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# Empowering Elementary Students with Community-Based Engineering: A Teacher's Experience in a Rural School District

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**Abstract:** This paper presents a case study of an elementary teacher, Holly, who participated in a federally funded summer professional development (PD) program aimed at integrating community-based engineering into elementary education. The study examines how Holly's teaching practices and beliefs about teaching engineering contributed to the significant increase in her students' attitudes toward engineering and their perceptions of engineering as a potential career. Data was collected over three years through multiple methods including post-PD interviews, lesson recordings, and a post-teaching interview. We analyzed classroom videos using a video analysis protocol. We used open coding to analyze the interviews. Once the analysis of interviews and videos were completed, we engaged in a sense-making process to identify connections across data points (videos and interviews). Findings showed that Holly extensively incorporated scientific inquiry into her lessons. This approach enabled students to develop their inquiry skills and facilitated a smooth transition to engineering design activities. By connecting class activities to the local context, students were able to see the relevance of engineering to their everyday lives and take ownership of their learning. This study demonstrates the potential of community-focused engineering to foster meaningful science and engineering practices in elementary education.

**Keywords:** community-based engineering; elementary education; professional development; engineering identity

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## 1. Introduction

The literature extensively emphasizes the benefits of introducing engineering education to elementary classrooms [12, 23]. Significant efforts have been made within the past 20 years to widen access to engineering education in primary schools [3, 11]. However, engineering is still perceived as detached from students' personal lives [22], leading to a lack of student interest in engineering or misconceptions about the role of engineering in society. One approach to overcome this issue is to introduce community-based engineering in elementary classrooms and offer students multiple opportunities to increase their understanding of the real-world implications of engineering and its relevance within local contexts. In this paper, we address how elementary teachers can implement such an approach in their classrooms. In doing so, we present a case study of an elementary teacher, Holly, who participated in a federally funded summer professional development (PD) program aimed at integrating community-based engineering into elementary education. After Holly taught community-based engineering lessons that she developed for her 4th grade classroom, survey results showed a significant increase in her students' pre and post scores of attitudes toward engineering and their conceptions of engineering as potential career aspirations. These findings were reported in a prior publication [18]. In this paper, we elaborate on how Holly's beliefs and practices made the difference in her students' attitudes and identities. Specifically, we target the following research questions in this paper:

RQ1: What meaningful practices occur in the implementation of engineering and community-based engineering lessons in an elementary teacher's classroom?

RQ2: What are an elementary teacher's beliefs about teaching/integrating community-based engineering lessons?

## 2. Theoretical Framework

### 2.1. *Engineering Education in Elementary Schools*

The world is increasingly technologically driven, requiring that its citizens are technologically literate in order to make well-informed choices in their role as consumers [28]. To meet these demands, industrialized nations such as Australia, the UK, and the USA have instituted national reform efforts aimed at enhancing engineering education in primary schools [30, 32, 29]. In the USA, where the present study takes place, 88% of states have adopted or adapted standards influenced by the Framework for K-12 Science Education document and require engineering be taught in primary grades [8]. Further, the Framework for P-12 Engineering Learning states that there are three dimensions that should guide the implementation of authentic engineering in schools: Engineering Habits of Mind, Engineering Practices, and Engineering Knowledge [1]. Further, these documents emphasize the importance of all students, regardless of demographic factors, having the opportunity to engage with the three dimensions of engineering learning so that they can grow into engineering and technologically literate individuals.

While it has been ten years since the National Research Council (NRC) called for the inclusion of engineering in elementary classrooms in the USA, adoption has been slow. Most teacher preparation programs do not include engineering in their coursework, leaving the majority of US primary teachers underprepared to teach engineering to their students [2]. Further, many states have mandates in place requiring teachers to focus the majority of instructional time on tested subject matter such as math and reading, leaving little time for engineering instruction [10]. Despite these barriers to implementation, numerous studies highlight the benefits of primary students engaging in engineering learning, including high levels of student engagement [23], improved understanding of engineering, technology, and science [12, 40], and enhanced communication skills [3]. As such, concerted efforts have been made over the past two decades to support the implementation of engineering in primary classrooms [35].

### 2.2. *Community-based Engineering Education*

Engineering is a social process that takes place within communities and can impact those communities in both positive and negative ways, yet many students view engineering as disconnected from their personal lives [22, 38]. Holding misconceptions about or perceived mismatches between engineering and one's self or community could inhibit interest in engineering and continue to limit who engages in engineering. To counteract this, teachers need to identify ways to connect "to their students' communities for examples of projects and applications of engineering learning that can intentionally teach desired engineering concepts" [1]. In doing so, teachers can utilize community-based engineering as a way to promote equity, connecting school-based engineering learning to local knowledge, culture, and community.

The Engineering for Sustainable Communities (EfSC) Framework developed by Tan and colleagues [37] is one approach to implementing community-based engineering into educational interventions. The framework requires students and teachers to consider "how problems and solutions are defined, adapted, and optimized in response to community needs" [37]. They do this by upholding the four principles of EfSC: (1) use community ideas in engineering, (2) help the community solve their problems in engineering, (3) care about the environment, and (4) design solutions for now and in the future [37].

Similarly, Chiu et al. [9] encourage teachers to draw upon student and community resources to co-design or adapt curricular materials that allow students to define problems that are relevant to their communities, seek input from community stakeholders, and present their design solutions to community members who might be affected by those designs. Scholars have reported the benefits of such efforts on student self-efficacy [24], students connecting personal lived experiences to classroom engineering activities [5], and social-spatial shifts that resulted in "youth engineered authentic projects that mattered to them and their communities" [5].

## 3. Methods

This study reports on a federally funded project focused on connecting local knowledge and contexts to engineering activities taught in primary classrooms. The project included a multi-year summer professional development (PD) program and academic year support for primary grade teachers in a predominately rural state in the northwest region of the US. In this paper, we purposefully focused on the case of one participant teacher, Holly (all names are pseudonyms). Our rationale was to understand how Holly integrated engineering and community-based engineering into her teaching. The reason we chose to focus on Holly was that we found a significant increase in her students' pre and post scores of attitudes toward engineering and their conceptions of engineering as potential career aspirations. These findings were reported in a prior publication [18]. In this paper, we are elaborating on Holly's beliefs and practices which made a difference on her students' attitudes toward engineering and seeing it as a potential profession.

