Affordances of Engineering for Elementary-aged English Learners (Fundamental, Diversity)

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Introduction

English learners are a rapidly growing population in elementary schools [1, 2]. Over 16% of children entering kindergarten are English learners and this number is growing [3]. These students bring a wealth of perspectives and ideas to the classroom and need the opportunity to participate in classroom experiences, including those in engineering, science, and math, to develop interest in and knowledge of these fields. Currently English learners are underrepresented in STEM fields. Tapping the ideas and knowledge of English learners is important to bring greater equity to school systems, advance the technological literacy of an expanding portion of the population, and improve the skills of the workforce [4, 5].

For the past two decades, we have worked to design educational experiences that reach all children, particularly those who are currently underserved or underrepresented. We have studied the literature, developed inclusive design principles that guide our work [6, 7], and worked collaboratively with educators who regularly teach students from underrepresented populations as we designed curricular resources. The Engineering is Elementary (EiE) curriculum is designed to introduce students to engineering concepts and practices. Each of the 20 units focuses on a field of engineering (e.g., chemical, biomedical, industrial); introduces students to an age-appropriate, five-step engineering design process; and scaffolds their engagement in and reflection about an open-ended design challenge that permits many possible solutions. (See eie.org for more details about the curricular materials.) As we developed the curricular materials, we worked closely with educators, soliciting their ideas and feedback, observing and testing in their classrooms, and analyzing data from their students.

During our interactions with teachers, they shared the impacts that engineering was having on their students. English learners were one population they highlighted. Fueled by their anecdotes and testimonials, we began to think more deeply about the possibilities. A review of the literature surfaced no extant research about K-12 engineering and English learners. We believe that the opportunity to read, write, speak, listen, draw, and represent ideas as they engage in engineering activities can help English learners in a number of ways. This paper is a first effort to begin to systematically investigate these possibilities. As an exploratory study, we seek to understand the perspective of participating teachers. Our research question asks: What are the affordances of engineering for English learners at the elementary level?

Theoretical Framework

Our work is grounded in a sociocultural view of learning in which students, working with peers and the classroom community develop facility with engineering concepts and practices by actively engaging with and discussing ideas and design solutions. This sociocultural view of learning emphasizes the importance of engaging in the social practices of a discourse community, such as that of various engineering disciplines [8]. In this way, the learning occurs not only in social settings, but also with the artifacts and cultural tools created by more-knowing-
others in educational or professional settings [9]. Through engagement in engineering design and analysis students come to internalize the ways of talking, knowing, and being that constitutes engineering [10, 11]. In this way, the ongoing, concerted activities of engineering in educational settings provide numerous opportunities to learn the knowledge and practices of engineering including addressing client needs, balancing criteria and constraints, optimizing solutions, considering human factors, and persisting and learning from failure [12].

All students develop proficiency with knowledge and practices through meaningful engagement and authentic discourse. Discourse is defined as language-in-use that includes verbal exchanges, gesture, proxemics, written texts, sign and symbols, and other semiotic resources [13, 14, 15]. In engineering, consideration of discourse processes is particularly important given the need to interact with clients, work on teams, and use multiple semiotic fields to solve complex problems. Discourse serves multiple functions in social situations beyond just communicating information. Social order, relationships, and identity are constructed in and through discourse [16, 17]. As groups (engineering teams, classroom communities) affiliate over time they establish roles and relationships, norms and expectations, and rights and obligations that come to constitute being a member [18]. Through such social and discourse processes, members of a group create particular ways of talking, thinking, acting, and being [17]. Over time, as these concerted activities may become patterned, they establish cultural practices of members of a group [19, 20].

Access to disciplinary knowledge and practices is constructed through discourse processes. Linguistic features of science and engineering often pose challenges for students given the new technical vocabulary, interlocking definitions, obscure symbols and notational systems, and nominalization [21, 22, 23]. Furthermore, the Next Generation Science Standards [24] both introduce engineering as a core discipline for the first time in U.S. curricula and situate learning across three dimensions: science and engineering practices, crosscutting concepts, and disciplinary core ideas. These standards advocate for more active uses of language to advance learning in science and engineering and pose new challenge and opportunities for English Language Learners [25]. Lee et al. [25] identified ways that disciplinary knowledge and practices can be enhanced through particular uses of language around sense-making, across difference modalities, and with varying registers. Similarly, Moschkovich [26] identified ways that productive uses of discourse processes support understanding in mathematics. Taken together such uses of language can provide access to all learners. Engineering offers unique opportunities for learning with and through language because of the reliance on teamwork, the materiality of engineering design, and the coordination across verbal and symbolic meaning making.

Data Sources and Analysis

Over the past decade, educators have shared the impacts that Engineering is Elementary engineering challenges have had on students who were learning English. Intrigued by this feedback and our observations in classrooms, we began to consider ways that engineering might engage English learners. We were particularly interested in how we could continue to develop engineering curricular materials to encourage English learners to use language and participate in their classroom community.
Our proposed set of affordances of engineering for English learners (ELs) emerged through a set of complementary activities. We began by reviewing research literature. Although to date there have been no studies of engineering with K-12 English learners, research related to ELs in science and mathematics as well as studies of ELs more generally informed our thinking [25, 26, 27]. We also gathered information from classroom teachers. As part of our work with EiE, we developed curricular resources for elementary engineering that infused principles for high-quality materials for English learners. Our observations of these materials in classrooms with ELs and our surveys, feedback, focus groups, and conversations with teachers who field tested the materials surfaced many ideas about how and why the engineering activities (designed from a sociocultural perspective) were effective with ELs. Such work, conducted over a three-year period, led us to generate an initial set of ten affordances of engineering for English learners. This paper reports our efforts to test our early ideas about affordances with teachers and further refine and revise them.

