Leveraging Rhetoric and Logic in the Classroom to teach Math, Science and Engineering

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Teaching is a form of human communication. As such, understanding to communicate more effectively using rhetoric and logic can be applied to the development of curriculum and to improve teaching technique in the classroom. In math, science and engineering curriculum, the "language" of communication normally includes spoken and written words familiar to the teacher and student, as well as Greek letters, mathematical functions, graphs, and interactive software and hardware that may not be familiar to the student at the beginning of a course. The student must learn the symbols and the concepts they signify within the context of the course and the technical discipline of the wider profession. The literature on *how* we learn what signifiers *mean* is extensive, multidisciplinary, and dates back over thousands of years. This paper introduces a few concepts from that literature and their application to teaching math, science and engineering.

An educator in the math, science and engineering disciplines introduces students to a new language, using unfamiliar symbols, to represent concepts that often do not have a physical form. A parent teaches a child a language using physical examples and speaking the "name" of the object. For example, a dog can be seen, touched, has a wet nose, has a smell, wags a tail and will interact with the child playfully, often licking the child. All of these sensory inputs are associated by the child with the verbal sound "dog" spoken by the parent. Not all dogs are the same and as the child encounters a variety of dogs, the meaning of the verbal sound "dog" grows to encompass these additional experiences. Not all experiences with a dog may be pleasant and the child associates connotation to the spoken word. Similarly, the child later learns to associate the letters, d – o – g, as a written symbol representing those learned experiences and similar in context to the verbal sound, "dog."

In contrast, it is likely that a child will first encounter the verbal sound "cosine" or the written symbol *cos* in the classroom. It is incumbent on the educator to provide the student with an understanding of the meaning, context and possible variations of what *cos* signifies. The function *cos* is a concept that can represent something real but does not possess physical attributes, like a dog. The educator can provide the student with physical manifestations of *cos* with which the student can interact to develop a metaphysical understanding of that term. Depending on which examples the student is provided and how the student learns and remembers the concept, when a successive educator mentions "cosine" or writes *cos* on the board, the student may envision a triangle with angles, a rotating vector on an x-y plot, a sinusoidal line on a graph, the sound of a tone, or all or none of these things. The student that envisions a triangle only does not understand amplitude and frequency in context with *cos*. The student that has learned *cos* in the context of only two dimensions does not understand its use in modeling the propagation of fields in three dimensions. An educator may also find that the symbol *cos* has a pleasant or unpleasant connotation for some students based on past experience. How we reason, communicate, teach and learn is something the Greek philosopher Aristotle examined years ago.

In the fourth century, B.C., Aristotle wrote about logic in the *Organon*, primarily on deduction and to a lesser extent induction. In his treatise, *On Interpretation*, Aristotle describes communication in terms of verbal and written symbols. He makes the important observation that people use different symbols to communicate similar ideas and that a similar, or even identical, symbol may have different meanings based on an individual's background. This is an important observation for the classroom as well. Students come to class with different educational backgrounds. Different teachers have taught them the same concepts using different symbols. For example, a student may learn that *E* represents voltage in a physics course whereas the symbol *V* represents voltage in an electrical engineering course. The symbol *i* can signify an imaginary number in some courses and electrical current in others. As discussed above, *cos* can be used to solve problems in many different contexts and yet the function is the same in each context. An educator has a limited amount of the student's time in class and out of class to develop the understanding required to successfully apply concepts within the context of a single course, much less to develop the relationships and linkages to the application of these concepts in previous or forthcoming courses (Shoop, Nowak, & Shay, 2005). However, knowing that there are these different symbol interpretations, an educator *can* develop course curriculum and lesson plans which account for these differences with linkages to other contexts thereby lessening the confusion a student experiences and increasing a student's understanding of a concept.

Aristotle also wrote *On Rhetoric*. Aristotle introduces many concepts of rhetoric, including the concept of persuasion (Gross & Dascal, 2001). Aristotle discusses two types of argumentation: from example and from enthymeme. Argument by example also has two types: the use of past facts and the invention of new facts. Teaching is a form of argumentation. The argument can be overt as an interactive classroom discussion, or the argument can take place internally by the student during a lecture (Palmer, 1990). The teacher organizes the use of symbols and examples (visual aids, sounds, demonstrations and rhetoric) to persuade the student to cognitively accept a new concept. The teacher intends to have an effect on the student. In speech act theory, the effect the teacher has on the student is called a perlocutionary act (Sitarama & Agogino, 2001). Developing course curriculum and lesson plans with an understanding of rhetoric, and teaching as a perlocutionary act, can also improve the effectiveness of communication between the educator and student.