### *3.1. Participant*

Holly is a 4th grade (ages 9-10) homeroom teacher with 14 years of classroom teaching experience. She has a master's degree in education technology. She is responsible for covering all of the fourth grade state level standards in the content areas of mathematics, English language arts, social studies, and science. While she has some experience with technology enhanced engineering activities and has previously used robotics kits such as Lego WeDo in her teaching, she chose to participate in the program because she felt that science and engineering were the areas where she struggled the most in her teaching. Further, it should be noted that Holly's school has been transitioning to standards-based grading over the past few years.

### *3.2. Description of PD*

The PD program was hybrid and consisted of two phases. The first phase was implemented in the summer of 2020 and aimed to equip participants with skills in ethnographic methods [15], such as photo journal elicitation. The intent of this first phase of the PD was to provide teachers the data collection and analysis skills coupled with learner documentation techniques like photo journal elicitation and apply those new skills to their classroom instruction. This approach was designed to accomplish two purposes. First, none of the teachers in the program live in the community where they teach, so the training in ethnographic methods allowed them to gain a better understanding of the communities where their schools were located. Second, with a better understanding of the local school community, teachers were able to connect local knowledge to classroom instruction, allowing students to learn more deeply about their communities. The first phase also introduced teachers to engineering design-based teaching in addition to different ways to integrate educational technology and engineering into science teaching. The second phase was held in the summer of 2021 and focused on building upon the first session by supporting teachers in developing community-focused engineering curricula. During this phase, teachers worked with project team members to identify local opportunities around which to center classroom engineering activities and developed a plan for implementing the community-based engineering lessons in their classrooms throughout the 2021-2022 academic year (for additional details see [19, 21]).

### *3.3. Data Sources*

For this multiple methods study, we collected data from multiple sources spanning over three years. For this paper, we analyzed Holly's data that included post-PD interviews, lesson recordings, and a post-teaching interview. At the end of each PD phase, Holly discussed her experience and learning outcomes as well as her future plans for teaching engineering in her classroom. We videorecorded her lessons to explore her implementation of engineering in the classroom (Tables 1 and 2). In total, we recorded twelve lessons totaling almost seven hours of instruction. Several of the lessons, like “Weathering, Erosion, and Deposition” and “Flooding and Community-based Engineering” took place over several days. Table 1 outlines how much instructional time was devoted to each lesson. After the lessons were recorded and analyzed, Holly participated in another interview (post-teaching interview) in which we asked her about her perspectives on the analysis we reached from the videos of her lessons and her views of teaching community-based engineering lessons.

**Table 1.** Video recordings of the lessons

| Lesson | Duration | Content |
|---|---|---|
| Lesson 1 | 0:27:13 | Volcanoes |
| Lesson 2 | 0:45:33 | Volcano and Fossils |
| Lesson 3 | 0:28:41 | Weathering, Erosion, Deposition |
| Lesson 4 | 0:27:56 | Weathering, Erosion, Deposition |
| Lesson 5 | 0:29:00 | Weathering, Erosion, Deposition |
| Lesson 6 | 0:27:20 | Weathering, Erosion, Deposition |
| Lesson 7 | 0:43:34 | Fossils |
| Lesson 8 | 0:29:00 | Flooding and Community-based Engineering |
| Lesson 9 | 0:23:33 | Flooding and Community-based Engineering |
| Lesson 10 | 0:48:20 | Flooding and Community-based Engineering |
| Lesson 11 | 0:44:52 | Flooding and Community-based Engineering |
| Lesson 12 | 0:29:00 | Flooding and Community-based Engineering |

**Table 2.** Lesson descriptions

| Lesson | Description |
|---|---|
| Lesson 1 | Holly, the teacher, started Lesson 1 by discussing the discovery of eleven-million-year-old rhino fossils in [State]. Holly posed the question, Why did it take so long for scientists to find them? This question led to the discussion of volcanoes. Students explored the various characteristics, such as the type of lava and color of rocks, that distinguish the two types of volcanoes. Then, students conducted an experiment called Bubble Trouble, which is available at https://mysteryscience.com/rocks/mystery-2/volcanoes-rock-cycle/55#slide-id-889, to learn about the connection between thin and thick lava and why some volcanoes erupt gently while others explode. |
| Lesson 2 | Students engaged in a group discussion to determine which type of lava would be more likely to cause a volcano to explode. Holly explained the connection between the types of lava, rock colors, and the cause of volcanic eruptions, linking it to the discovery of the eleven-million-year-old rhino fossils. |

| | |
|---|---|
| Lesson 3 | Holly encouraged students to think about the cracks in rocks around their environment. They discussed the concept of root wedging and its effects on mountains and rocks over time. Students were also introduced to a story about a pyramid found under a tree (available at https://mysteryscience.com/rocks/mystery-3/weathering-erosion/57). |
| Lesson 4 | Students conducted an experiment with sugar cubes to explore the process of erosion. They shook the sugar cubes in a container and predicted the outcome after 200 shakes. Students then connected their observations to what happens to rocks as they tumble down a mountain. |
| Lesson 5 | Holly showed a picture of fossil layers and asked students to think about how the fossils ended up buried beneath layers of sand, rounded rocks, and volcanic ash. Students were given a text to read, which contained information about erosion (weathering, erosion, and deposition). They were asked to collect evidence from the text to help answer the question and discuss their findings with a partner. |
| Lesson 6 | Students were encouraged to share their responses with their partners, drawing upon the reading text and evidence to explain their claims. They were prompted to use the phrase, "the evidence that helps me explain how the rounded rocks and sand landed on the fossils is..." Their partners were then encouraged to listen and respond with either, "that is similar to my idea that..." or "my idea is different because..." |
| Lesson 7 | Students had previously mapped out volcanoes on their maps. Now, they were asked to add mountain ranges and a river to their maps. Holly then revisited the mystery question from the beginning of the lesson series, asking how the sand and rounded rocks formed a layer over the volcanic ashes and why it took so long for scientists to find the fossils. Students used their maps and evidence from experiments and texts to make predictions, discussing how ice and water (flooding) can contribute to the formation of rocks and sand. |
| Lesson 8 | Holly showed a video of flooding occurring in a town near the school and prompted students to think about the causes and effects of flooding on people. Students were also encouraged to consider how scientists and engineers help limit the negative impacts of flooding on communities. |
| Lesson 9 | Holly asked students to work on a cause and effect chart about floods based on a text Holly assigned. Holly stressed the importance of understanding the term floodplain. |
| Lesson 10 | Students explored floodplain dynamics and flood mitigation strategies. Students placed houses in the floodplain and recorded the water flow during a simulated flood. Students then individually designed plans to prevent flood damage, before collaborating in groups as if they were engineering teams. Holly facilitated a group discussion to encourage possible redesigns based on cost, feasibility, and environmental impact. |

