International Society of the Learning Sciences

"Shake the Slinky More": Exploring the Medley of Meaning in Middle School Science Students' Language

Jared Arnell, Utah State University, jared.arnell@usu.edu
Hillary Swanson, Utah State University, hillary.swanson@usu.edu
LuEttaMae Lawrence, Utah State University, lu.lawrence@usu.edu

Abstract: Learners routinely struggle to adapt to the rigorous nature of scientific language. Discrepancies between scientific terms and their casual counterparts can create challenges for science communication and instruction. We observed the language used by a classroom of middle school science students as they learned about mechanical waves. We documented instances in which the same language was used to convey different meanings. Specifically, students used "speed" to refer to both velocities and frequencies and used scientific terms like "force," "energy," and "power" interchangeably. The teacher was dedicated to helping students make sense of the meanings behind the words they were using, however, time constraints made it difficult for her to address all the terms. Developing tools and interventions to identify language challenges and providing educators with the skills and resources needed to implement those tools are important tasks for the Learning Sciences.

Introduction

The language of science can be difficult to master. Casual, everyday words can transform into rigid, definitional vocabulary in the physics classroom, sometimes with radically different meanings and connotations (Williams 1999). Experienced physicists have years of practice exercising precision in scientific language. Novices must develop their language practices while simultaneously incorporating novel terminology into their lexicon. Often, physics educators and textbooks will use physics terms without considering the disparity between their technical definition and students' informal definitions. Students then formulate conceptual connections based on how they understand the terms in use, leading to alternative conceptions that can increase the challenge of learning normative science conceptions (Touger, 1991). Student difficulties with language can persist beyond introductory courses; Itza-Ortiz et al. (2003) found that a majority of nonscience majors surveyed in a traditional physics course struggled to articulate the difference between the everyday and formal definitions of words like force, momentum, and impulse. Going further, intermediate physics students who have completed the introductory courses and moved on to more advanced classes still misplace terms and use imprecise language (Arnell et al., 2022).

Refining students' use and understanding of scientific language is paramount to supporting their learning. Linguists have long examined the profound influence language has on cognition (Lakoff & Johnson, 1980). Every aspect of language, from definitions to grammar, shapes the way our minds conceptualize the subjects of our communication (Evans & Green, 2006). Such influences are especially important in science communication, where conceptual models can be encoded by the grammatic and semantic components of language, even when the speaker is unaware of the subtext (Brookes & Etkina, 2007; Talmy, 1988). This work positions the natural language of novices as a window into student understanding; our goal in this paper is to attend to the words used by young learners during sense-making activities and decipher their meaning.

Theoretical framework

The development of the featured instruction and the subsequent analysis of its data were guided by a cognitive perspective called knowledge in pieces (KiP; diSessa, 1993), which views knowledge as a complex network of atomized elements and resources that guide sense-making when activated. Novices tend to both under- and overextend resources due to inexperience, misleading cues, or context. For novices to cultivate expertise, they must gradually reorganize and repurpose knowledge elements and their contextual applications. This view of refinement over replacement makes KiP a constructivist, anti-deficit framework (Smith et al., 1994) and sets KiP in contrast to "misconceptions" perspectives, which label prior knowledge as an obstacle to learning (McCloskey, 1983). Where these perspectives would frame the purpose of instruction as identifying and confronting students' incorrect ideas (Maclin et al., 1997), KiP advocates encouraging students to articulate and reflect on their own thinking (Hammer et al., 2012).

KiP is well suited to analyze the language of naïve learners. In his foundational monograph, diSessa (1993) postulated that primitive knowledge resources would be situated in "areas of strong descriptive (representational) capability" (p. 122), predicting a close relationship between student intuitions and the language they use to describe their reasoning. Later KiP work would refine the methodological considerations for applying the theory to language analyses (diSessa et al., 2015). Redish and Kuo (2015) discuss in depth how KiP and the wider cognitive linguistics field have many congruent tenets, such as conceptualization through bodily experience, flexible application of ancillary knowledge, and context-driven synthesis of meaning. As a language-centric example of KiP, Parnafes (2007) compared the way physics students speak when reasoning about a swinging pendulum or a vibrating spring. Parnafes found students used terms like “fast” and “quick” to refer to both the velocity of the pendulum and the frequency of the spring, despite these characteristics being conceptually distinct. The ambiguity seemed unproblematic from the student’s perspective but presented a challenge for their learning, as the blended concept interfered with their ability to attend to relevant system features. The application of KiP theories to these episodes elucidated both the origin and consequence of students’ language decisions.

