AC 2007-316: ASSESSING ENGLISH-AS-A-SECOND-LANGUAGE MIDDLE SCHOOL STUDENTS' ABILITY TO LEARN ENGINEERING CONCEPTS

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Assessing English as a Second Language Middle School Students' Ability to Learn Engineering Concepts

Abstract

This paper presents evidence that English as a second language (ESL) middle school students can effectively learn engineering concepts through a sequence of one hour, hands-on activities. Electrical and mechanical engineering concepts are introduced through an integrated sequence of one hour modules. These cross-disciplinary modular activities include exploring mechanical potential through flowing water, building electric circuits, and using this knowledge to build a model electric car. These engineering-based activities provide a rich source for enhancing academic language skills through speaking and writing in English. Methods for training undergraduate and graduate Engineering Teaching Fellows to work effectively with ESL students are provided. The process of creating K-12 engineering-based lessons and activities for publication in the TeachEngineering Digital Library, part of the National Science Digital Library, is outlined using the engineering-based curricular unit created in this project. This project was completed by a senior undergraduate student in the Department of Biomedical Engineering at Duke University in partial fulfillment of the requirements for the Bachelor of Science in Engineering Degree.

Introduction and Background

This paper discusses how meaningful engineering content may be taught in an English as a second language (ESL) class by undergraduate or graduate Engineering Teaching Fellows. It discusses the skills necessary for an Engineering Teaching Fellow to be able to teach effectively in an ESL classroom and examines ways of preparing Engineering Teaching Fellows to work in ESL classrooms. The work of one of the Fellows in the Engineering K-PhD Program at Duke University is used as a case study for effective teaching of engineering content in the ESL classroom. The case study was performed at Sherwood Githens Middle School in Durham, NC. In-class time consisted of seven weekly, one-hour class blocks. The class was composed of eight ESL students including six Hispanic students and two Southeast Asian students, all of whom have been in the United States for less than two years and have a novice level of English proficiency. All were in sixth grade, and their abilities to use the English language were extremely limited. Their teacher described the students' average English reading capability as below grade level, equivalent to lower elementary. From this case study, methods for training graduate and undergraduate Engineering Teaching Fellows to work with ESL students are presented, and suggested pedagogical methods are provided. Evidence for student learning among case study participants is provided. Finally, the process of publishing these lessons and activities in the TeachEngineering digital library is described.

Engineering provides a vehicle to teach middle school students that they can use science and mathematics as tools to creatively design and build solutions to problems. Numerous outreach programs placing graduate and undergraduate engineering students in K-12 classrooms as Engineering Teaching Fellows have demonstrated the ability to positively impact K-12 students through instruction in engineering[1-6]. The National Science Foundation (NSF) Graduate

Teaching Fellows in K-12 Education (GK-12) program has funded such Fellows programs at more than 20 engineering schools. These programs primarily utilize graduate students as resource agents to assist with the creation and implementation of project-based engineering curricula to teach math and science concepts in K-12 classrooms. Other educational funding agencies have supported similar engineering teaching Fellows programs. Fellows in many of these programs encounter limited English proficiency (LEP) students[6,7]. Four Fellows programs have been implemented by the Pratt School of Engineering's K-PhD Program: Duke-NCSU Engineering Teaching Fellows in Elementary Education sponsored by an NSF GK-12 Track 1 grant[8], MUSCLE: Math Understanding through the Science of Life sponsored by the GE Foundation Math Excellence Program[9,10], MUSIC: Math Understanding through Science Integrated with Curriculum sponsored by an NSF GK-12 Track 2 grant[11], and *Techtronics*: Hands-on Exploration of Technology in Everyday Life sponsored by the Burroughs Wellcome Fund's Student Science Enrichment Program[12-14]. One intention of these programs is that, after participating in the program, students who were initially intimidated by science and mathematics will be more interested in these subjects in high school and ultimately more inclined to pursue engineering at the college level. Student motivation in an ideal middle school engineering program includes encouraging students to "think like engineers" and be creative in their approaches to generating unique solutions to design challenges. This process of inquiry through creative design is most effective when the students have the opportunity to perform meaningful tests of their designs in order to gain understanding from their successes and failures.

Goals of these programs include empowering students, especially from at-risk populations, by providing avenues to experience the excitement and potential for innovation through an age-appropriate introduction to engineering. At-risk populations often contain a significant percentage of students for whom English is not their first language. The number of ESL students in the United States is growing. During the 2004-05 school year, Department of Education statistics indicate that 10.5% or just over 5 million public school students nationwide were English language learners[15]. In light of the number of ESL students in the United States, especially in lower income neighborhoods, it is important for school systems to address their needs. ESL students must be provided the same opportunities that regular English speaking students are afforded. Engineering content taught by ESL teachers through a Lego robotics course has been outlined previously[7]. This paper provides another model by which engineering may be introduced into ESL classrooms through the use of Engineering Teaching Fellows.

Language and cultural barriers present significant obstacles to teaching ESL students. In standard reading, writing, and mathematics curricula, these students present a greater challenge to teachers than English-speaking students. ESL students live in households where English is not the primary language and many are placed in classes appropriate for their age but inappropriate for their language abilities. Cultural context is also important in working with ESL students[16,17]. When selecting starting points for lessons, it is important that students can relate to those starting points. For example, an engineering design problem based on building a skyscraper may not have very much meaning for a student who has never been to a big city. Additionally, students may have different expectations for classroom conduct if they are from a different background than the teacher[18].