Our data are drawn from elementary teachers and classrooms that have used engineering curricula with their students, who include English learners. For this first study, we began with a convenience sample. We aimed first to validate our ideas and see if our perceptions and articulation of affordances were supported by educators—if they held up with this population, we planned to continue to investigate the affordances in more rigorous ways. A majority of the teachers in this first study had used our EiE curriculum because we recruited respondents through the channels we use to reach teachers using our materials (a convenience sample). However, because we were interested in testing the generalizability of these affordances for elementary engineering education beyond a singular curriculum, we invited elementary educators who had done any engineering with ELs to respond. Our data sources for this study include:

(a) A focus group with 13 grade 1–5 teachers from the greater Boston area who had led Engineering is Elementary engineering challenges in classrooms with English learners. During this three-hour session we probed teachers’ perceptions of how engineering activities engaged English learners. We also solicited comments related to our proposed affordances. Throughout the focus group, multiple staff took detailed running record that captured the conversation. Based participants’ feedback, we revised our thinking and the affordances.

(b) An online survey of elementary teachers (N=44) who had taught EiE units with their students within the past year (the “initial survey”). These teachers received the materials and professional development as part of a grant during the 2017–8 school year. The grant-funded project worked with teachers from six regions and public school districts across the country (WA, MA, NC, CA, TX, UT) that were selected by the funder. As part of the final evaluation for the project, teachers who had taught ELs in their classrooms (N=25) were asked about the impacts of engineering on ELs. These teachers were asked a series of questions about the specific affordances of engineering that had been identified in interviews and focus groups.

(c) An online survey of elementary teachers (N=80) who had taught engineering in classroom with ELs (the “final survey”). Any elementary teacher who had taught
engineering with ELs was invited to complete the survey. Teachers were recruited using social media and email. The majority of the teachers (89%) had used EiE materials, but some had not. A cursory analysis indicates no difference between the two populations. Teachers were asked about the impacts they had observed of engineering on their ELs, and then queried about whether or not they have observed each of affordances.

The surveys asked teachers about the specific affordances of engineering that had been identified during the focus groups and discussions with teachers. The respondents for both surveys answered questions about the impacts of engineering activity on their EL students. It also asked teachers to compare the experiences of ELs in school overall to their experiences with engineering with respect to their engagement, learning of content, and confidence in their abilities. Teachers indicated whether they had observed the 10 affordances and then indicated which they thought were most valuable. (See Appendix A for the survey instrument.)

After each set of data was collected, the research team reviewed them. We looked for evidence of additional affordances we had not previously considered, attended closely to suggestions for changes in wording; considered whether categories should be compressed, expanded, or clarified; and probed whether all affordances were necessary. The online survey data were downloaded from Formstack to Excel databases. We ran basic statistics on both surveys to explore the categorical data and quantitative data and then merged the questions with similar wording to create a comprehensive data set for those items. Qualitative analysis of the open-ended questions generated themes and anecdotes that supported and fleshed out the quantitative data.

Participants

The respondents for the initial survey were primarily classroom teachers: 84%. A couple indicated they were instructional coaches. For the final survey most respondents were classroom teachers (36%) or science or STEM specialists (41%). Table 1 shows the breakdown of students in the teachers’ schools receiving Free and Reduced Lunch.

Table 1: Percentage of Students in the School Receiving Free or Reduced Lunch (FRL)

<table>
<thead>
<tr>
<th>% FRL Students</th>
<th>% of Teachers Selecting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Survey</td>
</tr>
<tr>
<td>0-25%</td>
<td>18</td>
</tr>
<tr>
<td>26-50%</td>
<td>30</td>
</tr>
<tr>
<td>51-75%</td>
<td>34</td>
</tr>
<tr>
<td>76-100%</td>
<td>18</td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
</tr>
</tbody>
</table>

Teachers’ classes also varied with respect to the numbers of ELs. Table 2 reports the percentage of students who were ELs in teachers’ classes. The students spoke a number of different languages at home as reported in Table 3. Over 84% of teachers taught students who spoke Spanish. High percentages of teachers also taught children who spoke Arabic, Russian,
Vietnamese, and Chinese. Overall, the students spoke a variety of home languages. Table 3 shows the percent of teachers with at least one student speaking the listed home languages.

Table 2: Percentage of Students in the Teachers’ Classes Classified as English Learners

<table>
<thead>
<tr>
<th>% ELs</th>
<th>% of Teachers Selecting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Survey</td>
</tr>
<tr>
<td>1-20%</td>
<td>40</td>
</tr>
<tr>
<td>21-40%</td>
<td>24</td>
</tr>
<tr>
<td>41-60%</td>
<td>24</td>
</tr>
<tr>
<td>61-80%</td>
<td>12</td>
</tr>
<tr>
<td>81-100%</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3: Language Spoken by Students at Home (Percentage of Teachers Selecting)

<table>
<thead>
<tr>
<th>Language Spoken at Home</th>
<th>% of Teachers Selecting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Survey</td>
</tr>
<tr>
<td>Arabic</td>
<td>40</td>
</tr>
<tr>
<td>An African language other than Arabic</td>
<td>16</td>
</tr>
<tr>
<td>Chinese</td>
<td>24</td>
</tr>
<tr>
<td>Haitian Creole</td>
<td>4</td>
</tr>
<tr>
<td>Korean</td>
<td>4</td>
</tr>
<tr>
<td>Polish</td>
<td>4</td>
</tr>
<tr>
<td>Russian</td>
<td>36</td>
</tr>
<tr>
<td>Spanish</td>
<td>84</td>
</tr>
<tr>
<td>Tagalog</td>
<td>12</td>
</tr>
<tr>
<td>Vietnamese</td>
<td>32</td>
</tr>
<tr>
<td>Other:</td>
<td>48</td>
</tr>
</tbody>
</table>

Findings

Impacts of Engineering on ELs

Before we shared with teachers the affordances of engineering for ELs that we had posited, we asked teachers an open-ended question about the impacts engineering had on their EL students. A content review of the responses indicates that teachers identify the benefits that we distilled. They articulate that students are engaged by the hands-on activities that provide an opportunity to show what they know. Because engineering does not rely on solely on verbal communication it reduces language barriers. Many mentioned that students find the activities relevant and meaningful and thus engineering presents opportunities for them to use academic language and build their vocabulary and understanding of science and engineering concepts. The role of students in the class was also a major theme—a number of teachers commented on their EL students’ willingness to participate in engineering activities, that these students were included in the activities, and that they actively participated with their teammates and peers in ways they
often could not in other academic subjects. ELs success with engineering activities developed their confidence and they were more willing to take risks and persevere through failure. Teachers evoked that the “playing field” is much more level for these students during engineering and mentioned how they could draw on their own ideas and backgrounds as they solved challenges. An analysis of the comments indicates that teachers’ open-ended responses generated elements of all ten engineering affordances that we subsequently asked them to review.

