

ANCESTRAL GENRES OF MATHEMATICAL GRAPHS

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Graphs are presented in school mathematics as neutral, objective mappings of the plane. There is no sense in which such graphs are meant to be loaded with cultural stories, bodily associations, cosmology or mythology. I contend, however, that Cartesian graphs are freighted, unintentionally, with just such associations – cultural, bodily and cosmological resonances – and that these associations accrue via the *ancestral genres* of graphing. Miller writes that “ancestral genres help define the potentialities of the genre” (Miller & Shepherd, 2004, p. 10). I argue that, without an understanding of these potentialities, we ignore students’ uptake of the genre, whether this uptake is provoked intentionally or unintentionally.

The literal meaning of the term *genre* is a “type” or “sort” of something. At its most basic, a genre is a culturally recognizable type of thing or category, whether from high culture or popular culture. Cowboy movies, ghost stories, piano concerti, TV sitcoms and mathematical word problems are all examples of genres within the fields of film, oral literature, classical music, television shows and mathematics education respectively. But although a genre may be a category, it is a generative, self-referencing, dialogical, resonant one, constantly in a state of change and development. For this reason, a particular genre cannot be defined in any effective way, since it is a “moving target”, always in a state of change, and often productive of new sub-genres and cross-genres (for example, the “space cowboy movie”). Genre analysis, the theoretical and methodological basis for this essay, offers an interdisciplinary way to make sense of diverse cultural forms, including novels, films, folktales, musical forms, modes of workplace talk and writing and the commonplace forms of schooling [1].

I will not focus on the question of whether Cartesian graphs themselves constitute a genre. Instead I will trace some of the ancestral genres related to graphs through historical or generic echoes (Jamieson, 1975). Although my discussion is ontological (“what *are* graphs, and what meanings and forms do they invoke?”), suggestions for practice do arise from my discussion. By acknowledging the unavoidable entanglement of body, emotion and culture in the human invention that is the Cartesian graph, I challenge the disembodied, Platonic view of mathematics in general and thus of graphs in particular. A close consideration of Cartesian graphs shows that it is not possible to completely erase traces of the body, even if we wished to do so. The dream of a wholly abstract, idealized, disembodied mathematics is simply not achievable; mathematics is a system of human interpretation of the world and has human qualities inextricably woven into its very nature.

A graphs and gestures project

My interest in the ancestry of graphs stems from a research project on graphs and gestures in secondary school mathematics classrooms. In this project, students in the early years of secondary school work with a mathematics educator and a choreographer using gesture, movement and sound to focus attention on mathematically salient features of the graphs of functions (roots, extrema, symmetries, asymptotes, etc.).

Gestures are necessarily made with reference to our bodies and an early result from the project showed that different students placed the x -axis differently in relation to their own bodies. The positioning of the x -axis against the body and the distinction between *being the graph* and *seeing the graph* in elicited gestures turned out to be key factors in diagnosing a student’s level of mathematical understanding. Quite consistently, those students who placed the x -axis low with reference to their bodies, who kept the gestured graph “within reach,” and who described themselves as “being (in) the graph”, were the ones who had been rated by their teachers as showing in-depth understanding of mathematics. In contrast, students who placed the x -axis high (at throat or nose level), who kept the gestured graph “within sight” at arms’ length, and who used eye tracking to “see the graph” as if it were being drawn in the air, had been rated by their teachers as “average” students who relied more on memorization than a deep understanding of mathematics (Gerofsky, in press).

Videotaped interviews with students from the first years of this project led to a consideration of the ancestry of graphing. For example, when one student was asked why she had placed the x -axis at heart level, she quickly responded, “Because that’s the centre of *me!*” Responses from other students were similar. The idea that the *origin* might be identified with “the centre of me” raised intriguing questions about connections between students’ identification with the origin point when gesturing the shape of a graph, mythological traditions in a number of cultures about a centre or navel of the world (the *omphalos*), and more general questions about other cultural and embodied resonances with Cartesian graphs.