| | |
|---|---|
| Lesson 11 | Holly asked students to create an individual plan. They were asked to design a plan to prevent flood damage based on their experiences with the model in the previous lesson. The teacher emphasized the importance of drawing and labeling their ideas, identifying the safest place for houses, and writing about their plan. |
| Lesson 12 | Holly encouraged students to create their group plans, emphasizing safety and minimal environmental impact of flooding as modeled in the previous lesson. The students discussed floodplain maps, the role of floods in ecosystems, and potential solutions like retention ponds. They considered costs and environmental impacts while striving for balance between safety and preserving the environment. The students then provided feedback on each other's plans using sticky notes, focusing on creating environmentally conscious designs that ensure safety in the event of floods. |

### *3.4. Data Analysis*

We used multiple methods to analyze the data (see Table 3 below). To address the first research question about the meaningful practices that occurred during the implementation of the community-based engineering lessons, we analyzed all the classroom videos and Holly's post-teaching interview. To do so, we developed a video analysis protocol (see Table 4) using two observation protocols: Capobianco and Radloff's Engineering Design-based Science Teaching Observation Protocol (EDSTOP) [7] and Sawada et al.'s Reformed Teaching Observation Protocol (RTOP) [34] (see Table 4). We adapted the protocols based on the research questions addressed in this paper and the specific needs and goals of the project. We used RTOP to investigate the meaningful practices Holly demonstrated in her teaching, and we used EDSTOP to investigate Holly's teaching of engineering in her science classroom. To more closely examine Holly's use of community-based engineering in her lessons, we added codes to the protocol that focused on connecting engineering to local context, such as REAL-ENG (The teacher makes connections to the engineering in the local context) or CNTX1 (modification of EDSTOP's CNTX code to include direct connection to local community or culture) (see Table 4). The first author rated each lesson (as listed in Table 1) following the protocol and prepared detailed data sheets to evaluate the presence of the codes in the protocol (see Table 4 below). To ensure reliability, the second author coded 10% of the videos as recommended by Campbell et al. [6], and the inter-coder agreement was found to be 100%. To increase the reliability of the study, Holly was also included in the data analysis, and her perspectives were obtained through a 30-minute interview (post-teaching interview). To address the second research question which focused on the teachers' beliefs about teaching engineering lessons, we used open coding to analyze the interview data (2020 Post-PD interview, 2021 Post-PD interview, and post-teaching interview) [33]. This process identified four themes that illustrated Holly's beliefs about engineering and community-based engineering lessons in elementary schools.

**Table 3.** Data sources for each research question

| Research Questions | Data Sources | Data Analysis |
|---|---|---|
| What are an elementary teacher's beliefs about teaching/integrating engineering-focused lessons? | Summer PD interviews/debriefs (Post-PD)<br>Post-teaching interview | Open coding |
| What meaningful practices occur in the implementation of community- | Lesson recordings<br>Post-teaching interview | Observation protocol<br>Open coding<br>Connecting |

| | |
|---|---|
| based engineering lessons in their classroom? | |

**Table 4.** Observation protocol

| Code | Description |
|---|---|
| PK | The instructional strategies and activities respect students' prior knowledge. (Source: RTOP, 2012) |
| FoK | The instructional strategies and activities respect students' funds of knowledge. |
| STEX | In this lesson, student exploration proceeds formal presentation. (Source: RTOP, 2012) |
| MoI | The teacher encourages students to seek and value alternative modes of investigation or problem solving. (Source: RTOP, 2012) |
| PRDCT | Students make predictions, estimations and/or hypotheses and devised means for testing them. (Source: RTOP, 2012) |
| QS | The teachers' questions trigger divergent modes of thinking. (Source: RTOP, 2012) |
| REPR | Students use a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena. (Source: RTOP, 2012) |
| SBJ | The teacher had a solid grasp of the subject matter inherent in the lesson. (Source: RTOP, 2012) |
| INTGR | Connections with other content disciplines and real world examples. (Source: adapted from RTOP, 2012) |
| REAL-ENG | The teacher makes connections with engineering in the local context. |
| RSPCT | There is a climate of respect for what others have to say. (Source: RTOP, 2012) |
| PTNT | In general, the teacher is patient with students. |
| CONTX | The teacher provides the context of the problem by providing a design brief or presenting the scenario from which students will work on the task. (Source: EDSTOP, 2018) |
| CONTX1 | Teacher provides the context of the problem by providing a locally and/or culturally relevant design brief or presenting the locally and/or culturally relevant scenario from which students will work on the task. |
| PROB DEF | Students define the problem. (Source: EDSTOP, 2018) |
| PROB DEF1 | Students define the locally and/or culturally relevant problem. |
| BRAIN | Students brainstorm ideas or possible solutions, individually and in a team (Source: EDSTOP, 2018) |
| BRAIN1 | Students brainstorm ideas or possible solutions referring to their local and/or cultural context, individually and in a team |
| ASK | Students ask questions to clarify the problem, use of materials, and/or challenge an existing solution. (Source: EDSTOP, 2018) |
| ASK1 | Students ask questions to clarify the problem, use of materials, or challenge existing solutions referring to their local and/or cultural context. |

| | |
|---|---|
| PLAN | Students develop individual and team plans (Source: EDSTOP, 2018) |
| NEG | Students negotiate their ideas and finalize a unified plan (Source: EDSTOP, 2018) |
| CONST | Students carry out the development or construction of their prototypes (artifacts) or process (Source: EDSTOP, 2018) |
| TEST | Students test the artifact (Source: EDSTOP, 2018) |
| ANZ | Students analyze and interpret results from testing (Source: EDSTOP, 2018) |
| COM | Students evaluate and communicate results to another team and/or whole class (Source: EDSTOP, 2018) |
| IMP | Students identify one or more features to improve upon |
| REDES | Students redesign |

Once the analysis of interviews and videos were completed, we engaged in a sense-making process to identify connections across data points (videos and interviews). The objective of the connecting process is to maintain the context and examine the relationships in the data by establishing connections between themes and elements found across different data sources. Therefore, the goal of employing connecting strategies is to approach data holistically rather than in fragmented categories [26]. Below we present the themes derived from interviews and videos for each research question.