Another useful model that builds on Aristotle's ideas (Cavarero & Kottman, 2005) is the linguistic study of semiotics (Chandler, 2007). In this sense, the educator uses *signifiers* to develop a student's *signified* of a *referent*. The educator is concerned that the student's signified accurately reflects the referent within the context of the course and any linkages to previous experiences in other courses. Using the examples above, the spoken or written word "dog" is a signifier for the referent, the dog. What the child cognitively manifests when hearing or reading "dog" is the signified. The signified is based on all the referent experiences the child associates with the signifier "dog." These referents can include encounters with many different dogs of different types, pictures of dogs, reading about dogs, videos of dogs, etc. The spoken or written symbol *cos* is also a signifier. What the student cognitively manifests when hearing or reading *cos* is the signified. But what is the referent? What is the physical manifestation of *cos*? How can the student interact with *cos* to develop an accurate signified of the referent? The educator incorporates in the course curriculum examples, metaphors, analogies, visual and audio demonstrations as referents to enable the student to develop an accurate signified of the mathematical signifier (Lakoff & Núñez, 2000):

> In embodied mathematics, mathematical symbols, like 27, π, or $e^{\pi i}$, are meaningful by virtue of the mathematical concepts that they attach to. Those mathematical concepts are given in cognitive terms (e.g., image schemas; imagined geometrical shapes; metaphorical structures, like the number line; and so on), and those cognitive structures will ultimately require a neural account of how the brain creates them on the basis of neural structure and bodily and social experience. To understand a mathematical symbol is to associate it with a concept – something meaningful in human cognition that is ultimately grounded in experience and created via neural mechanisms.

The use of "cognitive terms" to communicate mathematical (and scientific) concepts also appears in the literature concerning abductive reasoning and discovery learning. For example, (Magnani, 2001):

> How does this kind of analogical and/or imagery reasoning function in scientific problem-solving? Nersessian (1984, 1995a and b, 1998, 1999b) has demonstrated that history of science abounds with instances of the use of imagery and of analogy to transform vague notions into scientifically viable conceptualizations of a domain. Her analysis deals with the important case of the use of imagery and analogy by Faraday and Maxwell in the construction of the concept of field….
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> Use of analogy, imagery, and visual/spatial thinking in ordinary and scientific problem-solving is very complex. Nevertheless, we may observe in many cases all the features of a *productive, creative* mapping, where such "transfer of knowledge" is essential to the development of a new concept. Imagery representations appear to function analogically. The value of an imagery representations is that it makes some structural relations immediately evident[7].

The literature on abductive logic and reasoning leads us to think about the use of cognitive referents and signifiers to develop a student's signified that is not limited to a definitive understanding of a concept, but a strategic understanding as well (Paavola, 2004):

> Jaakko Hintikka has emphasized a distinction between two sorts of rules in reasoning and logic (or in games in general): the definitory rules and the strategic rules. Hintikka maintains that for the theory of logic and reasoning, especially at the level of introductory textbooks and courses, the study of excellence of reasoning is often forgotten, and the emphasis is on the avoidance of mistakes in reasoning (e.g., Hintikka, 1999). According to him, students are not taught how to reason well but to maintain their logical virtue (i.e., to avoid logical fallacies and to learn what is and what is not admissible and valid). The focus has been on definitory rules of logic, and strategic rules have largely been

> neglected. The definitory rules tell what are valid rules in particular system of logic. By analogy: the definitory rules of chess tell what one is allowed to do in chess (how chessmen may be moved etc.). But by knowing only the definitory rules of chess one cannot say that one plays chess well. Excellence in chess requires that one master strategic rules extremely well. According to Hintikka, this same idea applies to logic. No one is good in logic and reasoning by knowing only the definitory rules of logic, but by mastering well the strategic rules.
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> Strategies have, however, been a quite neglected topic in philosophy of science. There are some exceptions. In the interrogative approach to inquiry, the meaning of strategies has been emphasized (Hintikka, 1985, 1989; Jung, 1996). But usually the merits of inference are assessed by investigating whether the truth of the premises guarantees or makes probable the truth of the conclusion. And this has also been the basic way of evaluating abduction.