It has been shown that teaching language through content is crucial to the development of ESL students in the public school setting[16,19-21]. Earlier approaches have favored teaching language skills prior to full course content or teaching students basic skills that are at the same level as their English language skills[19]. The problem with this approach is that it takes approximately seven years for ESL students to reach the language levels necessary for achievement at the level of their peers[22]. At this point, they are so far behind students for whom English is the primary language that they cannot catch up. Teachers without appropriate training in working with second language students often have trouble teaching them content. Content taught to students utilizing the same methods as first language students at grade level is not likely to be understood by ESL students. On the other hand, content should not be taught at a very low level simply because their language skills are lower since ESL students are capable of learning content at a level higher than their language skills. Therefore, content should be taught in conjunction with language skills. To make this possible, it is critical that content be divided into blocks of "comprehensible input."[23] Each block of discrete information must build on the preceding one in order to avoid flooding the ESL learner.

It is important to provide ESL students with context within which they can learn content vocabulary. A lecture with few pictures would be referred to as context-reduced and is very difficult for an ESL student to understand. Conversely, context-embedded language includes the use of visual clues, gestures, and facial expressions as "scaffolding" to make material less abstract and more comprehensible[24]. An important goal in teaching content and language skills concurrently to ESL students is to develop an embedded and cognitively demanding lesson context. Furthermore, the order in which concepts are taught is important. Concepts requiring less linguistic proficiency such as hands-on activities and demonstrations should precede the development of more abstract ideas requiring significant use of language skills[16]. Demonstrations and hands-on activities that are context-embedded aid in student understanding and serve as a solid foundation for more advanced content and language activities.

Research suggests creating opportunities for ESL students to work in cooperative groups fosters communication and learning content[7,16]. Project-based engineering design activities are ideal opportunities for group work provided that the students have sufficient English proficiency to communicate their design ideas. Students in the following case study lacked sufficient English proficiency to allow cooperative group work. They did, however, successfully complete a number of activities in pairs. As an example, students were partnered to build certain circuits, which allowed them to benefit from shared experiences to solve problems.

It is also important for ESL students to learn to express math, science, and engineering concepts in English in an academic setting. The ability to express abstract ideas in an academic setting requires students to learn an academic set of language skills, known as CALP (Cognitive Academic Language Proficiency[25]) and vocabulary rather than social language constructs[19], BICS (Basic Interpersonal Communication Skills[25]). Developing academic English language proficiency is crucial to academic success for ESL students.

Engineering provides a vehicle for introducing science and math concepts in comprehensible ways to ESL students just as it does for primary language students. In addition, engineering provides a context within which students can improve their English language skills. This paper discusses the preparation of Engineering Teaching Fellows to teach in an ESL class, introduces a project-based engineering module for use in ESL classrooms based on a case study, and discusses publication of the engineering module in the TeachEngineering digital library.

Engineering Teaching Fellow Training

Training in both classroom management and lesson planning are important to the success of Engineering Teaching Fellows in any classroom[26]. An ESL classroom poses additional challenges. Teaching in an ESL classroom requires that the Fellow prepare lessons that take into account the language proficiency of the students as well as their background knowledge of a topic. Prior to beginning an engineering activity, the Fellow must first identify the vocabulary words the students will need to learn in order to demonstrate mastery of the activity's learning objectives. Met[16] indicates that some vocabulary is "content obligatory" meaning it must be taught explicitly for the students to achieve the content learning objectives of the lesson. The Fellow must determine ways to define those content obligatory words using *realia* (actual objects or models and/or photos of actual objects), pictures, demonstrations, and simple language constructs, both vocabulary and sentence structures, that the ESL students will understand. Based on the current or future goals of a given ESL class, there may be other vocabulary that is "content compatible" meaning that it makes sense to teach as part of a particular lesson, but is not required to achieve the content learning objectives[16]. Hands-on activities are an important part of any middle school engineering curriculum and are particularly useful for ESL students. It is important that students learn the English words for the materials used in activities so that they can refer to them when asking questions and discussing their designs. Hands-on activities use the materials in front of the students to provide scaffolding for learning and understanding the vocabulary.

It is a tremendous challenge for Engineering Teaching Fellows to explain concepts utilizing vocabulary and sentences that ESL students can understand. For instance, the Fellow quoted below from his independent study final report on the case study noted that he had trouble characterizing the students' initial understanding of gravity in order to begin an explanation of mechanical potential because the students did not know a specific word he expected them to understand.

> "Though the students never told me directly, I realized they did not know the meaning of many of the words I was using during the discussion. For example, before I dropped the apple to the ground, I asked the students to point to where they thought it would land. I received no responses. I went around the room and asked each student the question individually. There were still no responses…then, the teacher asked them, 'Where will the apple go?' Immediately, all eight children pointed to the floor below the apple. They clearly were stumped by the word '*land*,' not the question itself. While they couldn't respond with the answer, 'The apple will land on the floor by your feet,' they were certainly able to point to that place and convey that they knew the correct answer."

Table 1 shows some of the terms determined to be content obligatory for this case study and the simplified definitions used with the ESL students. These are simplified because the students needed to understand not only the vocabulary, but the words in the definitions as well. For instance, initially, we talked about water or current flowing, but some students did not understand the word "*flow*." Instead, we simplified the definition by using the word *move*. *Alligator clip* was a vocabulary word added in the middle of the module because it was important for describing how to attach the pieces together. It is probable that some vocabulary words will be added as a lesson progresses. However, it is important to minimize these additions because otherwise the students may become overwhelmed.

