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Physics Hertz! An Analysis of the Language Demands of the Physics Classroom

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Abstract

This paper explores the language demands of physics for English Language Learners (ELLs), and the additional challenges presented. With a greater emphasis placed on Science Technology Engineering and Math (STEM) in the classroom, it has also become highly important to determine ways to assist ELLs with the learning of science. As physics is a science that relies heavily on the use of higher-level mathematics, the language demands in a physics classroom becomes two-fold for ELLs. Specifically, the ELL must learn the language associated with observational science, mathematical equations, graphs and tables, and advanced mathematical processes. This paper will utilize examples drawn from a college-level text to illustrate the complexity and difficulty of the language of physics. Using a college text represents an AP-level course in a high school setting, where ELLs can (and do) enroll.

Keywords: Language Demands, English Language Learners, Physics Education

1. Introduction

With an increasing emphasis on the importance of STEM in the classroom, it has become necessary to investigate the language demands of STEM curriculum with regards to the ELL. Physics poses a unique challenge, as it heavily relies on advanced mathematics as well as specific scientific language. Physics is already a daunting course for native speakers, which means it could pose a much more difficult challenge for the ELL. However, without analyzing and addressing the specific language demands of the Physics classroom, we could inadvertently exclude young minds who have the potential to be amazing scientists. Neglecting the ELL automatically eliminates approximately 10% of the school-age population[1], a percentage which has steadily grown annually. By performing an in-depth analysis of the language demands in a Physics classroom, we can address the challenges to make Physics more accessible to all students, regardless of language background.

To understand the language difficulties of Physics, it must first be broken down into its components. According to Merriam-Webster Dictionary, Physics is “the science that deals with matter and energy and their interactions”[2]. However, to accomplish that means having an in-depth comprehension of not just the language of science, but also the language of math. Physics relies heavily on the use of various mathematics such as algebra, trigonometry, and calculus. Therefore, an ELL walking into a Physics classroom must understand the specific language demands of two subject areas, and must possess a comprehension such that they can use one to describe the other. This paper will analyze basic Newtonian physics to demonstrate the various language demands made on an ELL and will utilize excerpts from an AP-level textbook to analyze the various aspects of language demands: vocabulary, discourse & grammar, register, and semiotics. It will then outline these specific language concerns as they relate to a lesson on atomic structure.

2. Vocabulary

Physics contains a vast array of vocabulary specific to itself. These words not only carry specific meaning in words but dictate how certain aspects are handled mathematically. A definition from Young & Freedman displays this well.

> When a physical quantity is described by a single number, we call it a **scalar quantity.** In contrast, a **vector quantity** has both a **magnitude** (the "how much" or "how big" part) and a direction in space. Calculations that combine scalar quantities use the operations of ordinary arithmetic… [3].

The vector is a critical concept in physics. As noted, it is a measurement that has both magnitude and direction. Failure to understand what a vector is prevents a student from adequately describing how a particle moves in space. However, a student must understand additional vocabulary to comprehend the above passage. They must understand the words *quantity*, *described*, *magnitude*, *space*, and *arithmetic*. Some words have a direct translation across any subject, such as "quantity". However, "space" in math and physics do not necessarily mean the same as what would be found in a book of literature. According to Encyclopedia Britannica, space in physics is "a boundless, three-dimensional extent in which objects and events occur and have relative position and direction." Outside the physics classroom, that same word could mean outer-space, a large room lacking objects, or the what is placed between words in a sentence. Understanding the specific uses of vocabulary in physics is important since a student must be able to construct models of a physical system to make calculations. This therefore necessitates the understanding of specific mathematic vocabulary.

In describing a vector in three dimensions, a student must understand that a particle's motion must be broken down into the components of the coordinate system they are using. For instance, read the following excerpt from Young & Freedman, "To define what we mean by the components of vector $\vec{A}$, we begin with a rectangular (Cartesian) coordinate system of axes"[3]. The student must understand the mathematical vocabulary of axes, Cartesian coordinates, and component to comprehend how this differs from a scalar number. Specifically, a student must take a vector and break it down into its x and y components solving for each. While these vocabulary elements are difficult for native speakers of English, they pose a compounded difficulty for ELLs.