Methodology

The data discussed in this paper come from the classroom of one teacher, whom we call Mrs. K, who teaches in a rural middle school in the Intermountain West region of the US. Mrs. K’s classroom had 31 eighth-grade students who worked both alone and in small groups. We partnered with Mrs. K as part of a larger design-based research project to co-design instructional units that engaged students in scientific theory-building practices. This study comes from one unit that scaffolded students’ construction of sound wave models. The sound wave unit covered two weeks and included a wide variety of demonstrations, activities, and visual aids. We draw our observations from one activity, in which the students were split into small groups and given a slinky, which they used to physically model waves. The students were given a worksheet which prompted them to state their predictions, record their observations, and articulate their reasoning while engaging in a theory-building process. We selected two open-ended questions from the worksheet for analysis: the first (Q1) asked the students how they might make a wave with higher frequency, while the second (Q2) asked how they might make a wave with higher amplitude.

Data analysis was done in accordance with knowledge analysis (KA; diSessa et al., 2015), a methodological approach which often accompanies KiP research. KA uses an iterative process of coding which allows patterns to emerge organically from the data. The students’ answers to each question were initially categorized by the language used in each response. These categories were then analyzed to understand how the students were using various scientific terms to represent their underlying reasoning. Video recordings of Mrs. K leading a classroom discussion at the end of the sound wave unit were also collected. These transcripts were reviewed to analyze Mrs. K’s reaction to the students’ language use.

Findings and discussion

Shaking the slinky

The focal activity asked students to stretch a slinky along a table and shake it to create mechanical waves. Q1 and Q2 asked the students to consider how they might alter the frequency and amplitude of the waves, respectively. The most common responses are shown in Table 1, along with a characteristic example.

Table 1
Frequency and Examples of Common Response Categories from Q1 and Q2

	n (Q1)	Q1 examples	n (Q2)	Q2 examples
Speed	7	“Move the spring way faster”	6	“Move hands faster”
Movement	0	*N/A*	8	“Shake the slinky more”
Effort	3	“Use more force and energy”	5	“More force moving the slinky”
Trade-off	4	“Go smaller”	1	“Make waves that are kind of slow”
Precise	2	“More pulses”	5	“Move the spring farther out”

Statements that incorporated the concept of *speed* were the most common response to Q1 (how to raise frequency) and featured prominently in Q2 (how to raise amplitude) as well. This is noteworthy because the physical motions to achieve higher frequencies and amplitudes are distinct: higher frequencies are made by making the slinky perform more wave cycles in a given time, while higher amplitudes are made by moving the slinky farther from equilibrium with each wave. At first, it may seem surprising that students would describe two experientially unique movements with nearly identical language. However, as was experienced by the students, both movements do result in the lateral movement *speed* of the slinky (or the hand holding the slinky) increasing. The tendency for students to use generic *speed* responses for both circumstances is in line with the findings of KiP. Novices have not yet developed the overarching or global connections of experts, resulting in a narrow focus on whatever concepts are deemed most relevant to the immediate problem. This contextual limitation was exemplified by three students who provided *speed* responses to both Q1 and Q2, despite the activities being only minutes apart. From the vantage point of the students, it was irrelevant that their *speed* statements could have also applied elsewhere; the salience and relevance of *speed* within the immediate context was enough to justify its use in describing the phenomenon.

