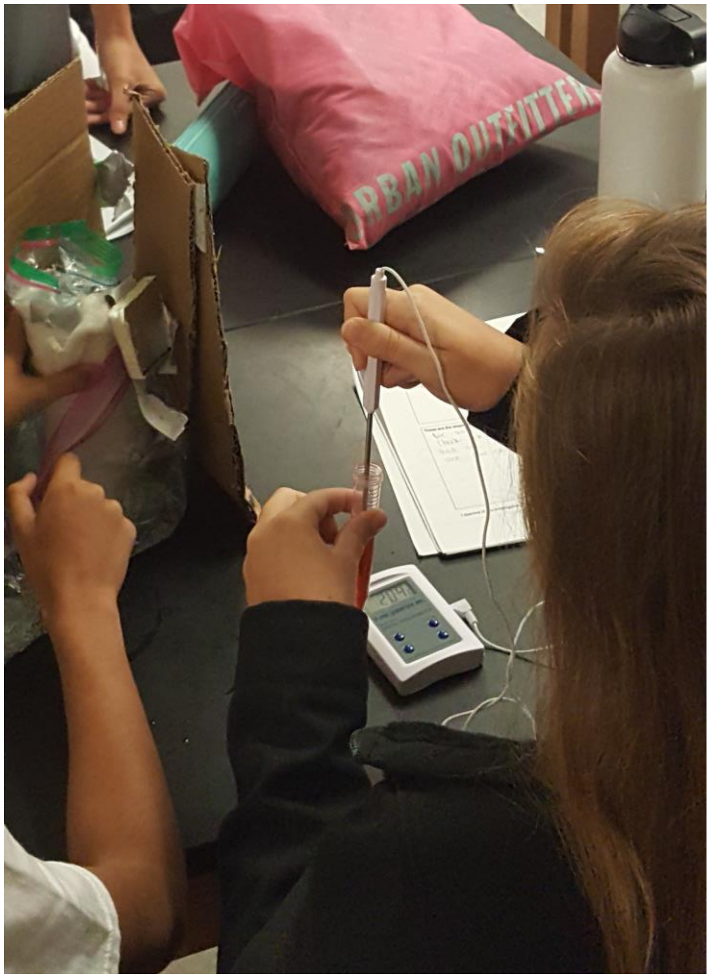

Fig. 4. A student team measures the temperature of their vaccine proxy to test their prototype storage device (Stage 5).

Stage six is a second argumentation session during which students present their final prototypes to their classmates (Fig. 5). As in stage four, student teams create a whiteboard to display their argument and participate in a gallery walk in which one team member remains with whiteboard while others circulate to view other teams' arguments. During this evaluation argumentation session, students critique the evidence and justification of their peers' prototype selection. From this peer feedback, further improvements can be made to teams' arguments.