**Engagement, Content Learning, and Confidence**

We next asked teachers about their perceptions of English learners’ experiences in engineering more broadly. We asked them to compare ELs experiences in engineering with their experiences in school in general with respect to three variables: their engagement, their learning of content, and their confidence in their abilities. As Figure 1 illustrates, for all of these variables, teachers ranked ELs experiences during engineering equivalent to or, in most cases, better than general classroom instruction (N=80).

**Figure 1: Comparison of ELs Engagement, Learning, and Confidence between Engineering and School in General**

![Bar chart showing comparison of engagement, learning, and confidence between engineering and school in general.]

These responses are interesting and suggest that there is something going on during engineering activities that reaches ELs in ways that promote more engagement, learning, and confidence in their abilities. These are important attributes for learning and for participating as part of the classroom community. We wanted to identify what some of the characteristics of engineering were that create these kinds of opportunities and outcomes. So we distilled some benefits (or affordances) and asked teachers whether they had observed them with their EL students.

**Affordances of Engineering for English Learners**
We posited 10 affordances of engineering for ELs. For each we asked teachers whether they had observed it in their classroom and if so, asked them to describe what they observed. These affordances (which we termed “benefits” on the survey so the language was more teacher-friendly) are listed below, followed by our shorted code for the affordance in parenthesis.

### Affordances of Engineering for English Learners

1) Engineering supports language acquisition by providing opportunities for English learners to engage in authentic discussion about things they find meaningful such as design decisions, cultural or geographic references, or results from testing.  
   *(Language: meaningful discussion)*

2) Engineering supports language acquisition by providing opportunities for English learners to practice and develop their social language skills, as they negotiate design decisions in collaborative groups. *(Language: social language skills)*

3) Engineering creates an environment where it’s okay to fail. This encourages English learners to take risks linguistically and engage more actively with their peers. *(Environment: fail & risks)*

4) Engineering allows students to experience success in ways that are not contingent on language fluency. For example, children can explore properties of materials, test their designs and make improvements based on testing data, without having language fluency. *(Success w/o English fluency)*

5) Engineering provides opportunities for English learners to engage in non-verbal communication in the form of writing, drawing, and gesturing. This allows students, who may not be able to articulate what they are thinking verbally, to participate. *(Participation: multimodal communication)*

6) Engineering creates an environment where all students are learning new content and processes for the first time. This can decrease the reliance on previous exposure to ideas, skills, and resources to create a more equitable learning space. *(Equitable learning space)*

7) Engineering activities provide unique opportunities for English learners to apply their science content knowledge in meaningful ways, even if they learned that science content in another language. *(Meaningful science application)*

8) In engineering, there is not one correct solution, but many. Having more than one correct answer to a problem lowers the stress associated with suggesting and trying ideas. This encourages English learners to participate by offering their ideas. *(Many correct solutions)*

9) English learners can experience success and become more active members of the learning community during engineering projects. Consequently, they, their teachers, and their peers have an opportunity to see them in a new light. *(Participation: community & perspective)*

10) Successful engineering design solutions benefit from diverse perspectives. Engineering encourages English learners to draw from their life experiences and
consider their personal backgrounds as assets when imagining and designing solutions. (*Diversity: experience & solutions*)

Our survey was designed to ascertain whether classroom teachers would validate these proposed affordances. Although we would not expect that every teacher would observe all of these affordances with her/his ELs or that that any individual challenge or activity would surface all of these affordances, we were interested in a broad sense whether these categories resonated with teachers’ experiences. Figure 2 summarizes participants’ (N=105) responses.

Figure 2: Teachers’ Observation of Affordances of Engineering of Engineering for ELs

![Affordance of Engineering for ELs](image)

We were surprised by teachers’ reports of the prevalence of these benefits—all of the affordances were observed by at least 86% of the teachers and 6 of the 10 affordances were reported by over 95% of respondents. There was no individual respondent who had not observed any of the affordances.

We turn now to briefly to explore each affordance, offering teacher responses to demonstrate how they experienced this with their students.

**Affordance 1: Engineering supports language acquisition by providing opportunities for English learners to engage in authentic discussion about things they find meaningful such as design decisions, cultural or geographic references, or results from testing.**

Students are more likely to use and learn language when they are motivated to communicate. Engineering challenges that invite children to connect to a real-world problem anchor conversations in an experience that children want to solve. The hands-on, project-based challenges permit ELs multiple ways to understand the activity and learn language. Using materials and testing the performance of their design solutions provide experiences and information that can spur communication.
In my experience, students often push themselves to communicate their ideas if they are sufficiently engaged, and engineering tasks (building a bridge to support weight, levitating a Maglev train, building a house to withstand severe weather) are tremendously engaging.

If the children create a project, they are motivated and are better able to communicate their ideas and explain their findings, since they have something tangible to analyze and better support them to use new academic language in discussing the evidence.

EL students are immersed in language by doing activities using the engineering design process. They are able to internalize and process language and vocabulary through repetition and experience. Students are able to participate and find success through manipulation of materials, building on their prior experiences and language while building their confidence in engineering, English, and learning.

In the context of engineering challenges, all students (including ELs) are learning new vocabulary that describes what they are doing. For ELs this can be particularly empowering. Learning vocabulary with a purpose helps all students, especially ELs, to remember it.

All students are learning the engineering language presented, so they ELL students see the regular students also practicing with the new words. It emboldens them to use the new language as well.

Vocabulary emerges as a result of trying to share their thinking and experiences - that way it is anchored and not just memorized.

Children want to share their unique ideas to their group or class, spurring them to practice and use the terminology and language. Teachers noted that during engineering experiences, ELs were more likely to participate:

English Learners are more likely to step in and share their ideas based on their experiences when they are engineering.