Table 1: Obligatory Vocabulary Words Identified by Engineering Fellow and Utilized in Case Study

Engineer	A person who designs and builds things
Potential	Difference in level (of water), can be used to move things
Current	Movement of electricity
Battery	Stores electric potential for use
Wire	Electrical current moves through this
Switch	Turns electrical current on and off
Resistor	Slows the movement of electrical current
Light Bulb	Creates light with electrical current
Motor	Creates motion with electrical current
Alligator Clip	Used to hold objects together

Beyond vocabulary alone, Fellows must develop ways of explaining content concepts using simple, repeated, patterned language structures that students will begin to recognize. Explanations should combine simple sentences with hands-on activities, visual demonstrations, and pictures. Pictures are crucial to conveying concepts to ESL students, and Fellows should use as many as possible when developing lesson plans, worksheets, and quizzes.

Fellows should also consider which English language skills are being taught in conjunction with their engineering content lessons. These may be content compatible vocabulary or academic sentence structures specific to science and engineering. For example, there are opportunities in the lesson outlined below to use language for comparison: the water moves faster or slower, or one cup of water is at a higher or lower potential. The use of the comparative terms faster, slower, higher, and lower provides opportunities for ESL students to *speak as an engineer speaks*. While it is important to speak in simple sentences, Fellows are also providing a model for the students to follow in speaking in an academic setting. Fellows should use more basic sentence structures than they would otherwise use when teaching middle-school students. One way to do this is to speak in shorter sentences, especially avoiding run-on sentences.

Fellows who have taken foreign language classes may find it useful to utilize their experiences learning a foreign language to help them prepare for the ESL classroom. ESL students are essentially learning a foreign language. Foreign language teachers often look for subjects for their students to talk about. In this case, the engineering activities provide opportunities for students to use English to explain ideas such as how their designs work. In many cases in the United States, Spanish is the primary language of ESL students. Working with those students may also provide opportunities for Fellows to practice their Spanish in an informal setting if they have studied or are studying Spanish. This may be of interest to Fellows who are interested in becoming more fluent in Spanish. ESL students will also greatly appreciate Fellows speaking the students' native language to clarify points of confusion.

Case Study Curriculum

The content goal of this unit is to teach ESL students basic principles of electric circuits and how engineers use these circuits in an electric vehicle. For this case study, three activity-based lessons were developed by the undergraduate Fellow to teach students about electrical engineering. First, an inquiry-based activity introduced students to basic components of electrical circuits. Second, a series of demonstrations provided context for students to learn basic electrical engineering concepts. Students emulated demonstrations with components they were given during the initial activity. Finally, once students had learned about electricity and electric motors, they learned how automotive engineers utilize these concepts. Students could then incorporate this information into designing and building model electric cars of their own. These lessons are described below in detail for use by Fellows and teachers along with examples from the case study.

Lesson 1) Inquiry-Based Introduction to Circuits

Begin the first lesson by asking students to name things they know that use electricity in their homes, thus activating prior knowledge. This brainstorming technique provides them with an opportunity to recall English vocabulary words they know and to learn a few new ones. This type of discussion is a good opportunity to extend their vocabulary while introducing the unit. In this case study, initially students were able to mention a few terms already known by them: light bulb, PlayStation®, television. Next, their teacher pantomimed the use of additional devices such as a vacuum cleaner, hair dryer, and washing machine. With this prompting, students were able to name some of these objects in English. For the majority of the devices, the students knew the equivalent name in Spanish or Chinese but had to look up the English translations. Students were generally excited to look up the English words once they had identified the name of each electrical device in their native language.

Table 2: Below is a list of circuit kit components provided to the ESL students.

Component	Quantity
9V battery	1
9V battery snap connector	1
Flashlight bulb	1
Flashlight bulb holder	1
Switch	1
10Ω resistor (for use with motor)	2
30Ω resistor (for use with light bulb)	2
Wires	4
Alligator clips	5

Next, provide each student with a kit containing the circuit components detailed in Table 2. Allow students time to explore the physical structure and appearance of the components as well as their functionality (approximately 10 minutes). Many students begin with two components that they recognize from everyday life, the light bulb and the battery. Some may observe the similarity between the 9V battery terminals and the snap connector and determine how to attach the parts. Some students may even begin exploring parallel and series circuits involving the battery, motor, light bulb, and switch. During this period, the teacher need only supervise for safety purposes and encourage student experimentation with each of the different components. When this activity was used in class, students were excited about trying to put pieces together. If the Fellow had intervened and stopped them and required them to follow a more guided structure, it would have impeded their exploratory process, an important step in motivating and engaging students in this activity.

After this period of exploration, introduce the vocabulary for four of the basic circuit components: *battery, switch, light bulb,* and *motor*. For each word, ask students to locate the component in their kits and hold it in the air. Say the name of the component and ask the class to repeat it aloud. Ask students to sound out the spelling of each vocabulary word and write the correct spelling on the board. After introducing the new vocabulary, draw a simple circuit on the board, using words students were just taught in place of symbols, and challenge students to build it. Provide assistance as needed. Students are building a circuit from a plan just as electrical engineers would. It may take some time for the students to understand how to connect the various electronics components together, but through experimentation with different connection methods, students discover the easiest method to connect the wires. From the teacher's perspective, it is preferable to start with a simple circuit that uses the light bulb rather than the motor because the motors make a lot more noise. If the first circuit includes a motor, the drone of the successfully completed circuits will make it more difficult to work with the remaining students. As an example of what students discover from this inquiry-based approach, students in the case study discovered that the metal clips need to be clipped to the metal portion of the wire rather than the insulation in order for the circuit to work. In this way, they began learning about conductors and insulators before they were introduced.