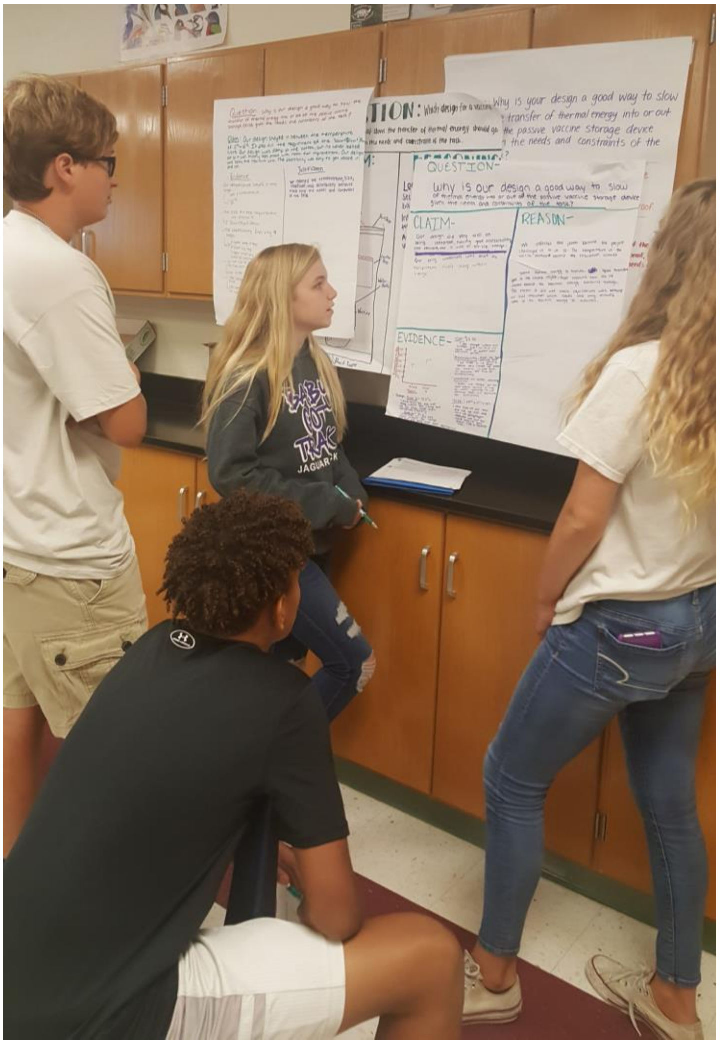

Fig. 5. Students participating in a gallery walk argumentation session (Stages 4 and 6).

The seventh stage of the ADE instructional framework is a reflective discussion session. This stage involves a teacher-facilitated discourse during which students talk about and reflect on what they learned during the investigation. This discussion also encourages the instructor and students to explore ideas related to the nature of engineering, including the most important big ideas in K-12 engineering: engineering design, trade-offs, optimization, constraints, analysis, and modeling [29]. Students submit a personal reflection following this group discussion.

The eighth and final stage of ADE requires students to write a final report to share and defend their team’s design. The reports summarize the design process including concepts that students generated, how they used the design matrix to select a concept, and a summary of their iterative prototype building, testing, and selection based on evidence. These reports are then peer-reviewed through a double-blind process, providing students with constructive peer feedback and encouraging them to develop and use appropriate standards for what counts as evidence in communicating their design solutions. Engagement in science-specific written argumentation has been shown to improve argumentation skills, writing skills, and understanding of core scientific ideas [30]. By explicitly explaining their thinking and relating the design to scientific principles, students are expected to develop a deep understanding of not only engineering but also science disciplinary core ideas. These reports are submitted to the teacher and evaluated as an individual assessment.

Implementation of ADE: Teacher Feedback from a Field-Test

Four EDTs were developed to test and refine the ADE instructional framework. These were piloted in May 2017, revised, and field-tested in 8th grade science at two middle schools during the 2017-2018 academic year. Hill Valley Middle School (HVMS) has 1,500 students in grades 6-8, where 18.5% are classified as Hispanic and 4.6% are classified as African-American. DeLorean Middle School (DLMS) has 1,100 students, of whom 42% are classified as Hispanic and 12.5% are classified as African-American. Students in this school district had previously engaged in Argument Driven Inquiry (ADI) [e.g., 24-25] and were familiar with scientific argumentation.

The first two EDTs were implemented in Fall 2017. EDT 1 (Fig. 2) applies physical science concepts of heat and thermal transfer to the problem of passive vaccine storage. EDT 2 also applies thermal energy concepts, but to a novel problem: designing hand warmers for the homeless using an exothermic chemical reaction. The last two EDTs were implemented in Spring 2018. EDT 3 references Newton's Third Law to inform the design of crash safety barriers to reduce injuries in collisions between vehicles and walls on highways, such as when a road splits into two. The fourth EDT applies concepts of ecology and trophic levels to design a biodiversity monitoring device that models the capture of primary consumers for counting.