My students love the engineering process because it challenges them to think on solving a problem. They are more open to talk with others in the team and are willing to share their ideas. It also helps them connect to real life situations and they feel empowered by their work.

The opportunities engineering offers for students to build their language through participating in authentic practices and situations were noted by the teachers. Students could use language at the level they were comfortable with—beginning by expressing their ideas in gesture or demonstration and then adding spoken or written language as they learned or needed it.

The experiences of investigating, planning, building, testing, and refining bring learning beyond linguistic barriers. There are many points of entry in a unit of study. The learning in a unit involving engineering moves beyond simple labeling and completing sentence frames.
It is dynamic learning and often can be used to reach a student at their exact language acquisition level.

The EL teacher and I loved doing EiE together because it was a chance for students to use academic language in authentic situations. The parts of the lesson where materials are tested was so valuable for all students but was so great for students who may not have used those materials before or didn't have the vocabulary to talk about them. I also love seeing how students could show what they knew through actions or a design working rather than language only. I think adding engineering to our program gave immense benefits to all students but especially to those new to English.

Affordance 2: Engineering supports language acquisition by providing opportunities for English learners to practice and develop their social language skills, as they negotiate design decisions in collaborative groups.

Engineers often work in teams. The teams are strengthened by the many ideas that its members bring, but ultimately the team needs to discuss and move forward with one (or a couple) ideas that are negotiated. Thus, there are many opportunities for rich communication. Because individual members bring their own, unique ideas, they want to share these with their team. Teachers commented that they observed that during engineering ELs engaged in “much more dialogue” as “They have something they want to talk about.” This also inspires ELs to learn the terms and language.

English learners usually understand English better than can communicate it which hinders them when asking and answering questions the core subject areas. I have found that they are more apt to attempt interacting in social activities when working on a design project. When they feel strongly enough about their design decisions, they work harder at making their point of view known. In other subject areas, they usually tend to try to not be noticed.

I have noticed that my EL students want to learn the language, both academic and conversational language, to understand what they are learning, and to communicate with their peers while collaborating.

Teamwork can also help build ELs social language and skills. All members of the team should understand what is happening and be involved in the decisions. ELs can work through their ideas and practice language as part of authentic tasks.

In a high needs school, like mine, EVERYONE needs language development. One time, there was an entire discussion about how to redesign a hand pollinator conducted in Karen (language from Thailand). When it was finished, one student said to another, "Now, let's try it in English." They translated their entire conversation, piece by piece and asking each other for help with translation, into English.... partially for practice and partially because they also had a native Nepalese speaker in their group.
They begin to ask more questions, and love to talk to their partners about trying new things so it reinforces their social skills.

Yes! Students are more able to talk to each other while they're having fun building objects and presenting findings. They work in groups and students talk about what issues they're going through while building their projects as a group.

Collaboration skills are very important when a group is working on designing and building something. They need each other and this provides them with real world opportunities to practice English in a comfortable setting.

As students become comfortable or committed to communicating their ideas, they are more motivated to express themselves. This engagement can result in ELs taking more communicative risks than they might normally do.

Since they are fully engaged, they are willing to take academic and communicative risks I don't typically see in other classroom activities.

They were excited by their ideas and forgot to stress about how they were expressing themselves. The excitement gave them power to express their ideas.

Affordance 3: Engineering creates an environment where it’s okay to fail. This encourages English learners to take risks linguistically and engage more actively with their peers.

An iterative engineering design process communicates to students that it’s expected that their first attempt will not be the final one—they will be improving their work. Failure in engineering should be embraced as a part of the process they learn from to inform subsequent attempts. A culture where it is okay to fail can carry over to interactions with the English language as well; English learner “students are engaged and more willing to participate and take risks” linguistically.

There are so many opportunities for EL students to attempt and practice new language skills. In working cooperatively and collaboratively, my EL students often become less aware of their language difference and are more likely to take more risks with trying new language structures in attempts to convey information and understanding.

This is a safety net for English learners. They are used to failing in most areas and have worked hard at not being noticed, so they will not be called upon. Engineering designs are rarely correct on the first attempt and can always be improved. With everyone working on designs that don’t always work puts the English learner at ease and they open up and begin to engage with others and become an active participate [sic].

Just like the Engineering Design Process, it is similar to language acquisition. Where the more you are willing to take risks with the language the faster that you learn.
Success in engineering can also help ELs become more confident in other subjects. One teacher mentioned that she observed “that students build confidence in their learning through engineering activities, and this boldness transfers over to other subject areas.” Also interesting was an observation that ELs’ previous experiences struggling and moving positioned them better that non-EL students to deal with failed attempts in engineering challenges:

My EL students tend to have a better developed ability to acknowledge and then move on with new approaches as a response to failure than do my non-EL students.

Affordance 4: Engineering allows students to experience success in ways that are not contingent on language fluency. For example, children can explore properties of materials, test their designs and make improvements based on testing data, without having language fluency.

This affordance and the next one stress that engineering invites multiple modes of communicating and engaging that do not rest solely on English abilities. One benefit of this is that students can experience success. They can be successfully engaged in the activities of exploring, testing, and revising regardless of their English proficiency. ELs can show what they are capable of, which can affect how they view their own abilities.

Engineering focuses more on planning, creating, and designing. Speaking the correct language is not always needed to be successful in this process. Some groups work by following the plan they drew and testing it. Proficient language skills are not required to be successful in engineering.

Hands on engineering can overcome language barriers. Students do and see. Students that have previously been labeled as low performing may excel at problem solving.

If the students could not understand each other’s language, they would create/build and then demonstrate. There was much demonstration going on.

There are so many opportunities and possibilities to share ideas, possible solutions, conjectures and outcomes that are not strictly bound to linguistic principles. The excitement and engagement in learning for my ELs is so evident when one enters the room that it draws comments from many of our support staff.

Affordance 5: Engineering provides opportunities for English learners to engage in non-verbal communication in the form of writing, drawing, and gesturing. This allows students, who may not be able to articulate what they are thinking verbally, to participate.