The *speed* answer can be correct in either case, but only conditionally: increasing *speed* would increase frequency only if the amplitude remained constant, and it would similarly increase the amplitude only if the frequency remained constant. None of the students who provided *speed* answers gave these conditions; instead, they categorically provided short, simple answers like “go faster,” “do it faster,” and “move it faster” in both Q1 and Q2. These minimalistic responses were likely perceived by the students as being wholly sufficient. After all, they could see the increased *speed* of the slinky directly causing a change in the properties of the wave. With such an easily observable causal mechanism, further clarification would seem unnecessary. The lack of specificity in the students’ *speed* responses means that these answers have multiple interpretations, only some of which may be correct for a given question. For an instructor attempting to assess the accuracy of their students’ conceptions, such responses could indicate success but could also hide crucial misunderstandings.

Another common response was to use more *effort* when shaking the slinky. This response had the most variation, with statements ranging from the casual “move it harder” to the more scientific “use a greater force and energy” and “more force and power.” These responses seem to be a more embodied version of the *speed* responses, focusing instead on the *effort* needed to grant the additional *speed* rather than the resulting *speed* itself. Once again, these answers are technically correct, but lack necessary precision. Increasing the *effort* used to shake the slinky could increase the *speed*, frequency, and amplitude in any number of combinations depending on the way the *effort* is expended. However, these numerous possibilities for the applications of *effort* were likely not present when the students were reasoning through their responses. Instead, they were merely reporting on the bodily sensation they felt when trying to impact the frequency and amplitude of their wave, and they used familiar language to describe the experience. Notably, the students’ *effort* responses appear to use the terms force, energy, and power somewhat interchangeably. This looseness with vocabulary also reflects the casual relationship the students have to the language used in their responses; they have likely heard force, energy, and power used similarly to describe *effort* in everyday conversations and are applying that informal definition here.

Overall, the students did not appear to struggle with conceptualizing the wave characteristics or how to modify them. In fact, the students showcased a variety of productive resources to explain their experiences; they were merely using accessible or casual language to describe their observations. This informality was seen as the students used identical *speed* language to describe multiple phenomena while also using a variety of *effort-related* language to describe a singular embodied experience. As a result, most responses (34 out of a total 40) were statements that may indicate correct reasoning but lack the precision necessary to interpret meaningfully. Only one student gave an answer that could only be interpreted as incorrect (saying “go shorter” for Q2).

Making sense of students’ language

At the close of the sound wave unit, Mrs. K invited each group of students to reflect on their experiences and summarize the most salient lessons they had come to understand through the activity. Mrs. K asked each group to share one lesson or observation in a class-wide discussion. She added each group’s on the board at the front of the classroom. Mrs. K noticed that several groups’ suggestions had similar imprecise wording. Four groups provided statements which described the relationship between volume and the size of a sound wave, though their language was inconsistent and unclear. Among their responses were “the closer the person is, the sound is bigger” and “the louder the volume, the greater the sound wave.” Mrs. K sought to bring the students’ attention to their use of language, saying “We have people saying things like ‘faster, greater, louder,’ and I’m not sure we’re all talking about the same thing… what does ‘greater the sound waves’ mean and look like?” Students attempted to clarify, suggesting that it meant “there are more waves moving through” and “the waves look bigger.” For each suggestion, Mrs. K offered methods for how the students could verify if these suggestions were valid, such as counting the number of waves in a period of time. If more time had been available, it may have been possible for Mrs. K to review more student responses, recognize these patterns, and address the problem areas. However, as is seen often in secondary education, she needed to move on to keep pace with the curriculum.

Conclusion

Helping novices develop precise language is of utmost importance to science education. Young learners need more experience to comfortably wield scientific jargon in the manner of experts, and so resort to using comfortable or familiar language. In doing so, they may inadvertently sow seeds of misunderstanding by entangling scientific words with their often-dissimilar lay counterparts. To compound the matter, novices should not be expected to be aware of such discrepancies, which means they will go unaddressed unless attention is actively directed to them by guiding experts. Catching these incongruities early and course-correcting is crucial to ensure students’ knowledge systems develop in the direction of normative science.