## 4. Findings

### *4.1. What meaningful practices occur in the implementation of engineering and community-based engineering lessons in an elementary teacher's classroom?*

#### 4.1.1. Connecting scientific inquiry with engineering design

Holly extensively incorporated scientific inquiry into her lessons. This approach enabled students to develop their inquiry skills and facilitated a smooth transition to engineering design activities starting from Lesson 8. Furthermore, it helped students recognize the relationship between science and engineering and encouraged them to see these fields as interrelated disciplines:

> They [engineering and science] kind of blend well together. And that's what I was trying to do. I was trying not to keep engineering so separate from science, because I felt like, that's kind of how I've taught it in the past, like, oh, here's all the science standards I have to teach, [and] will do engineering when I get done with those. And it's like, a fun add on project, as opposed to like embedding it throughout. But yeah, I think, you know, kind of teaching them to, like, ask questions and be curious and go through those, you know, science inquiry lessons can lead into what you do as an engineer (post-teaching interview).

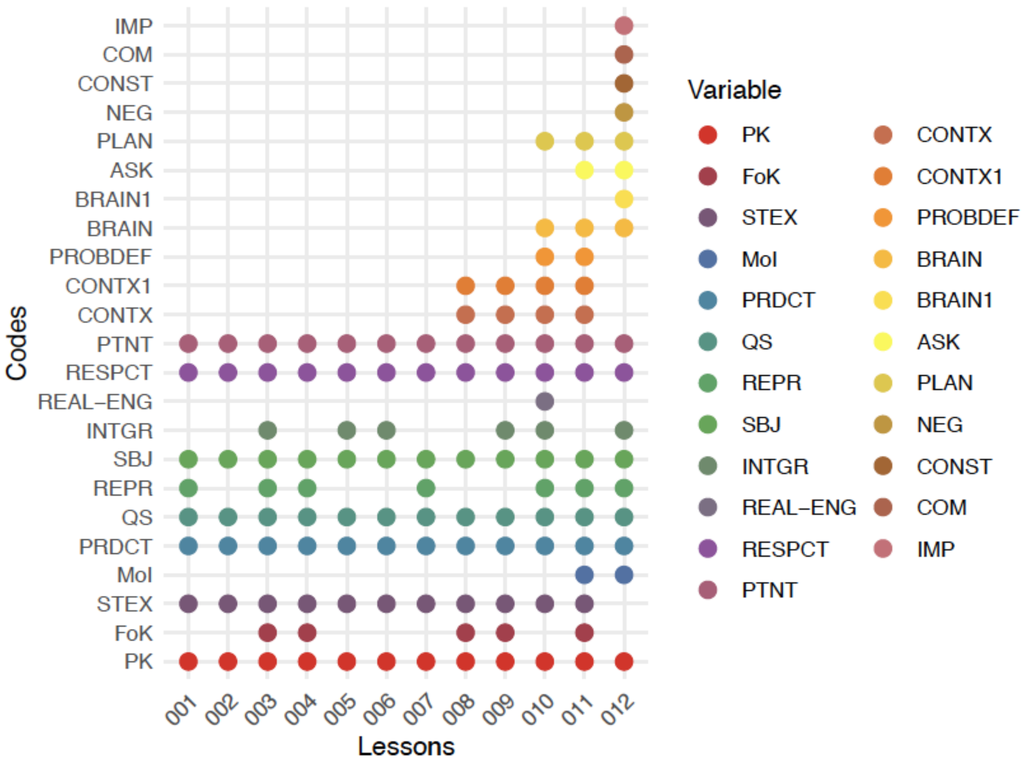
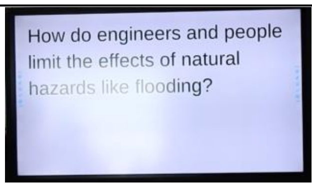
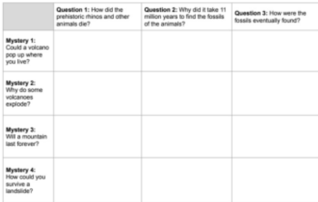



**Figure 1.** Scatterplot scoring the presence of codes for each lesson

As seen in Figure 1 above and in Excerpt 1 below, Holly effectively fostered the development of students' inquiry skills by emphasizing student exploration (STEX), respecting students' prior knowledge (PK), and encouraging predictions (PRDCT). Additionally, she utilized questions to trigger diverse modes of students' thinking (QS). These strategies were consistently applied across all observed lessons.

**Excerpt 1.** Holly's use of STEX, PK, PRDCT, and QS

| Codes | Screenshot | Description and Transcription |
|---|---|---|
| STEX |  | In the beginning of Lesson 8, Holly shows a local newspaper article and plays a video about flooding in a river close to the town where the school is located. She says, "So this is a video. This actually just happens like last week at the [Name] River. This is the headline of this article [which] says the [Name] River Ice Jam causes flooding near [Town]. So, this is on the [Name] River, really close to us… I want you to go ahead and talk about what do you think is happening in that picture? So go ahead and talk with your table partners. What do you think or in the video what did you notice or what do you think is going on?" (Lesson 8, 00:01:49-00:02:45) |

<table>
<tr><td>PK</td><td>
</td><td>Holly fosters their prior knowledge about how the effects of natural hazards are limited: “How do engineers and people limit the effects of natural hazards like flooding? So, you're going to write the question and write any initial thoughts you have right now. Remember, scientists change their thinking.” (Lesson 8, 00:15:59)</td></tr>
<tr><td>PRDCT</td><td>
<table>
<tr><td></td><td>Question 1: How did the prehistoric rhinos and other animals die?</td><td>Question 2: Why did it take 11 million years to find the fossils of the animals?</td><td>Question 3: How were the fossils eventually found?</td></tr>
<tr><td>Mystery 1: Could a volcano pop up where you live?</td><td></td><td></td><td></td></tr>
<tr><td>Mystery 2: Why do some volcanoes explode?</td><td></td><td></td><td></td></tr>
<tr><td>Mystery 3: Will a mountain last forever?</td><td></td><td></td><td></td></tr>
<tr><td>Mystery 4: How could you survive a landslide?</td><td></td><td></td><td></td></tr>
</table></td><td>Holly asks students to write their predictions to the third question on the worksheet and asks, “you'll make a prediction for Question Three about how you think the fossils were eventually found.” (Lesson 7, 00:09:58)</td></tr>
<tr><td>QS</td><td></td><td>Holly and students discuss erosion. Holly asks students to think about what happened to the pyramid in the pictures on the left.</td></tr>
</table>