A second, closely related benefit of experiencing engineering challenges that invite multiple modes of expression is participation. Students can express what they are thinking without written or verbal English.

Since they are able to draw their thinking, many can express what they want to convey
Engineering and design principles allow students at any linguistic level to access learning and provide many opportunities for communication of this learning.

Not only do the drawings and gestures help the English learners communicate, but they also provide a different way for them to do their school work that is not just writing or doing math problems.

The opportunity to convey their thoughts through drawing, gesture, or demonstration allows ELs to participate in their group’s deliberations. It allows them to learn content that is not language dependent. And can spur them to use English to speak or write as well.

Students who are usually reluctant to speak in class usually participate more and are more confident. Students can show mastery of concepts through challenges that they may not show in speaking or writing. Students sometimes choose to speak in their native language or show ideas through drawings.

show what they know through demonstration. They don't have to have the vocabulary to be successful in engineering. Our EL population of students is highly involved and successful at engineering because they are able to focus on the learning/solutions instead of vocabulary.

Students can be active participants in an experiment without the need for any discussion. However, once they are engaged in an activity, they often forget that they don't like to speak and get caught up in the experience while utilizing the new vocabulary they are learning.

Affordance 6: Engineering creates an environment where all students are learning new content and processes for the first time. This can decrease the reliance on previous exposure to ideas, skills, and resources to create a more equitable learning space.

For most students, engineering is a new discipline and (usually) all class members have not had previous experience. This means ELs and other students participate in a more “level” environment and learn with their classmates.

Engineering activities places ALL students on an even playing field where trial and error is a necessary process in order to design and create the best design possible.

Most of the time, my fifth grade students have no previous experience with engineering, so all students are on the same level with prior experience.

Because there is little frame of reference, everyone is scaffolded at the same time and level. There is very little access to prior knowledge which levels the playing field for all students and engagement.
As part of learning new engineering content and processes, a few teachers also pointed out that all students were learning new engineering vocabulary. Thus, ELs are part of the whole class in learning new words too.

All students are learning the engineering language presented, so they ELL students see the regular students also practicing with the new words. It emboldens them to use the new language as well.

The content vocabulary is new for all students, so no one feels out of place mispronouncing words or mixing up terms.

One teacher also mentioned that engaging with engineering concepts and practices early also affords more equitable opportunities by allowing the students who are English learners to envision futures for themselves as engineers.

Starting early allows the students to bridge the opportunity gap by having shared experiences and picturing themselves and as engineers and problem solvers.

*Affordance 7: Engineering activities provide unique opportunities for English learners to apply their science content knowledge in meaningful ways, even if they learned that science content in another language.*

Engineering activities can invite or require students to draw upon science content knowledge, in whatever language they learned it. They can demonstrate their understandings through artifacts or multiple modes of communication. Applying the concepts in an engineering challenge can help ELs to solidify or expand their understanding.

Students were able to demonstrate their knowledge of the science content with little language interference. For example, one novice 4th grade student was able to create and name the parts of an electrical circuit. He was also able to explain how an open circuit worked and a closed circuit did not.

The exciting part about engineering is that language is not necessary to participate. Students from other regions of the world have their own experiences and their newfound knowledge can be added to mix when they are teamed with others. Living in an area that is landlocked, I have had students come from areas where they were surrounded by an ocean. Their knowledge of sand and the effects of waves was beneficial in determining which soil type to use to build a structure.

*Affordance 8: In engineering, there is not one correct solution, but many. Having more than one correct answer to a problem lowers the stress associated with suggesting and trying ideas. This encourages English learners to participate by offering their ideas.*

Many engineering problems, including those we have developed for elementary students, allow for multiple possible solutions—the ranking of criteria and constraints as well as clients’
personal preferences all influence which are ultimately chosen. Students, including ELs, embrace the opportunities that the multiplicity of solutions affords. Students can learn from each other’s ideas and solutions. The possibility for an array of “correct” solutions, the iterative nature of the engineering design process, and the inclusion of failure as a learning tool all help to invite ELs to participate as valued team members.

There was a dramatic increase in the participation of English language learners. They were not passive participants and actively participated in the EiE process.

It all ties into the even playing field. Mistakes are going to happen and it is all right. The term, "trial and error" is frequent. Everything can be improved and there are many ways to solve a problem. This eases the stress of "right/wrong" and allows English learners the be actively involved without worrying about what others will think.

My students enjoy the open-ended aspect of the problems they'll be solving, and the hands-on experiences really allow the language to become concrete. This allows them to better share their thinking, but if they are having difficulty with the language to tell about their ideas, the hands-on aspect allows them to show their ideas. Because there are multiple ways to solve a problem, they feel success when they solve a problem, but also feel happy for others’ success as well. I had one student who was very limited in his English language, but when faced with a task to create something to solve a problem, he was the first to successfully complete the task in his group. It made him feel proud, and it let others in the group see that he had lots of knowledge, he just wasn't able to express it in words.

Affordance 9: **English learners can experience success and become more active members of the learning community during engineering projects. Consequently, they, their teachers, and their peers have an opportunity to see them in a new light.**

Many of the features of engineering discussed above allow ELs to engage more fully in the lessons. They can participate as active members of their group and class as they contribute their ideas. They can also share designs that show that they are creative and smart. Such substantive and meaningful interactions with their peers and the engineering task can help students’ develop confidence in themselves and their ideas. Classmates can also recognize the strengths that ELs bring to engineering activities.

I am often surprised by how eager my ELL students are to engage in engineering activities, even though they are usually very quiet during other activities in science.

When a student's ideas are praised and their success applauded, they feel a sense of pride. This is essential for English learners because they already feel different and inadequate. Engineering projects allows them the opportunity to show others what they are capable of doing without the stress of verbally having to convey their thoughts. They can just show and demonstrate what their design should do. This allows others to celebrate with their success with them. It is a win-win situation for ALL!
Engineering activities allow the EL students to really show that they have equal creativity, science/STEM understanding of concepts and application of skill/practices. Sometimes EL students are perceived as having fewer abilities in school . . . so often engineering activities allow them to shine, with boosts to their confidence, peer perceptions, and enjoyment of school! They remember the vocabulary because it has meaning for them in a successful situation.