After the students build some circuits, finish the class by introducing the concept of engineering and providing an overview of the unit. As with all discussions with the ESL class, pictures and visuals are very important. Begin by defining the word 'engineer' for them by writing it and its simple definition on the board. Then, show them some pictures of things that engineers have made and some pictures of engineers in action. These should include a wide range of different things: simple things they see in the room like a chair and a desk, more complicated things like the appliances that use electricity they discussed earlier, big things like the space shuttle, and smaller things like devices their doctors would use to measure their heart beat. Next, ask students to raise their hands if engineers make cars. Some will likely raise their hand and some will not. Let them know, as mentioned before, that all man-made things were first made by an engineer including cars. Then, tell them that in this unit, they will all get to be engineers and build a car. Finally, show them the model car they will be building over the next few weeks.

Lesson 2.1) Potential

The next few lessons introduce the more abstract concepts of current and potential while providing students an opportunity to use the new vocabulary words introduced in the previous lesson to describe the electrical components. Begin the next day by showing the students the car again and telling them that in order to be engineers and build the car, they are going to spend the next few classes learning more about electricity. Maintaining the connection to real world applications will help excite and motivate students. The electrical concepts of potential and current are taught through analogies to mechanical phenomena utilizing water moving through tubes. The first concept to address is ‘potential.’ Students explore mechanical potential through a hands-on, inquiry-based activity using a pair of transparent plastic cups connected through their bases by a length of vinyl tubing (see part of the accompanying worksheet in Figure 1). Water poured into one cup will flow through the tube into the other cup until no potential difference remains. Give each pair of students a pair of cups attached with tubing and allow them to experiment. They will quickly discover that the greater the difference between the height of the cups the greater the water flow.

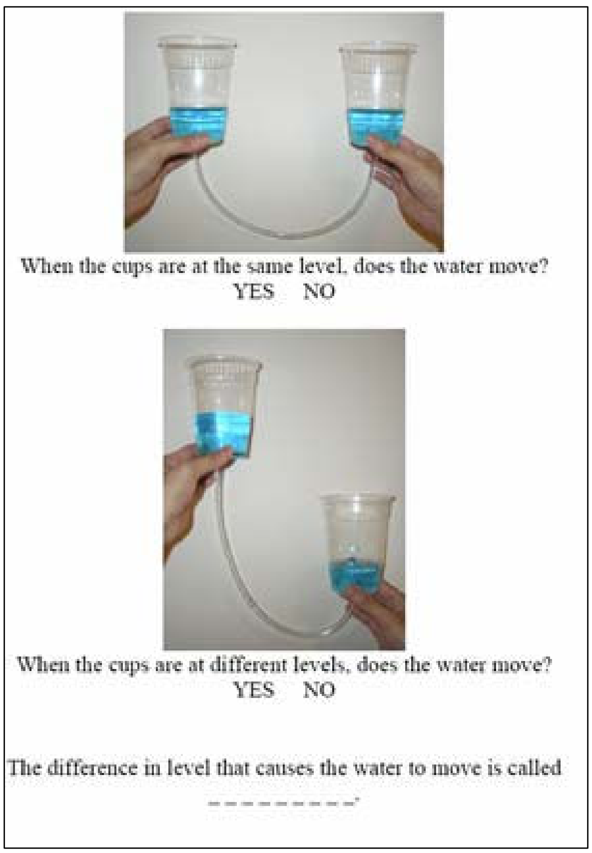


Figure 1: Above is one of the worksheets used to teach the concept of potential.

After students have experimented with cups, introduce ‘potential’ as a vocabulary word and define it as a difference in level that can be used to move things like water. Ask students to write the word in their notebooks along with its definition. Writing words down is very important with ESL students to assist in internalizing the word and also to be able to refer back to repeatedly. Also, indicating on a picture what is happening is an assessment tool for language and content. Figure 1 shows a portion of the worksheet developed for this case study designed to help students associate ‘potential’ with pictures. It is crucial to provide pictures for the students to associate with words and concepts in all cases. This is true even when a demonstration is also provided because the picture may be used in the future to refer back to the demonstration. In front of the class demonstrate the fact that the speed of the flowing water directly correlates with the difference between the heights of the cups. You can also point out that only the relative difference matters by doing the same demonstration near the floor and while standing on a chair.

Summarize by telling the students that a battery has electrical potential to make electricity move just like a cup of water held above the ground has mechanical potential to make water move. Show a battery to the students and ask them to recall its name, pronunciation, and spelling from the first lesson. Pass some different batteries around the classroom. As with electrical appliances in the first lesson, ask the students to brainstorm things that use batteries (such as cell phones). It is worth mentioning to the students that electric potential is called ‘voltage’ because the students may recognize the word from looking at batteries or hearing about electricity. That said, with ESL students it is unnecessarily confusing to have two words, potential and voltage, that both refer to the same thing, so it is not necessary to introduce ‘voltage’ as a separate vocabulary word from potential. End class by explaining that their cars will need potential in order to begin moving.

Lesson 2.2) Current

The goal of the third lesson is to revisit ‘potential’ and introduce the concept of ‘current.’ Reintroduce the connected cups and review the potential demonstration from the previous lesson. Then, shift the focus to the tubing, highlighting the fact that water moves through it. Tell the students that water moving through the tube is like electricity moving through a wire. They have seen wires before, but now is a good time to spell and define the word ‘wire’ and ask students to write it in their notebooks. Next, explain that current moves through the wire like water moves through the tube and define the word ‘current’ as the movement of electricity.