3. Discourse and Grammar

Science is a precise academic field of study and has elements of language, which compound the difficulty of an ELL understanding the concepts. In terms of physics, it tends to describe things in a very technical and clinical way, as from Young & Freedman,

> When a particle moves in a circle with *constant* speed, the motion is called **uniform circular motion.** A car rounding a curve with constant radius at constant speed, a satellite moving in a circular orbit, and an ice skater skating in a circle with constant speed are all examples of uniform circular motion. There is no component of acceleration parallel (tangent) to the path; otherwise, the speed would change. The acceleration vector is perpendicular (normal) to the path and hence directed inward (never outward!) toward the center of the circular path. This causes the direction of the velocity to change without changing the speed.[3]

To understand the passage and make use of the information, a student must break down the sentence into logical pieces to visualize what is being described. In the vernacular, the above passage states that if something is moving in a circle at a constant speed, that the only acceleration is towards the center of the circle. A student has to remember that a vector has both magnitude and direction. Since the velocity is changing in direction, and not in magnitude, it then has acceleration. They also need to be able to understand the word relationships and grammar of the sentence. Science speaks in the passive voice. In general, science textbooks "do not follow the simplest subject-verb-object pattern of English. This limits the syntactic clues an ELL student can access when trying to decipher a sentence."[5] As such, ELLs may have a difficult time deciphering the meaning of the textbook, as it uses a form of English not used in day-to-day practice. Additionally, Physics problems consist almost entirely of word problems. It is expected for the student to read the word problem, decipher what is known and unknown, and derive a method of finding the correct answer for what is asked, as this word problem from Young & Freedman demonstrates:

> An airplane's compass indicates that it is headed due north, and its airspeed indicator shows that it is moving through the air at 240 km/h. If there is a 100-km/h wind from west to east, what is the velocity of the airplane relative to the earth?[3]

Without being given contextual cues or assistance, this problem could prove all but impossible for any but the most advanced ELL, even if it is easily understood by their peers. While the problem does feature a diagram,

> Many science texts have multiple diagrams to help students understand key concepts. Unfortunately, the charts and visuals are often complex and require an understanding of key concepts and a great deal of text before they can be understood. They can be just as difficult to understand as the text they illustrate.[5]

To compound the language of physics even further, it must be recognized that it is the science most dependent upon mathematical equations. In fact, Lenke determined that, on average, physics books have 2.7 equations and 1.2 images per page.[5] These equations rely on the student's mathematical understanding of what was described in text. In the previous example, the student would have to understand that the two velocities given would construct a right triangle. Using this knowledge, a student could find the magnitude and direction of the velocity by using the Pythagorean theorem for magnitude, and trigonometric functions to determine the direction:

$$v_{\frac{p}{a}} = 240\frac{km}{h}\ due\ north$$

$$v_{\frac{a}{e}} = 100\frac{km}{h}\ due\ east$$

$$v_{\frac{p}{e}} = \sqrt{(240\frac{km}{h})^2 + (100\frac{km}{h})^2} = 260\ km/h$$

$$\alpha = \arctan\frac{100\frac{km}{h}}{240\frac{km}{h}} = 23°\ E\ of\ N$$

Figure 1. An example of a typical homework problem in a physics textbook.

However, this relies on the student fully understanding the problem described and understanding how to apply that problem to mathematical concepts. If they do not understand the words, or what those words mean in the context of a physics classroom, they will struggle to comprehend what they are to do with the information in a word problem.

4. Register

Writing and speaking in science entails specific uses of words which do not exist outside of the science classroom. Students are expected to generate or observe models. However, in the conventional English language, a model may be a miniaturized version of something else (model car, model airplane, etc.), physics describes a model as, "a simplified version of a physical system that would be too complicated to analyze in detail"[3]. In laboratory settings, it is routine for students to take the mass of an object. This means to place an item on a scale or balance and find out what the mass is (how much of something there is), although a student may be tempted to say "weight" and "weigh". However, the two are not synonymous, as weight is an expression of the gravitational force on an object of a specific mass, meaning an items weight could change if they were closer to the core of the Earth, or they could be "weightless" in space. It is to be understood that to describe a particle is to use laws and theories of physics to state what that particle is doing, whereas outside the classroom, describe would entail giving physical descriptions such as size and color of an object. In physics, speed is considered a scalar quantity, meaning it has magnitude only. To adequately describe a particle moving, physicist utilize the concept of the vector called velocity. An excerpt from Young & Freedman gives a very good example of the different use of language,

> *How long is an instant?* You might use the phrase "It lasted just an instant" to refer to something that spanned a very short time interval. But in physics an instant has no duration at all; it refers to a single value of time.[3]

For a student to be able to adequately function in a physics classroom, they must understand the unique use of language. They should be able to translate spoken or written word to mathematical relationships. Without this understanding, even explanations to set up the problem would cause problems for an ELL, as this explanation to solve an acceleration problem by Young & Freedman shows:

> …We take the origin at the sign, so $x_0=0$ for both, and we take the positive direction to the right. Let x_p and x_m represent the positions of the police officer and the motorist at any time. Their velocities are $v_{p0x}=0$ and $v_{m0x}=15$ m/s.[3]

Without understanding the register of a physics classroom, an ELL would have difficulty seeing how to set up a problem where they are to calculate the different accelerations of a police officer and a motorist. Additionally, the solution to the example would prove equally confusing. In the example above, the word verb "take" is meant as "assume". Subscripts are "p" and "m" are assigned to the variable x to assign specific positions at "any time", meaning that they do not need to be concerned with any specific period of time. "Represent" in this case means that we are using the variable "x" as a mathematical substitute in an equation. Interpreting these symbols are also important in developing understanding for a physics student.

