COMPLEMENTARY THEORETICAL PERSPECTIVES ON MULTIMODALITY

Laurie D. Edwards

Saint Mary's College of California

Francesca Ferrara

Ornella Robutti

University of Torino, Italy

The purpose of this paper is to consider several different theoretical perspectives on the notion of multimodality, and to propose a definition that synthesizes those aspects most useful to the analysis of thinking and learning, particularly within mathematics. In addition, an analysis is carried out of multimodality leading to a four-element framework, and the affordances of selective modalities are analyzed.

An increasing number of theorists and researchers in mathematics education have begun investigating multiple physical or semiotic modalities when analyzing mathematical thinking. These modalities include speech and other verbalizations, written inscriptions (including words, symbols and graphics), gesture, other bodily actions/stances, and physical interaction with objects in the world or with virtual "objects" on computer screens. The purpose of this paper is to examine the notion of modality, to consider several theoretical perspectives on the term, and to discuss possible benefits to mathematics education in connecting these perspectives.

MEANINGS FOR MULTIMODALITY

The term "multimodality" has been used in many different fields and analytic contexts, ranging from the study of communication to neurological processes. At base, a modality or mode simply refers to a "way" (for example, a way to transmit or take in information, or to administer a treatment). Below, we present four theoretical perspectives on modalities, and conclude by synthesizing a meaning for the term that may be helpful in analyzing mathematical thinking.

SENSORY MODALITIES

A medical definition states that a modality is: "One of the types of sensation (e.g. vision). The term is usually used to specify the sense (e.g. the visual modality, the touch modality)" (Milodot, 2009). The five primary sensory channels or modalities are: sight, hearing, touch, taste and smell. According to contemporary physiologists, there are four additional sensory modalities beyond the five identified by Aristotle and listed above: kinesthesia (joint sense), vestibular sense (balance as signaled by the inner ear), temperature sense, and pain (the last two are the so-called "somatosensory" modalities). As all nine of these sensory channels are receptive, we will call them "sensory" or "receptive" modalities," to distinguish them from the bodily-based expressive modalities discussed below.

Clearly sensory modalities make up an important element of learning, whether of mathematics or other subjects, for it is only via the senses that a learner has access to either direct experience or culturally transmitted knowledge. In addition to sight and hearing, sensory modalities like vestibular sense can provide the foundation for understanding more abstract mathematical concepts such as "balancing" an equation.

NEURAL MULTIMODALITY

Vittorio Gallese, a neuroscientist, and George Lakoff, a linguist, provide a different theoretical perspective on "multimodality," one tuned for a model of how concepts are created in the brain. This model offers an alternative to the information-processing stance toward cognition, in which it is held that perception, thought, and motor action are three separate brain processes (Barsalou, 2008). In the information processing model, the perceptual system first takes in outside stimuli (via the senses), which are then processed in an "association area" in the cortex. After this "central processing," the cortex subsequently directs action through the premotor and motor cortices. In contrast, Gallese and Lakoff's (2005) interactionist theory is built on recent discoveries that, in addition to action-only or perception-only neurons, there are neuron assemblages in the premotor and parietal areas that do two things at once: respond to sensory input and also initiate or simulate action. One particular neuron of this kind is called a "mirror neuron," described as follows:

> mirror neurons […] discharge when the subject (a monkey in the classical experiments) performs various types of hand actions that are goal-related and also when the subject observes another individual performing similar kinds of actions. (Gallese & Lakoff, 2005, p. 460)

It is this linkage of perception and action that Gallese and Lakoff characterize as "multimodality" at the neuronal level. They also note that the entire sensory-motor system, as well as language itself, is multimodal:

> …circuitry across brain regions links modalities, infusing each with properties of others. The sensory-motor system of the brain is thus "multimodal" rather than modular. Accordingly, language is inherently multimodal in this sense, that is, it uses many modalities linked together—sight, hearing, touch, motor actions, and so on.
>
> Language exploits the pre-existing multimodal character of the sensory-motor system. If this is true, it follows that there is no single "module" for language—and that human language makes use of mechanisms also present in nonhuman primates. (Gallese & Lakoff, 2005, p. 456)