Graphs and embodied spatial cognition

The orthogonal axes of Cartesian graphs divide the plane into four quadrants, distinguished in terms of up and down, right and left. By convention, “up” and “right” are associated with positive numbers, and “down” and “left” are associated with negative numbers. Of course, the naming

of positive and negative numbers is supposed to have no cultural value attached, nor is the association of up/down or right/left with positive and negative numbers supposed to be anything but an arbitrary assignment. In principal, mathematicians *could* have named the numbers greater than zero “negative numbers”; such numbers *could* have been placed in descending array to the left of and below the origin. This has never been the case though. I argue that the association of “up” and “right” with “positive” (and with the extended meanings of positive: good, affirming, indicating a profit, *etc.*), and the association of “down” and “left” with “negative” (and its associated meanings: bad, nay-saying, indicating a loss, *etc.*) are not at all arbitrary, but are deeply influenced by embodied and culturally-mediated human ways of knowing the world. In other words, the layout of the Cartesian plane is both influenced by and, through its proper cultural influence, a reification of shared embodied experiences and Western cultural traditions that associate “up” and “right” with positive qualities and “down” and “left” with negative ones. There is a great deal of evidence from cognitive science and research into embodied epistemology that elaborates on the origins of these associations. I will draw on work on embodied metaphors, spatial cognition and orthogonality to show that the layout of the Cartesian graph is not arbitrary, but rather a mapping of a certain bodily, cultural experience of the world onto this mathematical plane of representation.

Graphs in the Cartesian plane have their bases in fundamental human metaphors of up and down, horizontality and verticality that come from embodied experiences of the world. Lakoff and Johnson (1980, pp. 14-21) explore some of the basic orientational metaphors around experiences of “up” and “down” (embodied metaphors are listed in small caps following established convention): MORE IS UP; LESS IS DOWN – HAPPY IS UP; SAD IS DOWN – GOOD IS UP; BAD IS DOWN – VIRTUE IS UP; DEPRAVITY IS DOWN – HEALTH AND LIFE ARE UP; SICKNESS AND DEATH ARE DOWN – HAVING CONTROL OR FORCE IS UP; BEING SUBJECT TO CONTROL OR FORCE IS DOWN – ‘HIGH’ STATUS IS UP; ‘LOW’ STATUS IS DOWN – CONSCIOUS IS UP; UNCONSCIOUS IS DOWN – RATIONAL IS UP; EMOTIONAL IS DOWN. The familiar placement of positive numbers in the upper and right-hand quadrants of graphs and negative numbers in lower and left-hand quadrants also reifies the cultural metaphor that UP AND TO THE RIGHT IS POSITIVE; DOWN AND TO THE LEFT IS NEGATIVE.

Tolaas (1991) hypothesizes common experiences of infancy and early childhood that may account for metaphors like the ones cited by Lakoff and Johnson. For infants in the first few months of life who cannot yet sit or stand and who are dependent upon caregivers who will pick them up and keep them safe, LIGHT IS UP (whether the light from a window, the sun, or a lamp), WELL-BEING AND HAPPINESS ARE UP (based on adult caregivers lifting the infant up to be held and fed), BIG IS UP (and important), POWER AND CONTROL ARE UP – VIRTUE AND IDEALS ARE UP (since caregivers and role models are up) and UP IS ERECT – STANDING IS FIRMNESS, SUPPORT AND COURAGE; A FALL IS FAILURE.

Our bipedal, standing bodies have three axes, defining three orthogonal dimensions: a left-right axis of bilateral symmetry, an up-down axis bounded by head and feet (and

centred at the waist), and a front-back axis formed by our ventral and dorsal sides. Graphs on Cartesian coordinates use these three bodily axes respectively as the archetype to create a graphic grid with *x*-, *y*- and *z*-axes

Our perceived bodily axes are profoundly asymmetric and non-equipotential (Tversky, 1998) and so by extension are the axes of a Cartesian graph. Within the body itself, our vertical head-foot axis is asymmetric. It is important to note that the upper part of our bodies includes the head (with brain, eyes, nose, mouth and ears), the throat, arms and hands, and the heart – all frequently associated with the “higher” functions like thinking, talking, seeing and hearing, reading, making things, and having courage and deep emotion (in the traditional or folk interpretation of “heart”). The lower part of the body, in contrast, includes body parts whose functions have often been considered “low”, “base” or “dirty”: sexual organs, intestinal system, bladder, and feet.