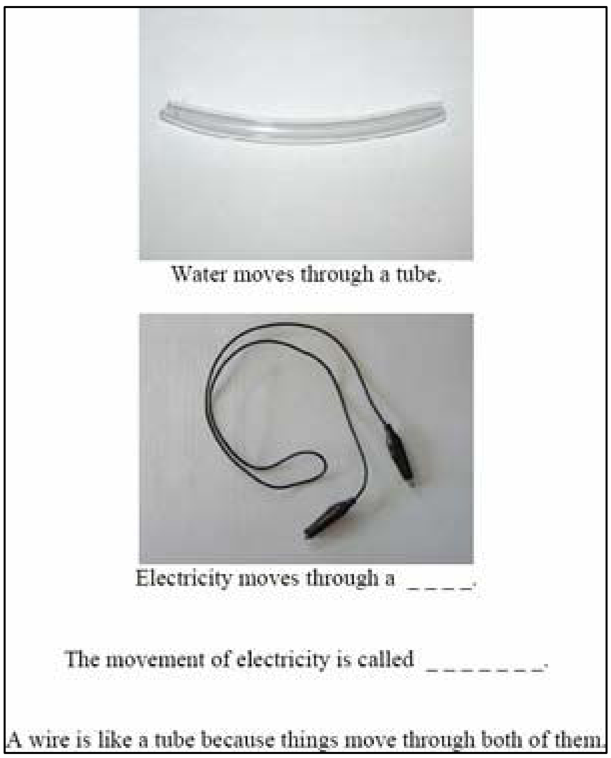


Figure 2: Above is the worksheet to accompany the introduction of current.

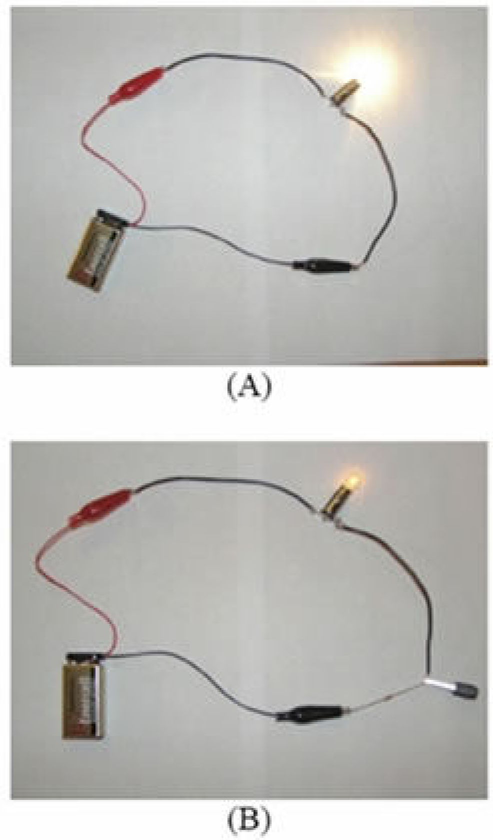
Show the students a light bulb from their kits and tell them that a light bulb can act as a measure of how much current is moving. Show the connected cups again with even heights and water levels with the water remaining still. Tell students that this is like an isolated light bulb that is off, indicating that current is not flowing. Raise one of the cups to a different height and show the students that a difference in potential causes the water to flow. Similarly, connect a battery to the light bulb to induce current flow, thereby turning the bulb on. Next, increase the difference in the height of the cups, which will cause the water to flow faster. Correspondingly, show students that an additional battery, connected in series with the first, causes the bulb to light more brightly, indicating greater current flow.

Next, define the vocabulary word ‘switch.’ Students were introduced to the switch when they experimented with the components during the first lesson, but now you can provide them with a definition to be written in their notebooks. Ask each student to locate the switch in his/her circuit kit and build a circuit containing a battery, a switch, and a bulb. Students can then use their circuits to demonstrate that the switch controls current flow, consequently turning the light bulb on and off. Next, ask students to brainstorm objects from their daily lives that have switches. Ask students if cars have switches. Some will likely say yes while others might say no. If they say no, point out that if a car did not have a switch to turn it off, it would run all the time. Holding up the key to your car, state that the key in the ignition is the switch for the car. If the students are more advanced, you can point out that cars actually have lots of switches for all of the different devices inside including the radio, the air conditioner, and the electric windows.

Lesson 2.3) Resistance

During the next lesson, introduce the concept of ‘resistance,’ which will be necessary to control the speed of the model cars. By inserting a cotton ball into a short length of the vinyl tubing, a mechanical resistance to air-flow is created. Give each student a short piece of tube and instruct them to blow into one end and feel the air coming out of the other. Next, ask students to repeat the process with a cotton ball inserted into the tube. Students will notice that air-flow sensed by their hand at the end of the tube is reduced by the mechanical resistance.

Show the students a resistor and introduce its pronunciation, spelling, and definition. Explain that a resistor is like a cotton ball for electricity because it lessens current flow. Ask the students to locate the resistors in their circuit kits and show them the difference between the 10Ω and 30Ω resistors. In pairs, ask students to experiment with the resistors in the following manner. Ask students to predict what a resistor will do to a battery-bulb circuit. Remind students that a light bulb indicates how much current is flowing. Then, ask one student in each pair to build a battery-bulb circuit and the other to build a similar circuit and add a 30Ω resistor as shown in the worksheet in Figure 3. Next, ask them to compare results. Repeat the comparison for a circuit with a single 30Ω resistor and a circuit with two 30Ω resistors. Working in pairs significantly enhances this activity; students can troubleshoot one another’s circuits if necessary and can perform a side-by-side comparison to truly observe the effect of a resistor on the circuit.