Thus, for Gallese and Lakoff, multimodality consists of either a linkage of perception and action, at the neuronal level, or the interaction of various sensory and action modalities at the level of the brain and body itself. On this basis, they propose a redefinition of the notion of a "concept", quite different from that of classical cognitive science. Within "first generation" cognitive science, concepts are seen as "modality-neutral and symbolic", based on a set of necessary and sufficient conditions (Gallese & Lakoff, 2005, p. 466). Instead, from the perspective of "second generation cognitive science," concepts are embodied: they arise as a consequence of human action or internal simulation of such action. The mechanism for the creation of concepts is through the formation of clusters of functional neurons, within larger structures they call schemas. Unlike the purely internal schemas of Piaget or information processing psychology, according to Gallese and Lakoff:

> Schemas are *interactional*, arising from (1) the nature of our bodies, (2) the nature of our brains, and (3) the nature of our social and physical *interactions* in the world. Schemas are therefore not purely internal, nor are they purely representations of external reality. (Gallese & Lakoff, 2005, p. 466)

The work on neural multimodality offers a biologically grounded basis for the notions of embodied concepts and schemas and, ultimately, for a theory of embodied mathematics.

SEMIOTIC MODALITIES AND MODES

In recent decades, semioticians and other scholars interested in discourse have drawn attention to the fact that communication occurs in ways that go beyond oral speech and written language. Kress (2001b), for example, describes multimodality as "the idea that communication and representation always draw on a multiplicity of semiotic modes of which language may be one" (p. 67-68). Researchers in mathematics education have also fruitfully utilized a semiotic approach to the examination of the multiple means of expression found in mathematical practice, from words to mathematical symbols to various kinds of imagery, including gesture (e.g., Arzarello, & Robutti, 2010; Radford, 2009, 2011). In contrast to the definition offered by Kress, many of these scholars examine the use of multiple modalities not only as resources for communication of ideas, but also as an integral aspect of their production.

Kress's characterization of multimodality comes within a framework that distinguishes the creation of content within a given mode from its dissemination (Kress, 2005):

> I use the term "mode" for the culturally and socially produced resources for representation and "medium" as the term for the culturally produced means for distribution of these representations-as-meanings, that is, as messages. These technologies—those of representation, the modes and those of dissemination, the media—are always both independent of and interdependent with each other. (p. 6-7)

Among the modes discussed by Kress and others (e.g., Bateman, 2009; Norris, 2004) are language, images and sound, although scholars now also consider more complex semiotic modes ranging from music and theater to color, clothing, and furniture layout (e.g., Kress, & Van Leeuwen, 2002).

As indicated above, Kress distinguishes mode from medium, that is, the material means for expression and communication (Kress, 2001a):

> Media are the material resources used in the production of semiotic products and events, including both the tools and the materials used (e.g., the musical instrument and air; the chisel and the block of wood). They usually are specially produced for this purpose, not only in culture (ink, paint, cameras, computers), but also in nature (our vocal apparatus). (p. 22)

From this perspective, the process of communication begins with an idea or concept that is created in some fashion not addressed by Kress. The idea is then expressed by utilizing one or more of several semiotic modes (language, imagery, sound, etc.), which is made concrete via a particular material medium. Although these elements are certainly part of the process of mathematical practice, we would like to propose a more expanded model that integrates other meanings of modality

AN EXPANDED VIEW OF MODALITIES

It is interesting to note that in defining a "mode," Kress considers only "culturally and socially produced resources." Bodily resources are mentioned only as a possible medium, presumably for meanings produced using elsewhere. From the perspective of embodied cognition, bodily resources are vital in the production of meanings, not just in communicating them. A student who painstakingly plots the points of a function for the first time and connects them into a (more or less) smooth curve is not simply expressing concepts that already exist, utilizing the medium of pencil and paper. His or her physical engagement with the graph paper and pencil, and the iterative action of consulting a table of values, and locating and plotting those values, we would argue, is an essential part of the construction of the concept of a graph. Later work with graphs may include another modality, gesture, the specifics of which can reflect how well the student understands this mathematical entity. The body is thus not simply a medium for the communication of meanings, but an important resource in the construction of knowledge. It is also, clearly, a vital element in receiving meanings generated by others, via the sensory modalities.