The axis that defines the front and back of the body is similarly asymmetric, with the front of the body the known and favoured side, since our faces, eyes, nose and mouth, throat, and vulnerable vital organs are located in front. (Note that in quadrupeds this corresponds to the vulnerable underside of the body, protected by the relatively invulnerable back.) Most people are either right- or left-handed and a preference for left or right manifests in terms of feet, eyes, ears, even sides of the mouth. So all three axes of the body are perceptually and functionally asymmetrical, with strong cultural biases towards up or down, front or back, left or right built into them from childhood.

The fact that numbers on a graph become increasingly positive as the graph moves “upward” and “rightward” is certainly not arbitrary, then, but is conditioned by bodily and cultural experiences that give greater positive value to “up” than “down” and to “high” versus “low” (and the higher, the better) and to “right” versus “left”

Straightness and squareness

A striking feature of Cartesian graphs (and to many aspects of modern buildings and cities for that matter) is a preference for straight lines and square corners as markers of what is “best” within modern scientific cultures, although this preference may owe more to a linear, visual bias within modernism than to primal experiences of the body (Davis, Sumara & Luce-Kapler, 2008). In a discussion of the “normal” in education (normal curves, normal schools, normal development...), Davis *et al.* identify “a whole family of terms rooted in Euclidean geometry” (p. 38) that link straightness and orthogonality with morality, truth and efficiency. For example, they contrast the following positively-valued terms whose etymological roots mean “straight” or “square”:

correct, just, rectified, regular, right, righteous, straightforward, true, upright

... with negative terms derived from images of non-straight, non-square forms like:

bent, deviating, skewed, twisted, warped

The square, linear grid of the Cartesian plane enacts an aesthetic of rectilinear straightness, evenness and normalcy that favours preferences of the Enlightenment project, but that,

in doing so, ignores the intrinsic asymmetricality and non-equipotentiality of our bodily experiences of the world.

Grids, graphs and maps: the historical shift from sacred hot spots to evenness and neutrality

The cultural ancestors of present-day Cartesian graphs and grids did not always pretend to the even, neutral interpretation of space espoused by modern mathematics and modernity in general. Mathematically, all points on a Cartesian graph are equally identifiable (by ordered pairs or triples) and equally valued. There are no points that are generally accorded special status or power; every location on the graph has the same value as every other location, although the origin perhaps carries a trace of particularity by its very naming

When orthogonal grids were laid over representations of the world, from Renaissance Mercator maps to grid patterns of city streets to present-day GPS grids, the same ethos was extended to the actual world. Every point was assigned unique coordinates and could be named, invoked and matched to a pair of numbers. In principle then, every location was given equal weight and significance as part of the grid, even though we know from experience that, say, a point on the edge of a cliff in Antarctica is qualitatively very different from a point in the middle of a city street. Grids and grid-based maps are used as levelers and equalizers. We gain the illusion of control over the world through the ability to name and pinpoint any location by its grid coordinates, whether or not we actually have any knowledge of and connection with the actual place

Research on the history of graphs and grids shows that this sense of their evenness and equipotentiality is a relatively new development in Western cultures. In pre-Renaissance Europe, representations of orthogonal axes (particularly the Christian religious symbol of the cross) indicated spiritual hot spots of heightened power and significance. In a similar way, maps of the world and the plans of cities in medieval Europe centred on hot spots held to

have great power. I will trace some of the difference in pre- and post-Renaissance Europe and the shift from a “hot spot” system of representation to one that emphasized the interchangeability and equal value of all locations. These differences also coincide with a shift from the hierarchical to the democratic, from the spiritual to the secular, from a more embodied, emotional and devotional approach to the world to a more abstract, mentalist and rational one.