Which picture has more resistors?
A B

Which bulb is brighter?
A B

Which picture shows more current moving?
A B

Figure 3: The questions above were on the resistors worksheet and were used while students were building the pictured circuits.

Lesson 2.4) Motors

In order to further explore what motors can do as well as to continue working with the concepts of ‘potential,’ ‘current,’ and the effect of resistors, reintroduce ‘motors’ and define them to start the next lesson. Motors were introduced in the first lesson but have been omitted until now since, as previously mentioned, teaching over the whine of motors can be difficult. In order to create a mechanical analogy for a motor running on potential, a water wheel can be placed at the end of a tube connected to a water reservoir and the students can observe that the flowing water turns a wheel just like electric potential from the battery turns a motor. This step may be unnecessary, but it is a good demonstration of potential. If the students are more advanced, the concept of 'power generation' can also be introduced here. Regardless, present the motor and explain that current flow due to the potential in the battery causes the motor to spin. Ask each student to build a circuit containing a battery, switch, and motor to observe the motor in action. Next, repeat the resistance experiments from Lesson 2.3 to solidify the concept of resistance and to demonstrate that resistors have a similar effect on motors as they do on light bulbs.

Finally, time permitting, have students gather around a central circuit composed of a battery, light bulb, and resistor. Replace the resistor with a potentiometer and turn the knob. The students will observe that turning the knob brightens and dims the bulb. Students will also see that more or less current is flowing based on the brightness of the light bulb. Explain to students that a potentiometer is a variable resistor, and that turning the knob changes the resistance. Mechanical audio system volume and tone controls are real world examples of potentiometers. Providing *realia* in the form of a physical example such as computer speakers or a CD player with a mechanical volume control on the outside would help this explanation.

Lesson 3) Building Electric Cars

The final project involves building an electric car and asking students to utilize their knowledge of electrical engineering to make it go faster and slower. For this project, model electric cars must be used that have an on/off switch and a battery. These could be made from scratch, but the cars used for this case study were made by Tamiya (www.tamiyausa.com and click on "Mini 4wd") and are part of their 1/32 mini 4wd series. These model electric cars snap together, are durable, and are customizable for racing by hobbyists. They are available online from Tower Hobbies (www.towerhobbies.com and search Tamiya mini 4wd). The kits are a somewhat expensive at approximately $10 apiece. However, they do not require glue and can be reused if necessary.

This project takes two, one-hour class periods to complete in order to allow enough time for students to experiment with the cars. In order to limit the amount of time spent on the project and limit its scope to the electrical engineering concepts presented, a portion of each student's car should be pre-built. Pre-build the models so that the students only have to put in parts that they can identify based on this unit: the motor, batteries, and switch. The copper conductor on the motor must be altered slightly in advance in order to allow a resistor to be inserted in series.

In class, guide students through completing the cars step by step. Ask them not to touch any parts until instructed to do so. Next, lead students through completing the cars by showing how each of the pieces fit together. The kits are well constructed and durable which minimizes problems in construction, though some troubleshooting may be necessary. Once the cars are built, it is time to test them and see what they can do. Testing probably should not involve a race since factors affecting how the cars perform are mostly related to how they are mechanically put together, which is determined prior to class rather than by the students. In this case study, students had the opportunity to test their cars on their own and were very excited to explore what their cars could do.

On day two of the car project, students will use their engineering knowledge to add some speed control to the cars. Ask students if their parents' cars sometimes go slow. Also ask them if they sometimes go fast. Next, ask students what they would need in order to make the electric car they built go slower. Let them think about this for a period of time. If no one responds with the answer (a resistor), give students the electronics kits again. Draw a circuit on the board with a motor, a switch, and a battery, and ask them to build it. Then, ask students if what they have built is the same as the circuit in the car. This may not be easy for them so let them think about it. If they are still having trouble, explain that it is the same as the circuit used in the car. It has a motor, a battery, and a switch. Then, ask them what they should use to make the motor go slower. They will have the resistors in front of them and will probably choose the resistor. Help them put the resistor in series in the circuit just as in the lesson on motors. Next, allow students to keep that circuit for reference and give them the cars they built. Show them where the resistor can be inserted into the car. Finally, ask students to experiment with the resistors to slow the speed of their cars. At the end of class, it is worth demonstrating that a potentiometer can be used as a variable resistor to provide many different speeds for the car.

Assessment

Assessing the engineering content knowledge gained by ESL students through participating in project-based engineering activities provides unique challenges because the assessment must not require the students to utilize English language skills that they do not possess. If the assessment contains language that is challenging for the students, it can be difficult to determine whether students' lack of understanding is due to lack of linguistic skills or a lack of content knowledge.