Thus, we propose a broader definition for modality that encompasses and goes beyond the notion of semiotic mode, and synthesizes the sensory and neurological meanings as well: modalities are the cultural, social and bodily resources available for receiving, creating and expressing meaning. In addition to sensory modalities, which receive information, this category would also include motor modalities, such as gesture, bodily stance, touch and so on – essentially anything that humans can do with their bodies. Motor actions are often instrumental, of course, carried out in order to achieve a purpose other than communication. But they can also be expressive, either intentionally or unconsciously (e.g., “body language”, facial expressions).

The semiotic modes to which Kress refers (language, imagery, etc.) are at a different level of abstraction than these bodily modalities, in that they are not specific in terms of the means of expression. But both bodily modalities and semantic modes play vital roles in the expressive process. In an effort to be as clear as possible about the ways that people express themselves, we have added a final category to this analysis of modalities, namely, the expressive products resulting from the use of the other modalities. These constitute the physical “traces”, whether permanent or ephemeral, of people’s actions, which may take the form of writing, utterances, dance, physical constructions or any other external “output”. These products are sometimes given the label “representations”; however, this term has often been used to imply (as with Kress) the existence of an internal meaning that is simply mapped onto an external representational system; for us, the situation is not so simple. Within an embodied framework, expressive products are not simply representations of internally-generated meaning; rather, they are the externally-apprehensible aspects of a process that is both internal and external, that is indeed an interaction between the actor and the environment.

Thus, we propose a more comprehensive view of modalities, one that distinguishes four aspects or elements, as shown in Table 1:

---

1. Bodily modalities
    - Receptive (sensory channels & modalities)
    - Expressive (motor actions or bodily movement) including:
        - - gesture
        - - gaze
        - - head movement
        - - full body movement
        - - other bodily movement
        - - manipulation of artifacts (see Material media)
2. Semiotic modes
    - Language
    - Sound
    - Imagery
    - Clothing, architecture, dance, color, and any other way in which humans express meanings
3. Material media
    - Bodily based
        - - Voice

- - Hands
- - Body (whole and parts)

- External to body
  - - Paper, blackboard, etc.
  - - Musical instruments
  - - Paint, clay, steel, etc.
  - - Electronic media
  - - Math “manipulatives”, building blocks, etc.
  - - Artifacts and materials of all kinds

4. Expressive products
   - Speech
   - Song/music
   - Sign language
   - Written/displayed text
   - Algebraic symbols
   - Graphs, diagrams, etc.
   - Musical score
   - Photo, painting, drawing, sculpture, etc.
   - Web page, text, etc.
   - A dance or other performance
   - Written dance choreography
   - Graphing programs and other interactive inscriptions
   - A configuration of cubes, rods, etc.

Table 1: A Framework for Multimodality

The analysis of a given episode of communication or meaning-construction may attend to only one or another of these categories, but in general, all would be involved. For example, the expressive product, oral speech, is mediated via the lungs, larynx and mouth, and involves both motor activity of these bodily parts as well as the sensory channel of hearing (because we hear ourselves when we speak). It might also involve a transmitting medium, such as a telephone. On the other hand, a deaf person using American Sign Language would express him or herself using a different medium (the hands, head and body) and a different sensory channel (sight). Thus, signing would be considered a different expressive product from speech. At a higher level of abstraction, both products would be considered language, a semiotic mode involving two specific kinds of symbol systems.