EL students can not only participate in activities, they often excel that them. Teachers recounted how their ELs are often the smartest students or best engineers during engineering. Such experiences can be highly affirming to the EL students and encourage them, and their classmates, to consider them and their abilities in new ways.

Sometimes, the students who are not great readers or writers yet, can shine and even do better than the high achieving learners.

Love it when an ELL explains content or context in a way others have not thought about. :-(

Engineering enables my EL students to be seen as some of the smartest in the classroom.

my EL students thrive in my engineering activities. It always boosts their confidence because there's often less of a gap between my EL students and their english speaking peers during these activities. My best engineer is a second grade student who has only been in this country for 2 years and speaks limited english.

My students have begun to see themselves as people who can interact with the world and change it. They struggle less to just keep up and excel in these challenges because they saw they have the power regardless of language ability.

One example from a teacher illustrates how a novice EL student was motivated enough by the challenge to engage with his group to try to communicate his ideas for improving the group’s parachute design. He was able to participate with other members of the group to share his idea and develop a more successful parachute:

Two years ago, Rashid [researcher-created pseudonym] came to our class from Pakistan speaking no English. I was convinced that he had retained little to no academic information all year. In the second week of the Engineering Adventure in package engineering, the class came to a complete standstill when we heard someone shout, "NO!!! NO!!!" Rahid went on to explain through hand gestures and some English, "No! Need two (two fingers held up) poof, poof (meaning parachutes)! No poof, poof (again meaning parachutes and using hand gestures) go splat (he hit his fist again the table) and all break. No good! REDO!!!" It was the most English anyone in the class had heard him put together to create an entire thought in the entire year. One of the other students in his group asked him to explain again and to sketch a model of his redesign. The group ended up labeling the new design, practicing the words, redesigning their package and testing a much more successful iteration. Engineering
enabled Rashid to shine. It didn't matter that he didn't know all the words, he was able to utilize the hands on, real world engineering challenge to express his ideas and grow as a learner.

**Affordance 10: Successful engineering design solutions benefit from diverse perspectives.**

*Engineering encourages English learners to draw from their life experiences and consider their personal backgrounds as assets when imagining and designing solutions.*

A hallmark of engineering is creative and out-of-the-box thinking. Bringing a multiplicity of ideas to brainstorming and iteration often results in stronger solutions. Classroom students who come from varied backgrounds can contribute different ways of thinking about a problem that are informed by their experiences and their cultural knowledge. Teachers mentioned that they saw evidence of perspectives from different cultures in their EL students’ engineering designs noting that:

English learners have a lot to offer from their own diverse experiences, especially if they have lived or visited another country.

They are often able to connect their personal, cultural and/or community assets to a particular project.

With having different backgrounds it allows for cultural understanding, which might not be the thought of before.

I had a student from an extremely impoverished neighborhood in a rural part of El Salvador. His favorite toy was a bike with only one wheel. He had some of the most creative ideas I'd ever seen.

Students were able to make connections to previous problems they have experienced in life to create a solution for the problem.

Engineering design challenges are often set in a larger context as a mechanism for helping children to connect to the work at hand. Teachers noted that their students responded to challenges that were set around the world. EiE units begin with a story that is set in a country around the world to set the context for the challenge. Other teachers created challenges based on new stories about children in other national or international locations. Teachers shared how such contexts were relevant to their students, especially those with knowledge of these countries.

The EL students are totally engaged in the hands-on activities that are a crucial component of the Engineering Process. Last year, STEM projects were developed after 3rd Grade students read about children in other countries that needed access to library books. Many of the EL students identified with those children and collaborated on engineering projects to help transport books safely to remote villages. Since the EL students were involved in the engineering design project they were able to present their idea with confidence to visitors.
during the STEM expo. The real life experiences during the Engineering give the EL students multiple opportunities to practice their English in small groups and with the whole class.

Students are actively engaged and really enjoy the different countries that are featured in the stories. They feel connected and enjoy sharing what they know about the different regions with the others in the class. Reading about real world problems that they need to figure out a solution to gives them the opportunity to share their knowledge of a specific area of the world that they connect with.

Assisting in solving the problem posed in the book placed them on an even playing field if not an elevated one. Especially if the book covered a region they were from. Students understood the terrain and the type of soil that was usually found in the region which aided them in the design process.

There have been many times where students have been able to connect with the curriculum because they were personally invested in the problem because that's either where they lived, that's where their family still lives, or they were problems that affected them. When designing packed for international food drops, one student shared about what it was like to live in Thailand and what the monsoon season was actually like. When designing walls, students connected with the fact that many of their families are trying to grow family gardens with plants from their home countries and are trying to keep out the deer and rabbits.

Of course, in the classroom these affordances of engineering are not experienced one at a time. Rather, they blend and mix depending on the students and tasks at hand to create an overall experience that benefits students in many ways. Engineering is a critical part of the equation as these two teachers point out in their comments, which also capture how intertwined the components are:

In my experience, engineering activities are a crucial component of the curriculum for all students, particularly ELs, because engineering encourages students to problem solve, observe, question, create, and collaborate. This enhances conversational language skills, boosts relevant academic vocabulary, and builds a common experience of productive struggle.

Engineering and design principles, by nature, provide all students with the opportunity to explore situations, test solutions to problems and refine their results. Very often, the models or mock-ups we explore cross linguistic barriers which, in my classroom, go beyond language differences, often also involving issues with literacy. Last year 10 out of 24 of my students received EL support, and 5 received support from Special Education for academic and linguistic challenges. The challenges involved in designing, building and refining their Maglev trains allowed all of my students to access critical thinking and reasoning skills that go beyond language differences and knowledge/skill-based challenges. My 3rd grade students were pushed to think outside the box to solve why their disk, strip and bar
magnets were not working to levitate their trains. They had every confidence in their designs and eventually realized that the poles were located in the wrong place to facilitate the desired outcome. We eventually levitated our trains and were able to reflect on our design choices and make connections to perseverance in our daily work and refining outcomes in long-term projects. Students were called upon to collaborate and communicate, in words and through modeling. The quality of engagement and the willingness to commit beyond easy outcomes were byproducts of their authentic investigations. My EL students ended the unit with much stronger communication skills, academically and socially. Their confidence and comfort levels increased. They were able to share learning and ideas beyond typical pencil and paper methods.