She believed that focusing on inquiry and exploration was important for her students to be ready for engineering activities as such an approach encourages shift of mindset from traditional grading systems to standards-based instruction. Further, this approach offers students reassessment opportunities and moments to learn from their errors and focus on growth:

> From day one, the expectations in this classroom are it's okay to make a mistake, it's okay to fail. Like, we talk about our mistakes, we celebrate mistakes, like when students, you know, make a mistake. And I'll ask them, like, are you okay with me sharing this mistake? It's a wonderful mistake, we can learn from it, like I talked it up...And so I think that that whole kind of like classroom culture lends itself into the kind of work that they can do with engineering because, I mean, one of the things that I noticed year to year is that even at fourth grade, they're so afraid to fail, like they're afraid to get something wrong...we talk a lot about that how, like, with scientists and engineers that they fail, or that they have a question, and they think that they have a certain answer, but then they do the experiment where they do the work or whatever. And they find out that they were wrong. And so then, they revise their thinking (post-teaching interview).

She frequently emphasized a safe-to-fail approach in her lessons and encourage her students to change their thinking and revisit their responses. For example, in Lesson 5, Holly said, "So here's your initial question that I want you to answer in your notebook. You may or may not feel like you have all the answers. That is OK. Remember scientists revisited the question, and they changed their thinking as they learn more information and they gathered new evidence. That's what we're doing today.”

#### 4.1.2. Building Background Knowledge

Holly emphasized the importance of building students' background knowledge and content understanding before introducing engineering design activities:

> At this age, just to have the background of like, you know, the different problems that they [students] looked at and examined. And that's kind of how I did all of the

> units, like whatever science unit I was teaching. I tried to have some kind of engineering design activity that related to the science, but it was usually after we had done kind of like the lessons to build the background knowledge and content first.

We observed in the videos that Holly provided a structured learning environment and scaffolding for students to build their knowledge and confidence:

> … it's really important at this age, because I think it [lesson] has to be open ended enough where they [students], they are the ones doing the discovery, and they're the ones working through it. But you know, I think if you leave it too wide open and don't have the support in place, then I think that they flounder too much. I guess it's more of like, if you can scaffold and kind of guide them through where it's like, I'm not giving you the answers. But like, here's the things that we're going to investigate and look at. It gives them the opportunity to have like, more productive struggle, rather than just sitting there not knowing where to start or what to.

To build students' background and content knowledge, Holly frequently used a variety of means (models, drawings, concrete materials, etc.) and asked students to represent phenomena (RPRS in Figure 1). For example, in Lesson 3, students drew the picture of root wedging and took notes to understand what root wedging is (see Figure 2).

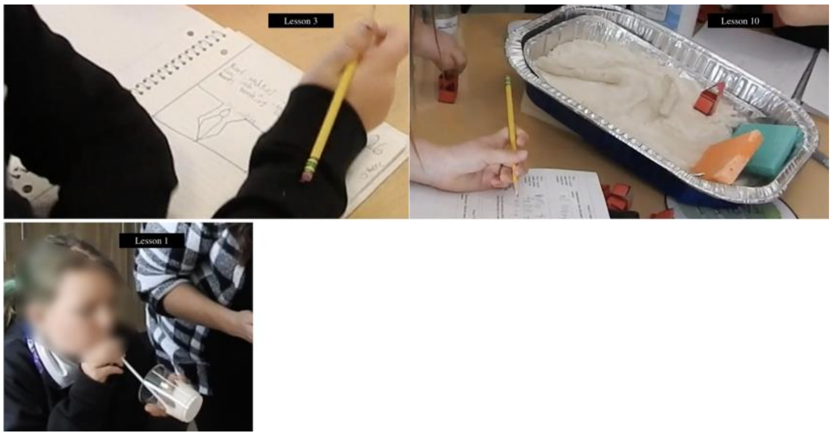



**Figure 2.** Examples to the means of representation

Furthermore, Holly integrated literacy into her lessons to further develop her students' understanding and content knowledge of the phenomena (INTGR in Figure 1). For example, in Lesson 5, Holly gave a text to students and asked them to read the text, dig into the text a little bit deeper, and look for evidence to help them with the question, "how did the rounded rocks and sand land on the fossils?" In Lesson 12, Holly directed students to a book called "The Good Influence" that highlighted the importance of floods in some ecosystems when students were puzzled with the idea of the positive effects of floods.

#### 4.1.3. Implementing Community-based Engineering Lessons

In implementing community-based engineering lessons (see Figure 1), Holly created opportunities for her students to engage in alternative modes of investigation (MoI) and encouraged them to approach engineering and problem-solving from various angles and utilizing different methods. For example, in Lesson 12, Holly asked her students to act as a team of engineers to work on a plan to protect people from floods based on the model of the river they drew earlier.

**Excerpt 2.** Holly's use of MoI

| Codes | Screenshot | Description and Transcription |
| --- | --- | --- |

| | | |
|---|---|---|
| MoI |  | Holly: "You have to put together a plan to keep people safe in the event of a flood based on the river that you're doing. Here's your list of things that you have to have. You have to have your river drawn neatly in the middle of your paper. You need to place houses where they will be the most safe. You need to label any modifications made to your house or river. So for example, if you're putting a levy down, you need to have that clearly labeled. And if you're building your house on fill or stilts or something like that, you need to have that labels. And then you have to explain how your plan will keep people safe." (Lesson 12, 00:46:00) |

It was interesting to observe that MoI (Alternative Modes of Investigation) had a limited presence in the first seven lessons focusing on scientific inquiry. These codes/aspects were covered more extensively in engineering lessons. REAL-ENG also had a place in engineering lessons. For example, from Lesson 8 to Lesson 12, students worked on the causes of floods and the ways to limit their hazards on people. Before they began working on the unit, Holly invited a local engineer to talk about the floods in the local area and the engineering they did to limit the effects of the floods:

> I had discovered, or I had, you know, talked with Dr. X [community member in [Town]], and we had talked about how [State] has the most amount of ice jam flooding in the lower 48 states. So then that kind of led into, like, well, what do they do about these types of floods, which then led me to finding a floodplain engineer. And so, he had come in and showed the kids like a model, like a simulation of like, different floodplains and what happens. And so then from there, then we created the lesson about looking at, you know, the different types of rivers and what can you do, and, you know, just kind of by talking with the engineer. (post-teaching interview)

In the community-based engineering lessons, as seen in Figure 1, Holly closely guided students through each step of engineering design process. She spent four lessons on setting the context (CNTX); three lessons on brainstorming (BRAIN) and planning (PLAN), two lessons on defining the problem (PROB DEF), and encouraging students to ask questions (ASK). In Lesson 12, students focused on negotiating the plan (NEG), carrying out the artifact design process (CONST), communicating the results (COM), and identifying features to improve upon (IMP).