In the realm of mathematics, an analysis utilizing the categories in Table 1 would suggest that “doing geometry” is a very different experience, conceptually, for a learner who is working with pencil and paper versus a dynamic geometry tool instantiated on a computer (indeed, a robust line of research has investigated the nature of students' experiences with computer-based dynamic mathematics systems (e.g., Moreno-Armella, Hegedus, & Kaput, 2008)).

The purpose of distinguishing the various usages of the term "modality" is not simply to label or categorize, but to bring attention to elements of the process of making meaning that may be overlooked. The field of education has moved beyond a simplistic model of teaching as the transmission of information, but is still elaborating the process whereby knowledge is constructed through bodily action, social interaction and iterative reflection involving various kinds of expressive products.

Affordances of modalities

This brings us to the question of what these different modalities make possible; that is, what are their affordances within the mathematical situation (Gibson, 1979). It is assumed that different modalities have developed at least in part because they have different affordances; that is, the characteristics of each modality bring into play different possibilities for action and communication. For example, Kress (2001a) claims that,

> The semiotic modes of writing and of image are distinct in what they permit, that is, in their affordances. Image is founded on the logic of display in space; writing (and speech even more so) is founded on the logic of succession in time. Image is spatial and nonsequential; writing and speech are temporal and sequential. That is a profound difference, and its consequences for representation and communication are now beginning to emerge in this semiotic revolution. (p. 339).

A particularly clear case of the complementary affordances of modalities can be found in looking at oral speech and gesture. McNeill (1992) was one of the first researchers to point out the complementary nature of these modalities, noting that, "Speech and gesture are elements of a single integrated process of utterance formation in which there is a synthesis of opposite modes of thought — global-synthetic and instantaneous imagery with linearly-segmented temporally extended verbalization. Utterances and thoughts realized in them are both imagery and language" (p. 35). He also points out the way in which, "each modality performs its own functions, the two modalities mutually supporting one another" (p 6). Goodwin (2003) stated that speech is not a more "evolved" form of communication than gesture, proposing that:

> … the way in which the structure of gesture differs markedly from language might reflect not the development of a new, more complex system from a simpler one, but instead a process of progressive differentiation within a larger set of interacting systems in which gesture is organized precisely to provide participants with resources that complement, and thus differ significantly from those afforded by language. (p. 23)

	Modality	Characteristics
Speech	• Spoken language	Ephemeral, linear, analytic (composed of meaningful sub-units). Prosody & volume can give emphasis.
Inscriptions (Expressive Products)	• Written text	Permanent, linear, analytic (composed of meaningful sub-units).
	•Written mathematical symbols	Permanent, generally linear, generally synthetic (although some symbols have meaningful sub-units). Compressions of more complex/abstract ideas utilizing metonymy.
	• Static graphs (e.g., Cartesian graphs: Important conventional blend, bringing together geometry and algebra)	Permanent. Global/holistic. Analytic – by convention, the parts are meaningful.
	• Static geometric diagrams	Permanent. Global (or holistic). Analytic. "Iconic" to elements of physical world, but intended to "point to" ideal forms.
	• Static conventional mathematical diagrams (other than graphs and geometric diagrams; e.g., Venn diagrams)	Permanent. Generally global/holistic. Have some characteristics of drawings and some of symbols. Non-arbitrary. Can be synthetic or analytic.
	• Marks drawn to highlight, emphasize or direct attention	Often spontaneous, can be permanent or ephemeral. Global/holistic. Synthetic.
	• Non-mathematical drawings	Permanent. Global. Analytic or synthetic
Interactive Inscriptions	•Computer/calculator-based mathematics systems •Dynamic geometry systems, function graphers, etc.	Same characteristics as the components (mathematical symbols, graphs, etc.). However, the system affords instantaneous feedback and iterative exploration. Interaction via mouse & keyboard.
Motor Actions	• Gestures with empty hands	Ephemeral, global, synthetic
	• Gestures holding artifact (pen, pointer etc.)	Affords more precise boundaries and point locations when gesturing
	•Gesture involving an object in environment (table surface or edge, etc.)	The affordances of the object can be incorporated into the meaning of the gesture
	• Other bodily actions/postures	Ephemeral, global, synthetic. Each with own particular affordances

Table 2 presents a summary of the affordances of modalities typically used in mathematics teaching and learning situations: speech, expressive products that leave a record (i.e., inscriptions) and motor actions.