Value of Affordances
To get a sense of which affordances are most important or valuable, the last question asked teachers to choose the three benefits they thought were most valuable for ELs. These data are interesting for a few reasons. First, there is no affordance that was not selected by at least 15% of teachers, and there is no affordance that was identified by over 50% of respondents. While the responses are distributed, it is clear that teachers perceive some of the affordances (or benefits) as more valuable than others.

Figure 3: Most Valuable Affordances of Engineering for English Learners

The affordances fall into three categories based on the percentage of teachers selecting them. Table 4 groups them in this way. The benefits selected by most teachers include allowing ELs to have success in ways that are not contingent on their English language fluency, the opportunities
Engineering presents to encourage risks and help children persevere through failure, and the possibilities for students who are engaged and motivated to use language in meaningful ways.

### Table 4: Value of Affordances Arranged by Category

<table>
<thead>
<tr>
<th>Less Than 20%</th>
<th>Between 20 and 39%</th>
<th>Above 40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meaningful science application</td>
<td>Language: social language skills</td>
<td>Success w/o English fluency</td>
</tr>
<tr>
<td>Equitable learning space</td>
<td>Participation: multimodal communication</td>
<td>Environment: fail &amp; risks</td>
</tr>
<tr>
<td>Diversity: experience &amp; solutions</td>
<td>Many correct solutions</td>
<td>Language: meaningful discussion</td>
</tr>
<tr>
<td></td>
<td>Participation: community &amp; perspective</td>
<td></td>
</tr>
</tbody>
</table>

### Discussion

Our work with teachers and students in elementary classrooms surfaced a number of ways that ELs were benefitting from engineering. This paper suggests that there are a number of affordances of engineering for elementary ELs that teachers observe. These cluster into four main types of possible impacts:

- Engineering supports English language development among English learners.
- Engineering supports science and engineering learning of English learners.
- Engineering encourages English learner students to develop their own positive engineering identity.
- Engineering provides an entry point for English learners to engage in the learning community.

The responses of teachers in our focus group and to our surveys support the ten affordances we propose. Based on our findings, we feel comfortable saying that engineering holds the potential to support these benefits. However, it is important to recognize that such outcomes are mediated by the instructional practices, classroom culture and norms, and experiences of the students. We should note that most of the respondents to our survey had used EiE curriculum materials. EiE was intentionally designed using a sociocultural approach to learning that structures activities and interactions in ways that involve students in the engineering practices that help develop engineering knowledge [28]. EiE lessons and units are grounded in a set of inclusive principles that strive engage all students in the activities [6, 7]. The curricular materials are intentionally designed to build understanding of engineering and science principles through participation in authentic engineering challenges. The materials also foster classroom environments that build student affiliation and identity with engineering [20]. How students experience engineering matters—these affordances likely do not stem from engineering alone, but rather are closely connected to pedagogy and classroom environments. Engineering holds the promise to do this but this must be actualized through curricular materials, teachers’ pedagogies, and student interactions.

Based on this first study, we believe that engineering can provide important avenues for developing language and science and engineering knowledge while offering important
possibilities for English learners to demonstrate their ideas, develop their identities, and connect with their classroom community. This is just a first step. We plan to further explore these constructs in a couple ways. First, the data in this paper are from a convenience sample of teachers. We can further validate and examine these affordances using larger, more representative samples with different survey designs. Having heard the teachers’ perspectives, we also want to turn to see these affordances in action. We have collected classroom video of teachers and EL students engineering, students’ work and artifacts, and have interviewed students about their engineering experiences. We have begun to analyze these data to examine how and when the affordances are present and hear the students’ perspectives. In the future, we plan to investigate how engineering activities, resources, and supports can be developed so they scaffold learning and participation.

One of the recurring patterns in teachers’ feedback was their articulation that the affordances and opportunities that engineering provides extend beyond English learners. This focus and attention on multimodal discourse processes was particularly valuable for all students. While the named affordances were identified due to benefits for students needing additional linguistic supports, the teachers emphasized that such benefits of engineering reached all students.

References


Appendix A: Affordance of Engineering for English Learner Survey Instrument

About Yourself and Your Setting

- While teaching engineering, have you ever worked with English learners?
  - Yes
  - No (Logic: ends survey)

- Name (first, last)
- Email
- State in which you taught/teach
- Occasionally, EiE uses survey comments for publicity. May we use your name when sharing these comments?
  - Yes, you can use my name and comments for publicity purposes.
  - Please do NOT use my name when sharing comments for publicity purposes.

- Which of the following best describes you?
  - Classroom teacher
  - Science or STEM specialist
  - English learner (EL) specialist
  - Afterschool/out-of-school-educator
  - Other: __________

- What are the typical grade level(s) of the English learners with whom you’ve worked?
  - Kindergarten
  - 1st grade
  - 2nd grade
  - 3rd grade
  - 4th grade
  - 5th grade
  - 6th grade
  - 7th grade
  - 8th grade
  - Other: __________

- Which of the following engineering curricula or resources have you used?
  - Engineering is Elementary
  - Project Lead the Way
  - FOSS Next Generation
  - TeachEngineering.org
  - LinkEngineering.org
  - TryEngineering.org
  - Novel Engineering
  - Science in the Classroom
  - Other: __________

- How many years have you taught engineering to students?
- Please estimate the percentage of students in your school/organization who receive free or reduced-price lunch.
In the settings in which you taught engineering, what percentage of your students were classified as English learners (EL)?

- 0-25%
- 26-50%
- 51-75%
- 76-100%
- I’m not sure

While teaching engineering, approximately what percentage of your EL students were:

<table>
<thead>
<tr>
<th>Beginner English proficiency</th>
<th>0%</th>
<th>1-20%</th>
<th>21-40%</th>
<th>41-60%</th>
<th>61-80%</th>
<th>81-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate English proficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced English proficiency</td>
<td></td>
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</tbody>
</table>

While teaching engineering, what were the home languages of your EL students? (Select all that apply.)