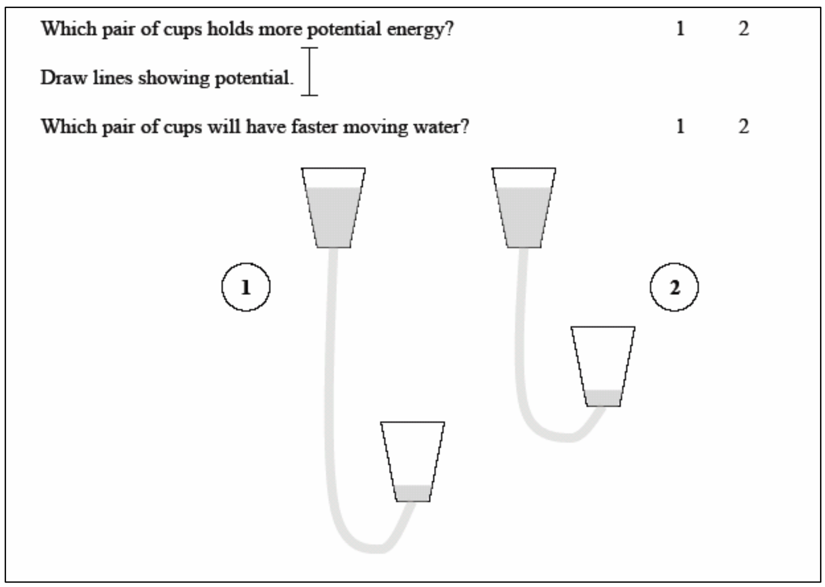


Figure 4: The above questions use the pictures as scaffolding to assess student understanding of the concept of mechanical potential.

When evaluating ESL students in content areas, it is important that teachers utilize scaffolding, just as when the concepts were introduced, to reduce the language demands of the assessment by utilizing a number of different techniques including the use of visuals, demonstrations, and projects[27]. The goal of scaffolding is to reduce the language skills required while still providing the opportunity for the student to demonstrate his/her understanding of the content knowledge being assessed.

Research has shown that initial paper/pencil tests for English language learners should consist of multiple choice and *cloze* (fill-in-the-blank) questions “particularly when a word bank is provided”[16]. Prior to this case study final exam, the Fellow helped the students brainstorm a bank of words they thought were important for the unit. Students wrote down the words and their definitions on a piece of paper. After students had written down these words, the Fellow erased the words from the board. This was to teach students the importance of taking notes. The majority of students in this particular ESL class were capable of answering linguistically appropriate multiple choice questions, especially involving pictures, and understood how to answer *cloze* questions with a word bank. For these reasons, a final exam was created utilizing mostly multiple choice and *cloze* questions.

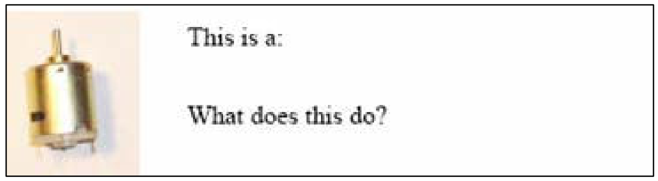


Figure 5: Above is an example of a vocabulary question assessing the students' knowledge of the word "motor."

The final exam created for the students included questions similar to those they had answered in class (Figure 1 through Figure 3). The exam was designed to eliminate as much of the language barrier as possible, while demanding performance that would challenge the average student in the class. It was important for the exam to be written in such a manner that it assessed content knowledge rather than language skills[28]. The use of pictures and demonstrations in the assessment was also important in order to create a context within which students could answer questions as described previously.

A few sample questions are shown in Figure 4 through Figure 6. Questions assessing student knowledge of mechanical potential are shown in Figure 4. Students are asked to select from a set of pictures rather than write answers in words. The question also asks students to draw lines of potential on the pictures, which assesses understanding of the concept without requiring students to write in English. To test vocabulary, students were shown a picture of one of the components discussed in class and asked to name the component. Next, they were asked to respond to the

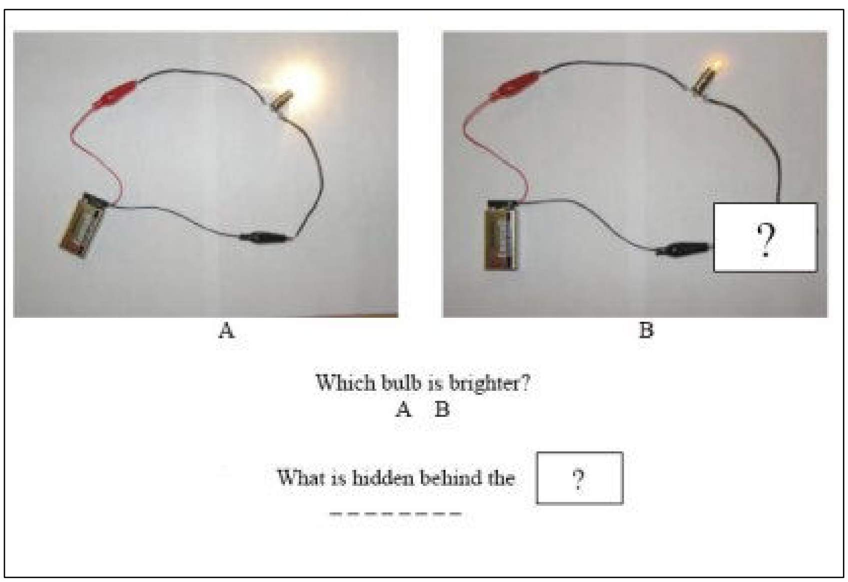


Figure 6: The figure above illustrates a series of questions designed to assess student knowledge of how resistors work. Questions and pictures are very similar to the worksheets so that students were familiar with them.

question "What does this do?" (See Figure 5). Finally, there were questions designed to assess whether students understood the purpose of various components. Figure 6 shows a series of questions assessing whether a student understood the purpose of a resistor. These questions were designed to look exactly like the student worksheets so that they would be familiar to students, but with sufficient change to require students to think about the material in order to answer the question. In this case, one of the electrical components was blocked by the box, and students had to identify the hidden component.