Table 2: Characteristics and Affordances of Modalities

It should be noted that not all of the modalities discussed above are equally efficient, particularly within with context of doing, learning and teaching mathematics. Mathematics is a discipline that may be rooted in physical experience, but its objects are what Font and his colleagues call "non-ostensive," which literally means that they cannot be pointed to (Font, Godino, & Gallardo, 2012). Mathematical "objects" are socially created through the use of definitions and formal logic; they do not exist in the same way as physical objects do. Thus, the particular modalities used for working with mathematical objects may be better or worse for indicating the mathematical meanings. It might be fine, as a teacher, to gesture through the air to indicate an increasing function, but if your goal is to prove a theorem about such functions, you need to use the written modality and a conventional set of symbols, both to “pin down” your thoughts, and to communicate your argument to others.

DISCUSSION

The purpose of this paper is not to close the discussion of modalities within mathematical thinking, learning, and teaching, but instead to attempt to clarify the various theoretical perspectives on the concept of modality and to propose a broad and encompassing definition. An additional purpose is to open a conversation about the affordances of various modalities used in mathematical practice, as a step toward a more conscious and effective utilization of the many ways available for humans to express themselves.

REFERENCES

Arzarello F., & Robutti O. (2010). Multimodality in multi-representational environments. *ZDM – The International Journal on Mathematics Education*, *42*(7), 715-731.

Barsalou, L. (2008). Cognitive and neural contributions to understanding the conceptual system. *Current Directions In Psychological Science 17*(2), 91-95.

Bateman, J. (2009). Discourse across semiotic modes. In J. Renkema (Ed.), *Discourse, of course: An overview of research in discourse studies*, 55-66. Amsterdam, Netherlands: John Benjamins Publishing.

Font, V., Godino, J. D., & Gallardo, J. (2012). The emergence of objects from mathematical practices. *Educational Studies in Mathematics*. DOI: 10.1007/s10649-012-9411-0.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuroscience, 22*, 455-479.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Goodwin, C. (2003). The body in action. In J. Coupland & R. Gwyn (Eds.), *Discourse, the body, and identity*, 19-42. New York, NY: Palgrave/Macmillan.

Kress, G. (2001a) *Multimodal discourse: The modes and media of contemporary communication*. London: Arnold Publishers.

Kress, G. (2001b). Sociolinguistics and social semiotics. In P. Copely (Ed.), *The Routledge companion to semiotics and linguistics*, 66-82. London: Routledge.

Kress, G. (2005). Gains and losses: New forms of texts, knowledge, and learning. *Computers and Composition, 22*, 5-22.

Kress, G., & Van Leeuwen, T. (2002). Colour as a semiotic mode: Notes for a grammar of colour. *Visual Communication, 1*(3), 343-368.

Millodot, M. (2009). Dictionary of optometry and visual science (7th edition). London, UK: Butterworth-Heinemann.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought.* Chicago: Chicago University Press.

McNeill, D. (2005). *Gesture and thought.* Chicago: Chicago University Press.

Moreno-Armella, L., Hegedus, S., & Kaput, J. (2008). From static to dynamic mathematics: Historical and representational perspectives. *Educational Studies in Mathematics, 68*(2), 99-111.

Norris, S. (2004). *Analyzing multimodal interaction: A methodological framework.* New York: Routledge.

Radford, L. (2009). Why do gestures matter? Sensuous cognition and the palpability of mathematical meanings. *Educational Studies in Mathematics*, *70*(3), 111-126.

Radford, L. (2011). Embodiment, perception and symbols in the development of early algebraic thinking. In Ubuz, B. (Ed.), *Proceedings of the 35th Conference of the International Group for the Psychology of Mathematics Education*, 4, 17-24). Ankara, Turkey: PME.