It was observed that Holly consistently referred to the local context (from Lesson 8 to Lesson 12), making sure that the context of the engineering problem was locally relevant for students (CNTX1). She also referred to their local context when she asked students to discuss the needs of their local area (BRAIN1) (see Excerpt 3).

**Excerpt 3.** Holly's use of CNTX1 and BRAIN1

| Codes | Description and Transcription |
|---|---|
| MoI | Holly: "I don't know if you remember; this has been a while. We did a social studies activity about this at the very beginning of the year. We looked at places in [State] where people settled when settlers first came over and we talked about how they were all in areas where there was water close by because they needed that. At a certain point, you know, we couldn't just have, we didn't have |

| | |
|---|---|
| | plumbing systems; we couldn't bring in water. So, we had to settle in areas near water so that we had access to that, or we had access to things like fish or food or water that we could water crops with. So, there's many reasons why people might choose to live in a floodplain or they've had houses or land there for a long time. So now one of the things that we do is we look at how can we limit some of the effects of flooding." (Lesson 10, 00:09:12) |
| BRAIN1 | Holly: "We were having a conversation about how flooding really becomes an issue; when we have people involved or people's houses or people's structures. So sometimes there are natural hazards that happen that can actually be good for the environment too. So, in this case, and then the other thing maybe in [Town]…was that you don't want to go and start making a bunch of changes to the land that you don't need to do, right?" |

Finally, Holly observed that students initially had a limited understanding of what engineers do. However, through various activities and lessons, she noticed that students began to develop better understanding of the role engineers play in solving problems and creating products. Further, engineering was not confined to the 12 lessons we observed. Holly mentioned that they used read-alouds about engineers, scientists, and people who made discoveries through mistakes. Across the year, they discussed how scientists and engineers often experience failure, have questions, or revise their initial ideas after conducting experiments or working on projects. This helped students understand the role of engineering and engineers in real life.

#### 4.1.4. Classroom Culture and Expectations

Holly maintained a positive learning environment (RSPCT and PTNT) across all lessons. There was a climate of respect in the classroom, and Holly was patient with students. For example, in Lesson 7, Holly asked students to make a prediction about how the sand and rounded rocks formed a layer over the volcanic ashes, and the transcript below shows how Holly demonstrated patience with her student and encouraged him to think deeply:

> Holly (00:20:46): Can you tell us, make a prediction, use that sentence, "I predict." And tell us how you think that the rocks and sand ended up on top of that layer of volcanic ash that we have.
>
> Student (00:21:08-00:21:44): I predict that winds blew rocks and sands.
>
> Holly (00:21:44): Ok, so you think that winds picked up rocks and sands in the mountain ranges over here and blew them to Nebraska. (00:21:51) Does the map support that opinion?
>
> Student (00:22:07): Yeah. Rocks could have been over lava…

This transcript shows that Holly did not rush the student to answer. She gave the student time to think and respond, as evidenced by the time stamps. Holly gently guided the student to assess his prediction by asking, "Does the map support that opinion?" This approach helped the student to think critically and engage in the learning process without feeling discouraged or judged.

### *4.2. What are an elementary teacher's beliefs about teaching/integrating engineering and community-based engineering lessons?*

#### 4.2.1. Community-based Projects had a Significant Impact on Students' Engagement and Self-Perception as Engineers

Holly observed that community-based projects had a significant impact on students' engagement and self-perception as engineers. She noted:

> The difference that I saw between engineering lessons and the community-based engineering lessons where they were solving their community issue, was the way they talked about themselves, like, Oh, I'm doing this, this is fun. Like, I like this project, versus the community issues that we were solving was I'm an engineer. (post-teaching interview)

Holly emphasized that when working on projects that addressed real-life problem in their community, students felt more connected to their work and identified themselves as engineers. Holly believed that these community-based projects built relevance and connection by providing students with a better understanding of what engineers do in the field, solving real-world problems, and helping others in their community and beyond.

#### 4.2.2. Engineering Lessons are Aligned with the Curriculum and State Standards

Holly was motivated to integrate engineering lessons because they aligned with her existing curriculum and the state standards. She explained:

> The curriculum, they're one of our, you know, main standards for fourth grade, structure function in information processing. And so, I have a whole unit…it focuses on animals and plants, and I think it could just fit in nicely with that. (post-PD interview)

Holly added that engineering lessons could be incorporated into her lessons and would be also helpful for her students and their standing in the milestones testing.

#### 4.2.3. Principal Support Facilitates the Integration of Engineering into Classrooms

Holly noted that her principal was supportive of integrating engineering lessons into the curriculum. She shared, "She [her principal] is completely on board with this stuff [engineering]. Instead, it's good, she knows that it [engineering curriculum] aligns" (post-PD interview). This administrator support helped Holly feel more confident to implement these lessons without facing opposition or resistance from school administration.

#### 4.2.4. Understanding the Local Community Context is Crucial in Designing Community-based Engineering Lessons

Holly lives outside the community where she teaches. She initially thought that might disconnect her from the specific issues faced by the community and those faced by her students. Holly shared, "to be honest, I don't feel very connected to like the community of [Town]. Like I really don't have a clue as to what, like, issues are specific to [Town] that are outside of the school" (post-PD interview). However, she was hopeful that this challenge could be overcome by communicating with people from the local area and utilizing resources such as city council meetings. Indeed, as she engaged in ethnographic methods to learn about the community and talked with local experts, she began to learn more about the local context and funds of knowledge that were important to her students.