We observed numerous examples of middle school science students using vague or ambiguous language when studying wave mechanics. They regularly gave answers which contained productive elements but lacked the context or clarity to ensure an accurate interpretation. The most prominent example was the students’ application of the concept of *speed*, as students simultaneously applied the vague notion of *speed* to refer to conceptually distinct phenomena. The students also routinely used “force,” “energy,” and “power” interchangeably. When attempting to address the inconsistencies of her students’ language, Mrs. K began to help her students disentangle the multiple meanings they were giving their words, however, she did not have sufficient time to allot to the discussion and was forced to move on, leaving a number of language issues unattended.

Misalignments between students’ understanding and articulation can create challenges for later conceptual learning. The refinement of student language is an important facet to consider when designing interventions, curriculum, or learning tools. The utilization of KiP frameworks can help researchers identify the many diverse meanings underlying language used by students and locate productive resources for building scientifically precise and appropriate vocabulary.

References

Arnell, J., Swanson, H., & Edwards, B. (2022). Instructional landmarks: Describing a novel intermediate knowledge structure for physics learners. In Chinn, C., Tan, E., Chan, C., & Kali, Y. (Eds.). (2022). *Proceedings of the 16th International Conference of the Learning Sciences – ICLS 2022* (pp. 1393-1396). Hiroshima, Japan: International Society of the Learning Sciences.

Brookes, D., & Etkina, E. (2007). Using conceptual metaphor and functional grammar to explore how language used in physics affects student learning. *Physical Reviews Special Topics – Physics Education Research, 3*(1), 010105. https://doi.org/10.1103/PhysRevSTPER.3.010105

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, 10(2/3), 105-225. http://www.jstor.org/stable/3233725

diSessa, A. A., Sherin, B. L., & Levin, M. (2015). Knowledge analysis: An introduction. In diSessa A. A., Levin, M., & Brown, N. J. S. (Eds.), *Knowledge and interaction: A synthetic agenda for the learning sciences* (pp. 30-71). Routledge.

Evans, V., & Green, M. *Cognitive linguistics: An introduction*. Edinburgh University Press.

Hammer, D., Goldberg, F., & Fargason, S. (2012). Responsive teaching and the beginnings of energy in a third grade classroom. *Review of Science, Mathematics, & ICT Education, 6*(1), 51-72. https://doi.org/10.26220/rev.1694

Itza-Ortiz, S. F., Rebello, N. S., Zollman, D. A., & Rodriguez-Achach, M. (2003). The vocabulary of introductory physics and its implications for learning physics. *The Physics Teacher*, *29*(2), 330-336. https://doi.org/10.1119/1.2343227

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. The University of Chicago Press.

Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students’ preinstruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction, 15*(3), 317-393. https://doi.org/10.1207/s1532690xci1503_2

McCloskey, M. (1983). Naïve theories of motion. In Gentner, D. & Stevens, A. (Eds.), *Mental models* (pp. 299-323). Psychology Press.

Redish, E. F., & Kuo, E. (2015). Language of physics, language of math: Disciplinary culture and dynamic epistemology. *Science and Education, 24*, 561-590. https://doi.org/10.1007/s11191-015-9749-7

Smith, J. P., diSessa, A. A., & Roschelle, J. (1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences*, *3*(2), 115-163. https://doi.org/10.1207/s15327809jls0302_1

Parnafes, O. (2007). What does “fast” mean? Understanding the physical world through computational representations. *The Journal of the Learning Sciences, 16*(3), 415-450. https://doi.org/10.1080/10508400701413443

Talmy, L. (1988). Force dynamics in language and cognition. *Cognitive Science, 12*, 49-100.

Touger, J. S. (1991). When words fail us. *The Physics Teacher, 29*(2), 90-95. https://doi.org/10.1119/1.2343227

Williams, T. (1999). Semantics in teaching introductory physics. *American Journal of Physics, 67*(8), 670-680. https://doi.org/10.1119/1.19351

Acknowledgements

This work was supported by the National Science Foundation (1842375; 1941524).