5. Semiotics

Physics is a science heavily-dependent on math, it deals heavily with equations and variables. However, unlike algebra or trigonometry, physics deals with numerous instances where letters are used as substitutes for numbers. Additionally, mathematical operators are used throughout physics to describe an object. This compounds the difficulty of a physics classroom, as these symbols and expressions are used in lieu of words to describe a function or an action.

$$\sum F = n + (-mg) = ma \tag{1}$$

The above equation is Newton's second law, saying the magnitude of the acceleration is directly proportional to the magnitude of the net force acting on the body. In this specific example, the Greek letter sigma tells the student that they are finding a sum of force "F". That sum of F is equal to the normal force "n", or the force acting on the object, plus the downward gravitational force (-mg). The negative sign is used to signify a downward force of mass x gravitational acceleration. They would then have to know that to find "n", they would have to add "mg" to "ma", finally replacing those letters with given values. These are all cues to an expression a student would have to know just to be able to read the equation. However, they would also have to understand the concepts behind each variable, and how they relate to the overall formula. Another example where a student must understand what the math is telling them to do is a simple work equation:

$$W = \int_{x1}^{x2} F_x \, dx \tag{2}$$

Where "W" is equal to work, and "F_x" is the force. The elongated "S" is an operator to tell the student to find the integral, of the force, using the limits x2 and x1, with respect to "dx", or the change in x. This type of calculus can be difficult for native speakers, and with the right supports, ELLs can also do well with it. However, they first must learn these symbol's meaning in the context of math, then understand the new symbols used in physics. As each symbol in physics represents a potentially abstract concept, the difficulty of such an expression compounds. There are many times in physics where a specific value is unknown, requiring the student to perform sequential steps to find various pieces to find the final answer. This would require understanding the relationship between equations, and how they interrelate. To illustrate the complexity of the language learning environment as it relates to physics, an analysis of a lesson on atomic particles will be used.

6. Analysis

While chemistry is typically taught to students prior to physics in a high school, it is useful to conduct a pre-assessment of the class prior to the lecture. This is to gauge prior knowledge, so-as to tailor the lecture to each class based on its composition. This presents the first difficulty for an ELL, as a pre-assessment would compose of fill-in-the-blank, or short-answer questions to feel out the students' comprehension. A pre-assessment on atomic structure and associated particles would feature the use of vocabulary, such as neutron, electron, and proton; these are words that are used only in a science environment, and therefore would be difficult for an ELL to recall immediately. A Bohr's model of an atom would be used to determine if the students understand the idea of valence shells, and the number of electrons allowed in each shell. This would require a combination of understanding of vocabulary, such as valence, as well as semiotics for individual particles. Understanding that charge, as it relates to atoms would also need to be understood. Finally, a student would have to understand what atomic mass is and how to calculate it.

The learning objectives of this lesson would be:

1) Describe the particles of an atom, their charges, and how those charges flow to create electrical current.
2) Build a battery to demonstrate the understanding of electrical current.

In the first objective, a student would need to not only be able to know and recite the vocabulary associated with an atom but understand what they are and how they interact. Students would need to be able to translate concepts into written or spoken words to communicate the idea. This also means that a student would need to be able to construct a model, either mentally or on paper, to help them to build this description. As charge and electrical current are vectors, the student would also need to be able to convert the concept into mathematical equations to describe those concepts in a quantitative way. For the second objective, the students would need to apply the knowledge and understanding gained through the first objective by constructing a battery. This means they would have to understand the idea of relative charge, understand how charges are made, and then how to combine materials to develop the difference in potential to achieve electrical current. They would need to be able to read laboratory instructions, understand diagrams, and perform mathematical calculations. Finally, they would need to analyze the result and describe the functionality of the battery. They would need to use both mathematical expressions and written narratives to complete a laboratory report. This requires the ability to put together a report using the passive voice, mathematical computations, and the ability to describe results in their own words.