## 5. Discussion

Our work highlights the importance of providing teachers with targeted professional learning on how to identify local knowledge and potential community-based opportunities around which to build science and engineering lessons. Holly noted that one of the most challenging aspects of implementing the project was determining how to connect engineering to the local community. Holly, like many teachers, does not live in the community where she teaches, so she was not very familiar with the potential engineering opportunities within the community. This required Holly to take purposeful steps to learn more about her students' funds of knowledge [16, 27] and community by employing ethnographic methods [14, 39, 41] covered during the first summer PD [21] and reaching out to experts within the local community for additional information and support. That training and support was instrumental in Holly's lesson development and implementation.

Risk-taking plays an important role in the adoption of new teaching reforms, such as engineering design [31]. This often requires teachers to step outside of their comfort zones [21] to implement unfamiliar pedagogical strategies and new content. Holly's decision to participate in the program stemmed from her desire to enhance her science and engineering content knowledge and pedagogy. She was already an accomplished teacher highly respected in her school and community, but she demonstrated an authentic interest in building her own content and pedagogical practices in engineering. Further, Holly commented on the importance of having administrative support for her teaching of science and engineering. Previous studies have reported that lack of administrative support is a barrier to the implementation of engineering in primary school classrooms [13, 17]. Because Holly felt supported by her administrator, she was able to take the risk of incorporating new pedagogical strategies and content in her classroom, something she would not have been as inclined to do had she not had that support. This points to a need for PD providers and teacher educators to communicate closely with school administration when embarking on science and engineering projects with classroom teachers. Not only did Holly demonstrate this risk-taking theme when it came to her own professional development, but it trickled into her teaching beliefs and practices. With her pedagogical practices strongly rooted in inquiry and exploration, she routinely encouraged her students to take risks in their engineering activities, reminding them that scientists often revisit their own lines of inquiry and change "their thinking as they learn more information and they [gather] new evidence."

Our findings illustrate the potential of community-focused engineering for engaging students in meaningful science and engineering practices. By connecting class activities to the local context, students were able to see the relevance of engineering to their everyday lives and take ownership in their learning. Similar to the teachers in Radloff et al.'s study [31], Holly found that by implementing engineering design based teaching, levels of student engagement increased. Further, community-focused engineering education (e.g., flood mitigation) can also help students understand how climate and sustainability are connected to engineering design [25], connecting to multiple principles of the Engineering for Sustainable Communities framework [37].

Over the course of participating in the project, Holly shifted her perspective from initially seeing science and engineering as separate entities that were not connected in the classroom to viewing science and engineering as interrelated and complementary. To Holly, engineering was a natural way to engage students in alternative modes of investigation, during which they could apply the science content knowledge they had recently learned.

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## References

1. American Society for Engineering Education [ASEE] & Advancing Excellence in P-12 Engineering Education [AEEE]. *A Framework for P-12 Engineering Learning: A defined and cohesive educational foundation for P-12 engineering*. American Society for Engineering Education, Washington, DC, USA, 2020.
2. Banilower, E.R.; Smith, P.S.; Malzahn, K.A.; Plumley, C.L.; Gordon, E.M.; Hayes, M.L. *Report of the 2018 NSSME+*. Horizon Research, Inc., Chapel Hill, NC, USA, 2018.
3. Birt, L.; Scott, C.D.; Campbell, C.; Walter, F. Member checking: A tool to enhance trustworthiness or merely a nod to validation? *Qual Health Res*. **2016**, 26, 1802–1811. https://doi.org/10.1177/1049732316654870.