In addition to the written assessment, students worked individually with a Fellow who assessed their ability to build electric circuits. The Fellow asked each student to build a circuit that made the light bulb turn on. This was a good assessment of content knowledge because it allowed a nonverbal demonstration of understanding[28]. All of the students were able to build the circuit during the exam without help. After each had built the circuit, he or she was asked to make the light bulb dimmer. In order to accomplish this, a resistor was inserted in series with the circuit. All students were able to accomplish this as well. One student in particular illustrated the importance of separating language skills from content knowledge. When asked to "make the light bulb dimmer," he had no idea what to do. It was clear he did not understand the question. By talking to him, it became clear that he did not know what the word "dimmer" meant. The teacher was able to demonstrate the concept for him using a three- way lamp in the classroom. After the student understood what the word "dimmer" meant, he knew that he needed to insert the resistor in series with the circuit, and accomplished the task. This particular student understood the electrical engineering concept involving use of a resistor, but initially could not build the circuit without the visual scaffolding since he did not have the word "dimmer" in his English language skill set.

Students performed very well on the content-based final exam. The class mean was 82%, and all students were able to complete the hands-on assessment through building the two required circuits. Based on their work earlier in the unit, it was clear that these students had little, if any, experience with circuits before the unit began. Working on these projects uniquely designed for ESL students, they made significant progress in only seven class periods.

TeachEngineering Digital Library

An important part of creating lessons and activities in the Engineering K-PhD Program at the Pratt School of Engineering is refining and publishing those lesson plans in the TeachEngineering digital library (www.teachengineering.com). This allows K-12 teachers and university faculty across the country to have access to the lessons and activities in their classrooms. The NSF funded TeachEngineering collection is a searchable, web-based digital library featuring standards-based curricula for use by engineering faculty and K-12 teachers to teach engineering in K-12 settings[29]. University partners collaborating to create this collection include the University of Colorado- Boulder, Duke University, Worcester Polytechnic Institute, Colorado School of Mines, and Oregon State University. The TeachEngineering collection provides educators with access to an expanding set of curriculum with content evolving under stewardship of the American Society for Engineering Education. TeachEngineering has been funded under the National Science, Technology, Engineering, and Mathematics Education Digital Library (NSDL) program and is now part of the Engineering Pathway (www.engineeringpathway.org) creating a source for engineering content from kindergarten through the university level through NSDL. The TeachEngineering collection includes high-quality engineering-based curricular units, lessons, and activities for use at the K-12 level. These activities introduce engineering to K-12 students, integrating science and math. The collection includes lessons and hands-on activities that align with specific state and national science, mathematics and technology educational standards and the materials for most activities can be obtained from local hardware and/or grocery stores for less than $20 per class.

TeachEngineering offers authors the opportunity to publish three types of documents: lessons, activities, and curricular units. Each lesson is generally associated with one or more activities. The lesson includes the content knowledge a teacher is teaching, and the activities each provide hands-on, often inquiry-based, activities through which students learn and reinforce the content introduced in the lesson. A curricular unit is a collection of related lessons and/or activities. Essentially, the curricular unit document summarizes the unit and includes links and the order of the various lessons and activities within the unit. While there are guidelines for publishing curricula utilizing these three documents, they are designed to be flexible tools for publishing curricula in a searchable format for teachers. For instance, while it is encouraged that an activity be associated with a lesson, this is not a requirement and activities may also be published separately.

The first thing a Fellow must do in order to publish classroom work on TeachEngineering is to determine how many different lessons and activities will be taught and how they are related to each other. In this case, there are three lessons as described above. The second lesson is associated with five different activities while the first and third lessons are associated with one activity each. Once that has been determined, the Fellow may begin filling in pre-designed Word templates for each lesson and activity. If the Fellow is grouping lessons and activities into a curricular unit, that document may be left until last. When ready for publication, it is reviewed by a teacher and a technical content reviewer. If the curricular unit, lesson, or activity is accepted, it is converted to the xml format used by the TeachEngineering digital library and published as part of the collection. To get started, interested parties should contact the TeachEngineering team at www.teachengineering.org or the authors of this paper.

Conclusion

In conclusion, this case study and accompanying set of lessons and activities has demonstrated that engineering content can provide a rich medium for practicing language skills in ESL classes. This paper outlined skills necessary for an Engineering Teaching Fellow to effectively teach engineering content in an ESL classroom as well as examined ways of preparing Fellows to work with ESL students. Lesson content based on a case study was provided. The lessons, utilizing some inquiry-based methods in conjunction with teacher guided discovery, introduced basic electric circuits and culminated in students using their newly gained understanding of electrical engineering to show how speed of an electric car can be controlled. Beyond engineering content, time spent teaching vocabulary was more important for ESL students than for the native language students and for that reason formed a significant portion of the unit. Evidence for student learning among case study participants was provided. Finally, the process of publishing these lessons and activities in the TeachEngineering Digital Library was described.

Over the course of the unit, these ESL students transitioned from having shy and timid demeanors to demonstrating vibrant, animated, and confident behaviors. Working with a real world problem and learning to do things with their hands in a class that is generally about language was exciting to them. Students were enthusiastic about answering questions and eager to impress the Fellow working with them. Based on these results, it is clear that this project also achieved the goal of motivating these students to use both written and spoken English in an academic setting while teaching them that engineering can be exciting and meaningful to their broader life experience.

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