If we accept teaching math, science and engineering as a perlocutionary act where the educator is attempting to persuade the student to conceptualize (the signified) a descriptive or explanatory understanding of the physical world (the referent) using communicative devices (symbols), then we can further examine *how* symbols are used to communicate effectively, measure the accuracy of the student's signified, and the student's ability to apply that cognitive model to solve problems and create new knowledge.

Works Cited

Cavarero, A., & Kottman, P. (2005). *For More Than One Voice: Toward a Philosophy of Vocal Expression.* Stanford: Stanford University Press.

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Magnani, L. (2001). *Abduction, Reason, and Science: Processes of Discovery and Explanation.* New York: Kluwer Academic/Plenum Publishers.

Palmer, P. J. (1990, Jan/Feb). Good Teaching: A Matter of Living the Mystery. *Change 22:1* , pp. 10–16.

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Shoop, B. L., Nowak, G. A., & Shay, L. A. (2005). Deliberate Longitudinal Curricular Integration: Topical Linkages and Concept Reinforcement. *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition.* Portland: American Society for Engineering Education.

Sitarama, S., & Agogino, A. M. (2001). Speech Acts and Peer Learning in Product Development Case-Study Discussions. *Proceedings of the ICEE 2001 Conference* (pp. 7B3-18-23). Oslo: International Conference on Engineering Education.

Annotated readings:

Burch, R. (2007, September 21). *Charles Sanders Peirce*. Retrieved May 13, 2008, from The Stanford Encyclopedia of Philosophy: http://plato.stanford.edu/archives/fall2007/entries/peirce/

This website provides additional information about Pierce and his writings including a description on the differences in logical argument between deduction, induction and abduction. Pierce wrote on a wide range of topics and many more of his ideas could be applied to teaching. There is also an excellent bibliography for additional readings.

Frigg, R., & Hartmann, S. (2008, March 21). *Models in Science*. Retrieved May 13, 2008, from The Stanford Encyclopedia of Philosophy: http://plato.stanford.edu/archives/spr2008/entries/models-science/

This website provides an excellent overview of the philosophical study on the use of models in science. In the section on "Epistemology: Learning with Models," the concept of a model-based "transfer of knowledge" introduced in Magnani and Nersessian is further discussed.

Kuphaldt, T. R. (2003). *Socratic Electronics*. Retrieved May 13, 2008, from Socratic Electronics: http://openbookproject.net/books/socratic/

This website is a book project "intended as a basis for Socratic discussions on the subject of electronics." It is an excellent resource which includes his writings on teaching using the Socratic Method, interviews, syllabi, worksheets, and links to other resources.

Rapp, C. (2002, June 21). *Aristotle's Rhetoric*. Retrieved May 13, 2008, from The Stanford Encyclopedia of Philosophy: http://plato.stanford.edu/archives/sum2002/entries/aristotle-rhetoric/

This website provides additional information on Aristotle's writings on rhetoric and persuasion. This is an excellent introduction to Aristotle's work and its historical relevance. There is also an excellent bibliography for additional readings.

Smith, R. (2007, December 21). *Aristotle's Logic*. Retrieved May 13, 2008, from The Stanford Encyclopedia of Philosophy: http://plato.stanford.edu/archives/win2007/entries/aristotle-logic/

This website provides additional information on Aristotle's writings on logic and syllogism. It is especially useful to try to understand and compare Aristotle's two types of argument, induction and deduction, when reading about Pierce's third type of argument, abduction. There is also an excellent bibliography for additional readings.

Wesch, M. (2007, October 12). *Archive for the 'Vision of Students' Category*. Retrieved May 13, 2008, from Digital Ethnography @ Kansas State University: http://mediatedcultures.net/ksudigg/?cat=9

Professor Wesch is an assistant professor of cultural anthropology and is researching how technology changes have affected information processes and how those changes affect teaching. He has produced two very informative videos, A Vision of Students Today and Information R/evolution, and is developing a third video to address changes to bring the learning environment more "in tune" with the current information environment.