4. Brophy, S.; Klein, S.; Portsmore, M.; Rogers, C. Advancing engineering education in P-12 classrooms. *J. Eng. Educ.* **2008**, *97*(3), 369-387. https://doi.org/10.1002/j.2168-9830.2008.tb00985.x.
5. Calabrese Barton, A.; Schenkel, K.; Tan, E. Collaboratively engineering for social justice in sixth grade STEM. *J. Res. Sci. Teach.* **2021**, *58*, 28, 616–658. https://doi.org/10.1002/tea.21691.
6. Calabrese Barton, A.; Tan, E. Designing for rightful presence in STEM: Community ethnography as pedagogy as an equity-oriented design approach. *J. Learn. Sci.* **2019**. https://doi.org/10.1080/10508406.2019.1591411
7. Campbell, J.L.; Quincy, C.; Osserman, J.; Pedersen, O.K. Coding In-depth Semistructured Interviews: Problems of Unitization and Intercoder Reliability and Agreement. *Sociol. Methods Res.* **2013**, *42*(3), 294-320. https://doi.org/10.1177/0049124113500475.
8. Capobianco, B.M.; Radloff, J. Exploring the use of approximations of practice in the context of elementary teachers' attempts at implementing engineering design-based science teaching. In Proceedings of the Annual American Society for Engineering Education, 2018.
9. Carnegie Corporation of New York. *The need to align teaching with next generation science standards.* Available online: https://www.carnegie.org/our-work/article/need-curriculum-based-professional-learning-align-teacher-practice-next-generation-science-standards/ (accessed on December 10, 2022).
10. Chiu, J.L.; Fick, S.J.; McElhaney, K.W.; Alozie, N.; Fujii, R. Elementary teacher adaptations to engineering curricula to leverage student and community resources. *J. Pre-College Eng. Educ. Res.* **2021**, *11*(1), Article 5.
11. Cunningham, C.M.; Kelly, G.J. Epistemic practices of engineering for education. *Sci. Educ.* **2017**, *101*(3), 486–505.
12. Cunningham, C.M. *Engineering in Elementary STEM Education: Curriculum Design, Instruction, Learning, and Assessment*; Teacher College Press: New York, NY, USA, 2018.
13. Cunningham, C.M. Engineering is elementary. *The Bridge: Linking Eng. Soc.* **2009**, *39*(3), 11–17.
14. Douglas, K.A.; Rynearson, A.; Yoon, S.Y.; Diefes-Dux, H. Two elementary schools' developing potential for sustainability of engineering education. *Int. J. Technol. Des. Educ.* **2016**, *26*(3), 309–334.
15. Frank, C.R.; Uy, F.L. Ethnography for Teacher Education. *J. Teach. Educ.* **2004**, *55*(3), 269-283.
16. Frank, C. *Ethnographic Eyes: A Teacher's Guide to Classroom Observation*; Heinemann: Portsmouth, NH, USA, 1999.
17. Gonzalez, N.; Moll, L.C.; Floyd-Tenery, M.; Rivera, A.; Rendon, P.; Gonzales, R.; Amanti, C. *Teacher Research on Funds of Knowledge: Learning from Households*; Center for Research on Education, Diversity and Excellence: Santa Cruz, CA, USA, 1993. Available online: https://escholarship.org/uc/item/5tm6x7cm (accessed on December 10, 2022).
18. Hammack, R.; Ivey, T. Elementary teachers' perceptions of K-5 engineering education and perceived barriers. *J. Eng. Educ.* **2019**, *108*(4), 503-522.
19. Hammack, R.J.; Lux, N.; Gannon, P.; Hacker, D.; LaMeres, B.J.; Wiehe, B.; Boz, T. Connecting Classroom Curriculum to Local Contexts to Enhance Engineering Awareness in Elementary Youth. In Proceedings of the Annual American Society for Engineering Education Conference, Baltimore, MD, 2023.
20. Hammack, R.; Lux, N.; Gannon, P.; LaMeres, B. Using Ethnography to Enhance Elementary Teachers' Readiness to Teach Engineering. In Proceedings of the Annual American Society for Engineering Education Conference, Virtual, 2021.
21. Hammack, R.; Lux, N.; Gannon, P.; Wiehe, B.; Moonga, M.; LaMeres, B. Using Blended Modalities for Engineering Education Professional Development: Supporting Elementary Teachers' Development of Community-Focused Engineering Curricula. In Proceedings of the Annual American Society for Engineering Education Conference, Minneapolis, MN, 2022.
22. Hammack, R.; Stanton, C.R.; Boyle, J. "Step Outside": A portrait of an exemplary rural K-8 science educator. *J. Res. Sci. Teach.* **2022.**
23. Kant, J.M.; His Horse Is Thunder, W.; Burckhard, S.R.; Meyers, R.T. Why don't more American Indians become engineers in South Dakota? *Int. J. Eng. Soc. Justice Peace* **2015**, *4*(1-2), 17-34.
24. Lachapelle, C.P.; Cunningham, C.M.; Jocz, J.; Kay, A.E.; Phadnis, P.; Wertheimer, J.; Arteaga, R. *Engineering is elementary: An evaluation of years 4 through 6 field testing*. Boston, MA: Museum of Science, 2011.
25. Mejia, J.A.; Drake, D.; Wilson-Lopez, A. Changes in Latino/a Adolescents' Engineering Self-efficacy and Perceptions of Engineering After Addressing Authentic Engineering Design Challenges. In Proceedings of the Annual American Society for Engineering Education Conference, Seattle, Washington, 2015. 10.18260/p.23678
26. Martin, M.J.; Diem, S.J.; Karwat, D.M.A.; Krieger, E.M.; Rittschof, C.C.; Bayon, B.; Aghazadeh, M.; Asensio, O.; Zeilkova, T.J.; Garcia-Cazarin, M.; Alvelo Maurosa, J.G.; Mahmoud, H. The climate is changing. Engineering education needs to change as well. *J. Eng. Educ.* **2022**, *111*, 740-746. https://doi.org/10.1002/jee.20485.
27. Maxwell, J.A.; Miller, B.A. Categorizing and connecting strategies in qualitative data analysis. In *Handbook of Emergent Methods*, Leavy, P., Hesse-Biber, S.N., Eds.; Guilford Press: 2008; pp. 461-477.
28. Moll, L.C.; Amanti, C.; Neff, D.; Gonzalez, N. Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory Into Pract.* **1992**, *31*(2), 132-141.
29. National Academy of Engineering and National Research Council. *Technically Speaking: Why All Americans Need to Know More About Technology*; The National Academies Press: Washington, DC, 2002. https://doi.org/10.17226/10250.
30. National Research Council [NRC]. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academy Press: 2012.
31. Prinsley, R.; Johnson, E. *Transforming STEM Teaching in Australian Primary Schools: Everybody's Business*; Office of the Chief Scientist, 2015.

32. Radloff, J.; Capobianco, B.; Dooley, A. Elementary teachers' positive and practical risk-taking when teaching science through engineering design. *J. Pre-College Eng. Educ. Res.* (J-PEER) **2019**, 9(2). https://www.doi.org/10.7771/2157-9288.1208.
33. Royal Academy of Engineering. *Learning to Teach Engineering in the Primary and KS3 Classroom*; United Kingdom, 2018. http://www.raeng.org.uk/tinkering
34. Saldaña, J. *The Coding Manual for Qualitative Researchers*, 4th ed.; SAGE Publications: 2021.
35. Sawada, D.; Piburn, M.; Falconer, K.; Turley, J.; Benford, R.; Bloom, I. *Reformed Teaching Observation Protocol* (RTOP) (ACEPT Technical Report No. IN00-1); Arizona Collaborative for Excellence in the Preparation of Teachers: Tempe, AZ, 2000.
36. Sneider, C.I.; Ravel, M.K. Insights from two decades of P-12 engineering education research. *J. Pre-College Eng. Educ. Res.* (J-PEER) **2021**, *11*(2), Article 5. https://doi.org/10.7771/2157-9288.1277.
37. Strauss, A.; Corbin, J. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*; Sage Publications: 1990.
38. Tan, E.; Calabrese Barton, A.; Benavides, A. Engineering for sustainable communities: Epistemic tools in support of equitable and consequential middle school engineering. *Sci. Educ.* **2019**. https://doi.org/10.1002/sce.21515.
39. Tonso, K.L. *On the Outskirts of Engineering: Learning Identity, Gender, and Power via Engineering Practice*; Sense Publishers: 2007.
40. Watson-Gegeo, K.A. Classroom Ethnography. In *Encyclopedia of Language and Education*, vol 8; Hornberger, N.H., Corson, D., Eds.; Springer: Dordrecht, 1997.
41. Yoon, S.Y.; Dyehouse, M.; Lucietto, A.M.; Diefes-Dux, H.A.; Capobianco, B.M. The effects of integrated science, technology, and engineering education on elementary students' knowledge and identity development. *Sch. Sci. Math.* **2014**, *114*(8), 380–391. https://doi.org/10.1111/ssm.1209.
42. Zaharlick, A. Ethnography in anthropology and its value for education. *Theory Into Pract.* **1992**, *31*, 116-125.