In the world of late medieval Europe, the material world was seen as imbued with the power of the spiritual. Particular points on a grid, at the intersection of two axes, had the power to symbolize the “focusing potential of the coordinate” (Williamson, 1986, p. 15) as the point of contact or translation between the material and the spiritual worlds. Williamson (1986) writes that the medieval grid had symbolic status as:

a set of vertical relations between the superphysical above and material reality below, which were divinely generated by means of point coordinates conceived as “thresholds.” (Williamson, 1986, p. 15)

The prototypical model for the medieval grid was the potent symbol of the cross. In its Christian symbolism:

The horizontal and vertical beams are seen to represent - as is Christ himself - the conjunction of heaven and earth [.] It is the point of heavenly and earthly conjunction that is of fundamental importance here (*i.e.*, of God becoming flesh) [..] The combined emphasis on coordinate and intersection was thus indissolubly linked in the symbolism of the point-based grid of the later Middle Ages (Williamson, 1986, p. 18)

This religious hermeneutic interpretation of orthogonal axes, points and grids draws on the human spatial and linguistic metaphors (UP IS GOOD, *etc.*) discussed above, as well as on existing pre-Christian religio-mythical formulations like the world tree and world pillar (which I discuss below), in order to embody a world view in the form of a pair of axes, focal points of great potential power, and grids.

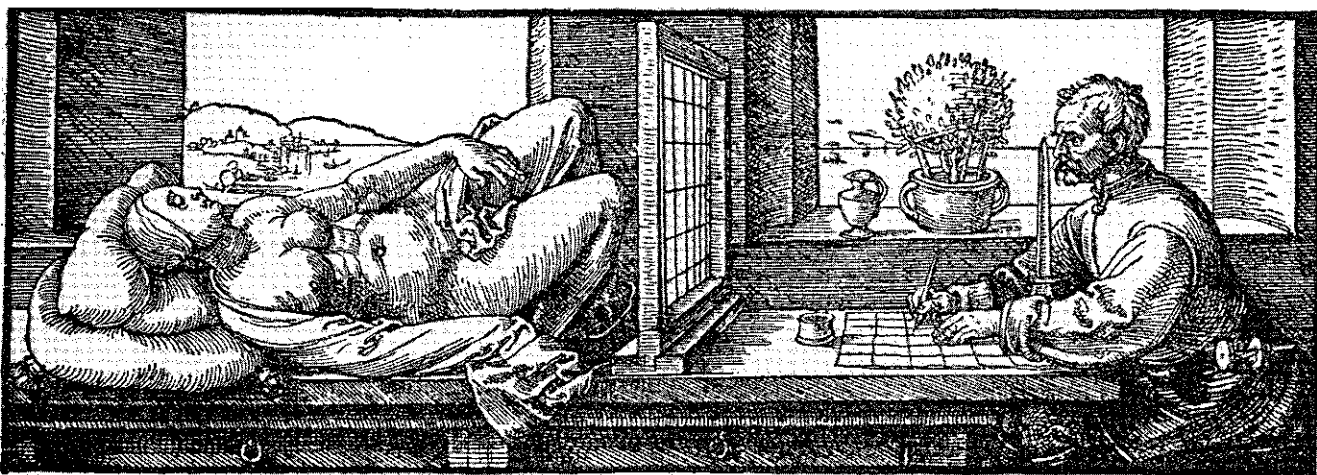


Figure 1 Duerer, Albrecht (1471-1528) Artist drawing a model in foreshortening through a frame using a grid system Woodcut from “Unterweysung der Messung” (Treatise on Perspective) (Nuremberg, 1527). The Metropolitan Museum of Art, New York. Photo Credit: Foto Marburg / Art Resource, NY.

In the shift from the sacred medieval to the (more) secular Renaissance world view, the grid shifted from one based on “value-loaded coordinates and intersections to one conceived of as a field comprised of points and axes possessing either neutral or numerical (quantitative) value” which focused on “horizontal relations occurring on a physical plane”, rather than on the relationship and interpenetration of the spiritual and physical realms (Williamson, 1986, p. 18). This physical, horizontal grid, which was now thought of as extending continuously to the horizon, was intimately connected with the expansionist, colonialist program initiated in 15th century Renaissance Europe.