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Students were able to effectively argue for their vaccine storage devices. A representative argument whiteboard (Fig. 6) shows that students successfully evaluated their design according to the criteria and constraints and used this evaluation as evidence for prototype. This team recognizes ways in which they could further improve their design, showing an understanding of the iterative nature of the engineering design process. They also exhibit typical confusion of criteria and constraints (these students use the term "criteria" for both parameters). Their justification shows their thinking about why the evidence matters, what that evidence can do for the improvement of their design, and how evidence can be applied to saving lives "by making a device that keeps vaccines cold." However, there is limited evidence that this specific group was able to apply an understanding of the underlying scientific core ideas of heat transfer to their design. They state, "The materials we use are good at preventing thermal energy transfer, we just need to close [the] device" but it is unclear from this that they understand the direction of thermal energy transfer. The whiteboard shown in Figure 6 represents a typical argument constructed by students during field-testing, with variation across groups in the amount of evidence presented and the robustness of their justification.

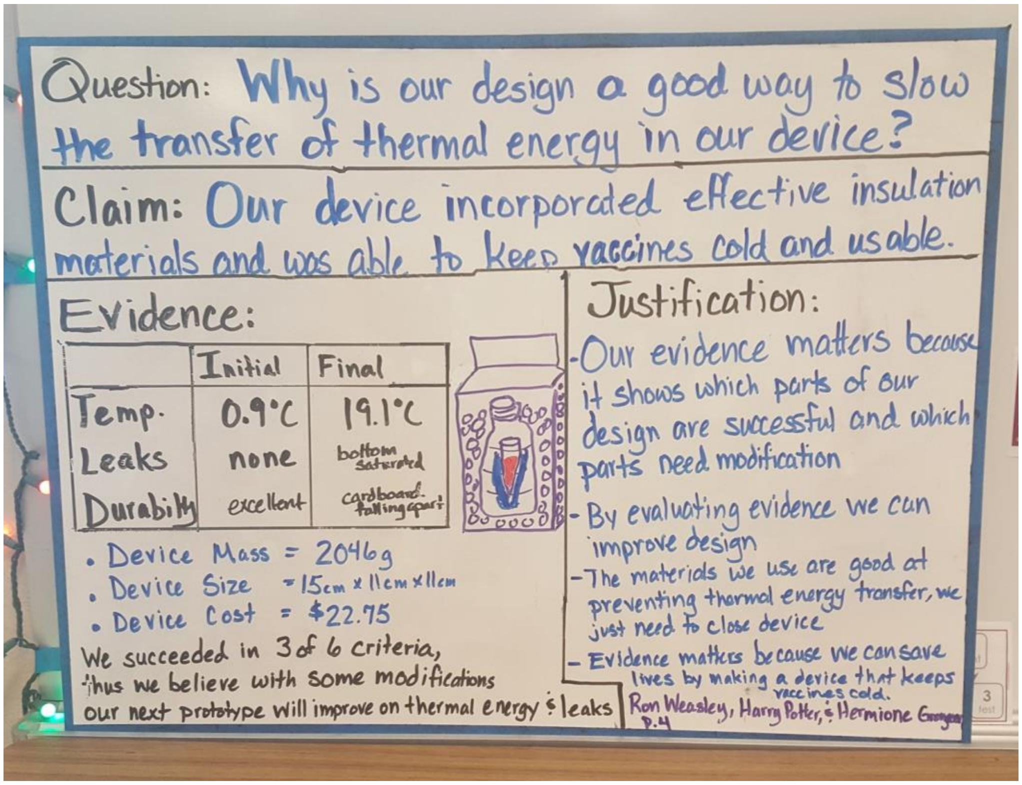

Fig. 6. An example of a final evaluation argument (Stage 6).

Teachers from HVMS were interviewed following the first EDT. Select responses provide first-person perspectives of the benefits of ADE they saw in their classrooms. Mr. McFly, for example, reported that he saw high levels of engagement during the first EDT. The following quote provides a good example of his views about the benefit of using the ADE instructional framework to teach engineering and science at the same time.