- Arabic
- An African language other than Arabic
- Chinese
- Haitian Creole
- Korean
- Polish
- Russian
- Spanish
- Tagalog
- Vietnamese
- Other:

Do you have an EL teacher/specialist on staff to support your teaching? (Logic: only shows if NOT an EL Specialist)

- Yes
- Briefly describe the type(s) of support this person provides (e.g., lesson planning, push-in support, lesson modifications).
  - No

- What impact(s) have engineering activities had on your EL students? (Please be as specific as possible and include any anecdotes from your experience.)

- As compared to their experiences in school in general, during engineering…

<table>
<thead>
<tr>
<th></th>
<th>Much Less</th>
<th>Less</th>
<th>The Same</th>
<th>More</th>
<th>Much More</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>My EL students were engaged.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>My EL students learned content.</td>
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<td></td>
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<td></td>
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<tr>
<td>My EL students were confident in their abilities.</td>
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</tr>
</tbody>
</table>

**Benefits of Engineering for English Learners**

*You’re almost done! Please carefully read the 10 statements below regarding the possible benefits of engineering for English learners and respond to the prompts.*

- 1) Engineering supports language acquisition by providing opportunities for English learners to engage in authentic discussion about things they find meaningful such as design decisions, cultural or geographic references, or results from testing.
  - Yes, I have observed this.
    - (Optional) Please describe what you observed.
  - No, I have not observed this.

- 2) Engineering supports language acquisition by providing opportunities for English learners to practice and develop their social language skills, as they negotiate design decisions in collaborative groups.
  - Yes, I have observed this.
    - (Optional) Please describe what you observed.
  - No, I have not observed this.

- 3) Engineering creates an environment where it’s okay to fail. This encourages English learners to take risks linguistically, and engage more actively with their peers.
  - Yes, I have observed this.
    - (Optional) Please describe what you observed.
  - No, I have not observed this.

- 4) Engineering allows students to experience success in ways that are not contingent on language fluency. For example, children can explore properties of materials, test their designs and make improvements based on testing data, without having language fluency.
  - Yes, I have observed this.
    - (Optional) Please describe what you observed.
  - No, I have not observed this.
5) Engineering provides opportunities for English learners to engage in non-verbal communication in the form of writing, drawing, and gesturing. This allows students, who may not be able to articulate what they are thinking verbally, to participate.
   - Yes, I have observed this.
   - (Optional) Please describe what you observed.
   - No, I have not observed this.

6) Engineering creates an environment where all students are learning new content and processes for the first time. This can decrease the reliance on previous exposure to ideas, skills, and resources to create a more equitable learning space.
   - Yes, I have observed this.
   - (Optional) Please describe what you observed.
   - No, I have not observed this.

7) Engineering activities provide unique opportunities for English learners to apply their science content knowledge in meaningful ways, even if they learned that science content in another language.
   - Yes, I have observed this.
   - (Optional) Please describe what you observed.
   - No, I have not observed this.

8) In engineering, there is not one correct solution, but many. Having more than one correct answer to a problem lowers the stress associated with suggesting and trying ideas. This encourages English learners to participate by offering their ideas.
   - Yes, I have observed this.
   - (Optional) Please describe what you observed.
   - No, I have not observed this.

9) English learners can experience success and become more active members of the learning community during engineering projects. Consequently, they, their teachers, and their peers have an opportunity to see them in a new light.
   - Yes, I have observed this.
   - (Optional) Please describe what you observed.
   - No, I have not observed this.

10) Successful engineering design solutions benefit from diverse perspectives. Engineering encourages English learners to draw from their life experiences and consider their personal backgrounds as assets when imagining and designing solutions.
    - Yes, I have observed this.
    - (Optional) Please describe what you observed.
    - No, I have not observed this.

One more question!
- Of the following statements (the same as the previous page), please choose the three benefits that you think are MOST valuable for English learners. (Please select no more than THREE!)
  - 1) Engineering supports language acquisition by providing opportunities for English learners to engage in authentic discussion about things they find
meaningful such as design decisions, cultural or geographic references, or results from testing.

○ 2) Engineering supports language acquisition by providing opportunities for English learners to practice and develop their social language skills, as they negotiate design decisions in collaborative groups.

○ 3) Engineering creates an environment where it’s okay to fail. This encourages English learners to take risks linguistically, and engage more actively with their peers.

○ 4) Engineering allows students to experience success in ways that are not contingent on language fluency. For example, children can explore properties of materials, test their designs and make improvements based on testing data, without having language fluency.

○ 5) Engineering provides opportunities for English learners to engage in non-verbal communication in the form of writing, drawing, and gesturing. This allows students, who may not be able to articulate what they are thinking verbally, to participate.

○ 6) Engineering creates an environment where all students are learning new content and processes for the first time. This can decrease the reliance on previous exposure to ideas, skills, and resources to create a more equitable learning space.

○ 7) Engineering activities provide unique opportunities for English learners to apply their science content knowledge in meaningful ways, even if they learned that science content in another language.

○ 8) In engineering, there is not one correct solution, but many. Having more than one correct answer to a problem lowers the stress associated with suggesting and trying ideas. This encourages English learners to participate by offering their ideas.

○ 9) English learners can experience success and become more active members of the learning community during engineering projects. Consequently, they, their teachers, and their peers have an opportunity to see them in a new light.

○ 10) Successful engineering design solutions benefit from diverse perspectives. Engineering encourages English learners to draw from their life experiences and consider their personal backgrounds as assets when imagining and designing solutions.

Follow Up

*Thank you so much for all of the helpful information you have given us in regards to your experiences and the ways in which you implement engineering!*

- Would you be willing to answer a few follow-up questions?
  - Yes
  - No

- Do you have anything else you would like to share with us?
- Please enter me into a raffle for one free [engineering curriculum] teacher guide and materials kit of my choice!
- Yes
- No