Mercator’s invention of the navigational grid of coordinates of latitude and longitude predated Descartes’ coordinate axes by a century, as did the use of grids to produce mathematical perspectives in art (see Figure 1). Mercator’s maps and globes also contrasted strongly with medieval maps, in which the spiritual as well as the physical world was depicted. These maps would locate Jerusalem as the centre and highest point, with other locations measured in value by their proximity to it. Jerusalem was taken to be the umbilical connection point between heaven and earth, the omphalos, the point where earthly and celestial axes meet (see Figure 2).

The Cartesian grid takes the Renaissance conception of the neutral, extensive grid one step further towards abstraction. The Cartesian graph represents the structure behind physical reality and the process of rational thought itself. Graphs on the Cartesian plane give visual presence to the power of abstract, disembodied mathematics, a notion we have inherited as part of Enlightenment and modernist thought.

Historically, this abstract graph was eventually applied to the landscape itself - in French formal gardens, national borders and roads, electrical transmission lines, and the design of modern cities. Davis (1981) documents the trend during the Reformation era to erase the sacred “hot spots” of the medieval Catholic city (shrines on sacred hills, grottoes, reliquaries) in favour of the even, rational grid of Protestantism, and to erase the “complex, bunched and irregular” (Davis, 1981, p. 60) medieval Catholic concept of ceremonial time and its rhythms with the “simple, even and uniform” (*ibid*) temporal grid associated with the Reformed church.

The enforced “neutrality” and non-specificity attributed to the Cartesian coordinate system takes on ideological status when a square grid is applied to both the immaterial world of abstract thought and time and the material world of cities and landscapes (see Figure 3), visual art and music (through the innovation of even-tempered and well-tempered scales).

Graphs and the axis mundi

Cognitive science makes the connections between everyday cultural and linguistic metaphors and their sources in embodied experience. The anthropology of religion includes work on the ways that cultures have extended those metaphors and experiences to cosmologies that echo bodily experiences of the world. Many of these cosmologies have been represented symbolically with graphics that are very similar in form to the axes of Cartesian graphs. The resonances of these cosmologies, like the resonances of the Christian cross, are antecedent genres of Cartesian graphs.

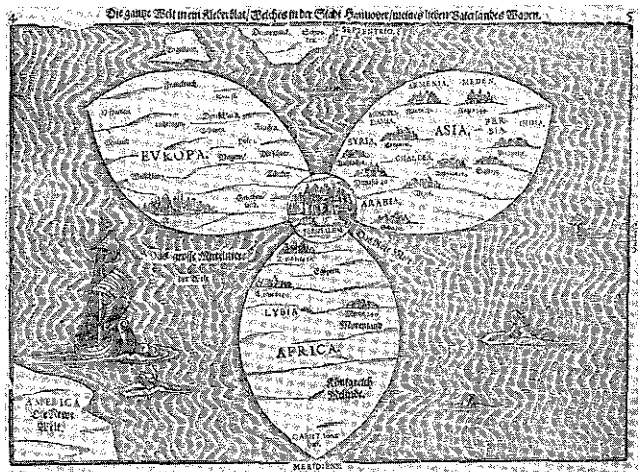


Figure 2 Bunting, Heinrich (1545-1606) *Die gantze Welt in ein Kleberblatt* Woodcut from “*Itinerarium Sacrae Scripturae*” (Magdeburg, 1581), showing Jerusalem as the centre of the world. Courtesy of the Osher Map Library, University of Southern Maine

In many cultures, the world we live in is conceptualized as a middle place, located halfway between the heavens and a subterranean underworld. For example, in the traditional pre-Christian Nordic cultures, our world was called Midgard (“Middle Earth”) and it was conceived of as situated between the heavenly realm of the gods and heroes above and the land of the dead below. Joining these three planes of existence was the Nordic world tree, called Yggdrasil, supporting Middle Earth on its trunk, whose top branches reached up to the heavens and roots reached into the depths of the underworld (see Figure 4).

There is a clear relationship between this conception of the world tree and the embodied metaphors cited earlier: VIRTUE IS UP; DEPRAVITY IS DOWN – HEALTH AND LIFE ARE UP; SICKNESS AND DEATH ARE DOWN – HAVING CONTROL OR FORCE IS UP; BEING SUBJECT TO CONTROL OR FORCE IS DOWN – ‘HIGH’ STATUS IS UP; ‘LOW’ STATUS IS DOWN. These metaphors can be extended to cosmological metaphors like THE GODS ARE UP; DEMONS ARE DOWN – ETERNAL LIGHT IS UP; ETERNAL DARKNESS IS DOWN – COSMIC POWER AND GOODNESS ARE UP; COSMIC SUBJUGATION AND EVIL ARE DOWN. Taken in conjunction with the



Figure 3. City built on a grid pattern.