> I've never had a project where the kids stayed engaged the entire time, and I think that's because every single day they would come in and there was like something slightly different than there was the day before. There was never like, in the past we've had, ‘Okay, three days, build, and modify, and test.’ It was like this big overwhelming portion where the kids could just like, ‘Ah, I'm going to check out for today’ and, ‘Ah, I'll pick it back up for tomorrow.’ But with this one being so structured, it was like every day they had something that they had to accomplish. Like, all the different pages in the packet. I feel like that made it more engaging for the students. … Yeah, definitely I felt like the more specific things were, the easier it was to facilitate. I liked the fact that each day we had something new to design or we had a new challenge every day. Every day it was a unique and different challenge.

Mr. McFly attributes this engagement throughout the several-day long process to the structured process outlined by the ADE framework. This is in contrast to less structured Project-Based Learning (PBL) activities that he used in the past, which did not engage students at this level. In addition to increasing student engagement, several other teachers who used the ADE instructional framework during the school year commented that their students were thinking more deeply about the science content because of the argumentation sessions (Stages 4 and 6). Ms. Baines, for example, made the following comment during an interview:

> Yeah, my students spent a lot of time talking about... I think they've heard the word insulator and conductivity, but they really had to understand those words, and use those words, in talking with their teammates, and then arguing their designs. They really had to take ownership of those words. They couldn't skate around them. Yeah, they definitely, the science concepts related to that task, they had them."

The process of arguing for their designs seems to encourage the students to think deeply and critically about the scientific concepts involved in design. These types of comments, although not definitive, suggest that students are able to learn about the core ideas of science as they design solutions to problems by including opportunities for them to participate in the practice of arguing from evidence.

Females are underrepresented in engineering careers [18]. Adolescent girls are also discouraged from pursuing STEM subjects by teachers and do not see themselves as engineers [19, 20]. Interestingly, Ms. Clayton noticed a high level of engagement in her female students when using the ADE instructional framework. During one of the interviews, for example, she described what her female students did during one of the EDTs.

> Ms. Clayton: "The girls, actually, were the ones that worked the best out of all my classes. All five."
>
> Interviewer: "Were they?"
>
> Ms. Clayton: "Mm-hmm" (affirmative).
>
> Interviewer: "In what ways?"
>
> Ms. Clayton: "They just got together, they worked together, they designed better, they thought about it better. It was obvious."

This increased engagement of female middle school students in engineering is promising and warrants further study. Finally, Ms. Baines reported that the use of the ADE instructional framework has additional benefits for students once they leave her class. She described the potential benefits of this type of approach as follows:

> I really want to be incorporating engineering into things that I'm doing because I can see what a future need it's going to be. I think that it will make my students more competitive in the world. I see a world in which we're creating a lot of problems that are going to have to be solved in the future. Growing population, using up all of our non-renewable energy resources, transportation, just having enough for the people that we have on our world, and have enough space. We're going to have problems that are going to become huge. We're going to need problem solvers. Obviously those are the engineers. These people who are coming up, they're going to have to face things that we haven't had to face.

Authentic engineering instruction such as ADE can help create the engineers Ms. Baines knows the world needs. Overall, ADE has shown great promise in its first implementation. Through participating in EDTs, students seem to be gaining skills in argumentation, learning core ideas in science and engineering, and experience engaging, authentic, hands-on engineering tasks.