7. Solutions

It is important for educators to remain cognizant of these factors which influence the ability of a student to learn. While many school districts have at least one ESL professional employed, it is important to understand that she or he must devote their time to every language learner in their district or, potentially, neighboring districts. It is also important to note that these teachers may not understand the subject areas a student is struggling with. This is where it becomes important for subject-area teachers to work with the ESL professional to construct their class in a way which helps develop the language of a student. Each teacher is the subject-matter expert in their field at that school, meaning they are the best equipped to employ strategies to assist language learners in their classroom. Awareness of the language demands allows teachers to employ solutions to enhance student learning.

These solutions do not eliminate the needs for the student to acquire the language, nor do they require the teacher to reduce the cognitive demands of the class. Examples of accommodations for language learners which can be used in a classroom include:

7.1 Group work and composition

Science and math are not isolated learning environments. The best learning occurs when students work together to develop answers to problems. By grouping language learners with proficient students, a teacher may utilize the idea of BICS to reinforce the CALPS[6].

7.2 Additional resources such as Screencast

One of the greatest resources used by students in math on a college campus is Khan Academy[7]. Sal Khan does an amazing job of demonstrating and explaining complex mathematical theory in a way which is easy to digest. He does this through actively working out examples using programs such as Screencast, but also speaks about the mathematics using a lower level of vocabulary. He actively reduces the language demands of a math lesson. Teachers can create similar resources for their students.

7.3 Reinforcement and assessment of the language

The overall idea of addressing the language demands in a physics classroom does not entail eliminating the need to learn the language of physics. Instead it entails finding ways to encourage language growth in the classroom while simultaneously ensuring that the student is able to learn the non-linguistic concepts of physics. This can be done through reinforcing the language and conducting non-graded, formative, assessments. Visual aids in the classroom is one easy way to accomplish reinforcement, but it also helps to remind students of vocabulary through questions[8].

7.4 Post-reading assessments

The primary purpose of a post-reading assessment should be to determine how well the students understood the reading material from the previous night. Asking students to complete a 3-2-1 chart or similar assessment not only gauges the students' comprehension of what they read the night before but reinforces language production through writing. Encouraging students to actively use the language in writing can help build their proficiency[10].

7.5 Remove the "fluff"

It is common in math and physics classes to use word problems to assess the students' ability to understand the content. While the word problems can be entertaining means to set up the problem for the student, it can pose significant difficulty for a language learner. For a student learning a second language every word is important to them, which means it takes them longer to deconstruct a word problem to get to the "meat" of the problem. Eliminating the chaff, or the distractors, from a physics problem ensures that the student is being assessed on their ability to use physics concepts to solve a problem, and not on their ability to pick apart the word problem.

7.6 Unlabeled diagrams[8]

Physics requires students to strip a problem down to determine what is known and what is unknown in a problem to solve a solution properly. This typically results in a diagram which describes the various forces at work on an object. A way to help language learners develop language proficiency in a physics classroom, while also building the student's ability to construct a physics problem is to have drawn, unlabeled diagrams where the student can focus on determining where the forces are, instead of having to also decipher what is present. This is a form of scaffolding which could be used early in the class, with information gradually removed. The idea is to give the student time to grasp the language of the subject while still learning the concept.

7.7 Use WIDA "Can Do" Descriptors

The WIDA Consortium has published a guide for language development and acquisition in the classroom. Specifically, the guide details what a student is capable of doing with the language at each stage of language acquisition. These "Can Do" descriptors are broken down by subject, grade, and linguistic task. Some states such as Pennsylvania have English Language Proficiency Standards (ELPS). WIDA and ELPS combined can help teachers to construct language learning standards within the framework of existing lesson content[9].

8. Conclusion

Physics is considered one of the more difficult courses that a student can take during their academic career. It is a science which revolves almost completely around mathematical computations, has a complex array of vocabulary, and features many abstract ideas. Because of this, the physics classroom can pose an increased level of challenge for both the ELL and the teacher. While this paper outlined the language demands of physics using textbook examples, it is important to note that most physics teachers speak in a very similar manner as text books do. Most concepts involve a teacher using physical models or analogies while the teacher explains using technical words. Equations are also typically explained in the same fashion. It is important for a physics teacher to understand just how technical a lecture on Physics is, and the compounded difficulty for a person who is still learning English. This would not only benefit the ELL, and allow them to be fully included in the classroom, but could help other students in the class who may not be able translate the complex linguistics into models and equations. Without taking language into consideration when teaching to a class with ELLs, the teacher could deny some students the ability to succeed and potentially dissuade promising students from taking up further studies in STEM fields. With STEM becoming an increasing need in our society, neglecting even one student is a loss we cannot afford.

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