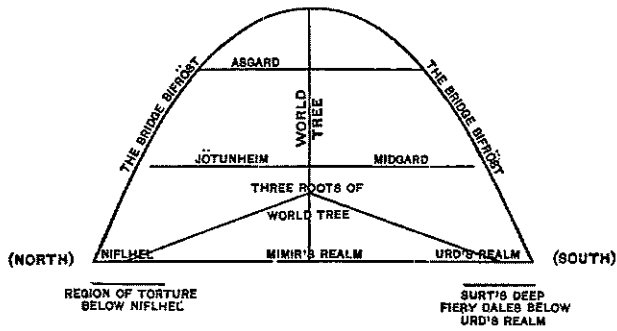


Figure 4. Schematic of Nordic cosmological geography (Litchfield, 1897, p 2).

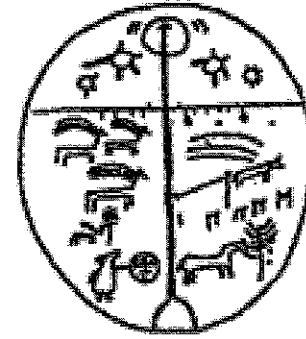


Figure 5 Cosmological illustration from Siberian shamanic drum (Mallery, 1888/9, p 515)

observation that the upper and middle parts of the human body are seen as clean, vital and valued while the lower parts of the body are often treated as dirty, base and coarse, the cosmologies of a heaven, hell and middle earth joined by a vertical world tree can be viewed as an extended metaphor for our own vertical bodies, joining upper, lower and middle realms with a sturdy vertical “trunk” (see Figure 5)

The imagery of a world tree is not unique to Nordic mythology, but occurs very widely in tribal cultures around the world. [2] Eliade (1953) named the concept of a vertical structure that linked Earth, heaven and the underworld the “Axis Mundi” or “axis of the world” According to Eliade, the Axis Mundi could take several forms: a tree, a mountain, a vine, a ladder, or even an ascending column of smoke, but in every case it served the function of linking worlds.

In some cases the Axis Mundi was also associated with the “omphalos”, or “navel of the world”, clearly reflecting a relationship to the human body. The omphalos was a sacred place at the centre of the world, where the three worlds of above, middle and below could communicate [3] The Greek Oracle at Delphi was located in a cave that was considered the omphalos in that culture, and many other cultures have had a specified secret, hidden place that is designated to be the powerful centre point of the world. The sense of a powerful,

sacred point that forms a threshold for transformation between celestial and earthly powers recalls the earlier discussion of the Christian symbolism of the cross, whose intersection point is interpreted as a similar “point of power”

What may not be immediately evident is the resonance between the omphalos and the (potently named) origin at point (0, 0) on the Cartesian graph, as well as the resonance between the vertical Axis Mundi and the vertical y-axis on the graph (spanning the “positive” upper quadrants and the “negative” lower quadrants), and between the horizon line and the horizontal x-axis. I have found no documentation related to the naming of the origin, and it is clear that Descartes’ and subsequent mathematicians’ intention in creating algebraic geometry on orthogonal axes was secular, neutral and abstractly mathematical. Still, it is hard to deny that cosmologic meanings still “stick to” this genre, carried by its ancestry and by the necessities of human physical existence and imagination.