Discussion

We developed the ADE instructional framework in response to current recommendations to give more opportunities for students to learn about evidence-based engineering design as part of the formal science curriculum. ADE requires students to use disciplinary core ideas, crosscutting concepts, and science and engineering practices to solve problems. It also makes the classroom more equitable by creating design projects that are sensitive to and inclusive of issues that are important to diverse groups of students. There are several additional benefits to using the ADE instructional framework. First, participation in ADE helps students understand how engineering designs are developed and evaluated, and how the disciplinary core ideas of science can be applied to solving problems in engineering and society. Secondly, they experience the applications of scientific and mathematical principles to design and the productivity of these principles in engineering. And finally, students have an opportunity to give and receive feedback about their performance in the student-centered classroom. ADE, as a result, is intended to be distinct from other approaches, such as the Maker Movement [31], that are designed to introduce students to engineering because it is a formal, structured framework that emphasizes the use of disciplinary core ideas, crosscutting concepts, and each of the science and engineering practices. Students participating in ADE have the freedom to try different ideas and explore new concepts yet are engaged in structured design toward a solution and specific learning goals. The feedback from the teachers after implementing several EDTs inside their classrooms suggests that ADE may be a useful way to integrate more opportunities for students to learn about evidence-based engineering design as part of the formal science curriculum.

The use of the ADE instructional framework also has the potential to have a broad impact on science education for three reasons. First, a focus on middle school introduces students to engineering early enough to impact high school and collegiate mathematics and science course selection. By integrating opportunities for students to learn about evidence-based engineering design in middle school science classrooms, students gain exposure to engineering early and have the opportunity to develop a sense of identity as engineers. In addition, ADE gives students more opportunities to engage in authentic design tasks, participate in engineering practices including argumentation, and communicate design solutions, which can help minimize the gap between engineering preparation and the future workforce and industry standards. Secondly, ADE engages girls as well as culturally and linguistically diverse student populations who are underrepresented in engineering. These populations are often interested in humanitarian and altruistic design solutions [21]. By implementing authentic design tasks that incorporate lessons learned in *Changing the Conversation* [3] to enhance interest in the field of engineering, ADE has the potential to broaden the participation of girls, minorities, and students with disabilities in engineering. Lastly, the development of a clear instructional framework allows for easier scale across grades and contexts. Since ADE is not a curriculum, it is adaptable and flexible. The EDTs that are developed based on the ADE framework can be used in different grade levels and EDTs can be developed for application of any science content.

The value of ADE may even progress beyond middle school. High school and even undergraduate students often lack the skills and competencies they need to succeed in engineering careers; engineers enter the work force equipped with technical knowledge, but unprepared to integrate their knowledge, skills, and identity to develop as professionals [32]. Current science and engineering education standards are not equipping all students with the rounded abilities they need to be successful. Additionally, Adams et al. [33] call for innovation in engineering education, especially in formative adolescent years, and reflect views found in *Changing the Conversation* [3] to emphasize social justice issues and their applications to engineering. By integrating subject area knowledge with science, mathematics, engineering, and literacy skills, as well as socially equitable design challenges, ADE responds to these calls.

Along with the development of the ADE instructional framework, our team is pursing answers to several additional research questions on ADE. During the 2017-18 school year, we focused on two questions. Our first question, grounded in the hope that ADE can broaden participation in engineering, asks how student attitudes change over time as a result of participating in the four EDTs [34]. Our analyses will disaggregate the data to focus on student groups who are often denied opportunities to participate in engineering design – female and culturally and linguistically diverse students. Our second question asks about factors impacting the integration of engineering design in middle school science classes. We have found that there are a number of tensions that arise during the design and implementation of engineering in science classes impacting the patterns of implementation by our participating teachers [35].

In the coming year, our research efforts will continue to explore the impact of ADE on student outcomes. Our team has been working to develop and validate an instrument that can be used to measure students knowledge of engineering design practices. During the 2018-2019 academic year, we will be using this instrument to measure the growth in students' knowledge of engineering design and to compare the students in our treatment condition to other students in the district who are not participating in any of the ADE unit. Second, we will study how middle school students participate in engineering design, determine how they propose, support, critique, and revise designs during this process, and how their use of science and engineering core ideas and practices as they attempt to solve meaning problems changes over time.

Conclusion

The feedback that we have received from teachers who have used the ADE instructional framework in their classroom suggests that this approach can be successfully used in middle schools. We hope that others can use the ADE instructional framework as a way to bring engineering practices into middle school science classes, and to meet the challenge of NGSS aligned instruction.

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