Table 1 shows a schema of the equivalences between the body, the cosmos as documented by anthropologists, an anthropomorphic image of the house common to many cultures (particularly Western ones), and my conjectures about the equivalences carried by the genre of mathematical Cartesian graphs

Body	House	Cosmos	Graphs
Vertical axis/ trunk of the body	House pillar/ tent pole	Axis Mundi (World Tree, World Pillar, Sacred Mountain, Sacred Vine, sacred smoke of burnt offerings)	Vertical y-axis
Top of the head	Roof	Heavens, realm of the gods	Positive y-values (but without a “ceiling” or “roof” representing maximum values)
Middle of body (navel or heart)	Hearth, fire pit, warm centre of the house	The omphalos, “navel” or centre of the world	The origin at (0, 0)
Outstretched arms or an imagined horizontal line at heart or navel level	The ground or floor of the habitable house	Middle earth, the realm of humans, located between the extremes of heaven and hell or ice and fire. The level of the earth/ the horizon line	Horizontal x- axis (the “roots” of a function occur where the graph of the function intersects the “ground” of this horizontal axis)
Lower, “unclean” part of the body; “below the belt”	Cellar, underground pits and caverns.	The underworld - the realm of the dead, the realm of demonic beings	Negative y-values (but without a “floor” representing minimum values)

Table 1. Cultural equivalences: body, house, cosmos, graphs.

A parallel set of analogies could be drawn relating the form of cities and towns, temples, churches and other sacred spaces from many cultures with the form of the human body. [4]

Discussion

The story we have told students for so long about the detached, idealized objectivity of mathematics may no longer have the ring of truth. We would do well to acknowledge mathematics as a human activity and mode of thought, intimately bound up with the physical world and human cultures. Making cross-disciplinary connections between mathematics and other areas of culture – for example, cognitive sciences, art history and anthropology – can help learners to make sense of mathematical conventions and genres in terms of general cultural trends and genealogies.

Graphs and grids *have* cultural and bodily associations, even if we as mathematicians might wish them to be neutral and wholly abstract. Students (as novices) will “read” these cultural bodily implications and associations from graphs, although this reading may be an unintended consequence.

Graphing starts from our sense of our bodies in space and in our cultural spaces. Being removed from our bodies (and thus objective and detached) is never fully possible. Graphs always contain traces of the body – in the origin, in a graph’s up/down and left/right orientations. We cannot erase the self and the human body from this genre; there is always a kernel of the embodied self that lurks within the supposedly neutral, objective graph.

Linking abstract and embodied understanding can help learners make personal connections with the mathematics, which might otherwise seem cold, distant and alienating. Part of what makes mathematics difficult for some learners is that there seems to be nowhere to “insert” the self, no way to “be the graph”. Acknowledgement of the inherent human qualities at the basis of graphing is one way to mitigate this apparent absence. Knowledge and acknowledgement of cultural/bodily associations embedded in graphs as a genre would allow teachers and students to learn to understand mathematics in its human context, and to make conscious the connections with human history and the emotional and spiritual meanings that are already tacitly present in graphs.

Rather than treating mathematics as an ethereal, Platonic realm of perfect forms which owes nothing to the embodied world, we may begin to work with mathematics as an embodied form of knowing – for example, through the treatment of mathematics as performance, and through kinesthetic, aesthetic and multisensory pedagogies. These approaches may play out in active, performative, multimodal approaches to teaching and learning.

A refusal to acknowledge the cultural loadedness of graphs and an insistence that graphs divide space without bias in an even, neutral way leads to an impoverished understanding of the genre and of human connections in mathematics, and an impoverished pedagogy as well. It is important for mathematics educators to see that, in working with graphing, we are not dealing with an objective neutrality, but with a human interpretation of the universe.

Notes

1 Genre theorists, including rhetoricians, literary and film critics, lin-

guists and others, have written extensively on the addressivity and chronotopes of genres (Bakhtin, 1986), their self-referential nature (Grant, 2003), and the functions of genres in discourse and social life (Swales, 1990; Campbell & Jamieson, 1978). A number of authors have used genre as a unit of analysis in mathematics education (for example, Morgan, 1998; Nardi & Iannone, 2005).

2 Note though that this is not by any means a universal cultural orientation of the world; for example, Clastres documents a Tupi-Guarani conception of the land of an afterlife existing in a horizontal rather than vertical relationship to the land of the living (Clastres, 1995).

3 Compare this to the navel on the human body, a central place where the fetus is joined to, and receives nourishment through, the umbilical cord from its mother’s body.

4 See, for example, Geertz (1984), Hultkrantz (1996) or Valins (2000).

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