A conversation on embodiment at the heart of abstraction *in mathematics education and music education*

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Introduction

This paper is, in some ways, a rant against the Platonism that inheres in much of mathematics and math education, despite the best efforts of many math educators, and in some areas of music and conservatory music education.

Davis and Hersch (1981), in their book *The Mathematical Experience*, interviewed dozens of research mathematicians and found that "the typical working mathematician is a Platonist on weekdays and a formalist on Sundays. That is, when he [sic] is doing mathematics, he is convinced that he is dealing with an objective reality whose properties he is attempting to determine. But then, when challenged to give a philosophical account of this reality, he finds it easiest to pretend that he does not believe in it after all" (p. 321).

The objects of the Platonist's objective reality are mathematical concepts that have been reified or objectified by those most familiar with them, and then treated as if they belonged to Plato's Forms, along with perfect circles, infinitely long lines that have no width, infinite numeric sequences, and so on. The Forms are taken as immaterial truths, existing prior to and above the world of physical mortal existence on a removed metaphysical plane. We reject this view of mathematical objects as transcendent, perfect, distant, and eternal.

In a similar way, patterns and "rules" of musical composition within the Western art tradition have also been treated as Platonic Forms, perfect, distant, and eternal, and existing eternally on a removed plane of being. Our ongoing conversation, from the two disciplines of music education and mathematics education and from differing theoretical groundings, has been an exploration of embodied and abstract knowing across disciplines.

We conceptualize embodied experience in a central place, at the heart of knowing, with the extended meanings of "heart" evoking emotional engagement, the core

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of existence, a pulsing basic rhythm of life. We theorize a resonance, a shuttling, back-and-forth movement, weaving bodily, sensory experience with the awareness and expression of patterns that emerge from that experience. We posit abstraction as the expression of pattern and the play amongst various representations of pattern, producing second-order patterns of patterns, but always returning back in touch with the embodied experiences which are their source. The movement (or oscillation, or resonance, or vibration) between lived experience and abstract pattern-noticing gives life to both.

Frank Smith, the highly regarded researcher in literacy and language education has recently turned his attention to the relationship between mathematics and language. In his 2002 book, *The Glass Wall: Why Mathematics Can Seem Difficult*, his thesis succinctly states an unsettling truism. Smith writes:

> The physical world is our familiar world of objects and events, directly accessible to our eyes, ears, and other senses […] The world of mathematics doesn't arise from the physical world (I argue)—except to the extent that it has roots in the human brain, and it can't be made part of the physical world […] The glass wall is a barrier that separates the physical world and its natural language from the world of mathematics […] Our physical environment and mathematics are worlds apart […] Music is yet another kind of world. It has its own landscapes to be explored, its own grammar and vocabulary, and it can't be translated into natural language—or into mathematics for that matter…. (Smith, 2002, pp. 1–2)

We disagree strongly with this assertion. Why would Smith (and many others) want to place mathematics and music in glass boxes, or on a separate, superior plane?

SUSAN:

As a starting point in addressing this large issue of worldview, consider Northrop Frye's idea of sky father versus earth mother religions, elaborated in his book *Creation and Recreation* (1980). Frye, an influential Canadian literary critic, divided cultures into either sky father or earth mother religions. Sky father religions look up and see the heavens with stars that appear to be fixed and unchanging in their patterns. The stars rise and set in different places throughout the year, but each year, they repeat the same patterns. The stars are distant and appear to be cold, crystalline, perfect, unaffected by birth and death and earthly contingencies. Of course we now know that the stars are big burning balls of gas that have their own life cycles, and they are not really fixed; but up to the time of Galileo at least, this is how the heavens were viewed. So cultures that by preference look up to view a kind of perfection, distant, cold, crystalline, and unchanging, not subject to the contingencies of our messy lives on earth, develop a sky father religion.

Cultures that develop an earth mother religion look down and see the ground with plants growing and dying and growing again. Things are composted, rot, and re-grow; new life comes out of old and trees grow out of nurse trees. It's messy, earthy, and cyclical, though it's not the same all the time. Frye contrasts the "cycle of the same" with the "cycle of the different." Sky father religions deal with the cycle of the same—the heavens appear to be unchanging. Earth mother religions deal with the cycle of the different. Every year different plants grow, but they're

very much like last year's plants. New baby animals are born, and the cycle keeps going. Earth mother religions are usually goddess religions, and of course many religions combine gods and goddesses.

The desire for an appropriation of Platonic abstraction and Platonic Forms is a sky father religion. In many ways its focus is on the desire for immortality and a shunning of the earthly world of birth and death, dirt and rot, and growth and flowering, all those living cycles of the different that are moist, warm, and organic. The world of Platonic Forms is cold, distant, clear, and crystalline, and it fits the cold, objective clarity of deductive logic and rationalism. Even in areas like mathematics and music, the notion of Platonic abstraction is forced; it's hard to find an absolute perfection in any human endeavour. There is always some slippage, some messiness and human error, and the materials used in these enterprises demand attention to their own physicality and imperfections. A Platonic view of math and music strives to ignore the presence of the human and physical; an embrace of embodied knowing says "yes" to physical lived experience.

These attitudes are played out in classrooms and in curriculum as a whole. For example when designing a mathematics curriculum, should learners simply be given mathematical facts and proofs as a finished, closed, completely perfected system? Is there room for learners to play or to contribute, or are they merely spectators in a display of elegant and inaccessible Forms? Who should be doing mathematics? Are we just looking for "the best," or is it for everyone? Are we only trying to prepare elite future physicists and mathematicians, or is there something else that we are trying to achieve?

In a music classroom, should students be spending their time only on learning techniques appropriate for realizing existing compositions in traditional musical forms (like sonata allegro and rondo form)? Who should be doing music—just the technically virtuosic, or those seen as theoretically and compositionally gifted?

There is a danger that we continue to be dazzled by our own inventions, to the point where we consider certain human-made cultural products to have a semi-divine, *a priori* existence on a separate metaphysical plane. I think that once we have invented a symbol system, for example the symbol system of algebra, or musical notation, or even the alphabet, there's a tendency to be mesmerized by it, and to worship the abstract system as the thing itself. The abstract symbolic system becomes reified as an object and is treated as a Platonic Form. For example, spelling and written language is treated as if it were prior to speech, musical notation is treated as if it were prior to the sounds and practices of music, and algebra is treated as if were prior and superior to the noticing of pattern in embodied modes.

SCOTT:

In the semiotics of C. S. Peirce, anything that is registered in consciousness is "cognized" as one of three general types of signs: icon, index, or symbol. An *icon*, which will be my focus here, is a sign that refers to the Object it denotes merely by shared quality. Some examples of icons include maps (which visually, qualitatively denote the terrain they represent); onomatopoeia (i.e., words that sound much like the sounds they are intended to denote, such as "bang" or "sniffle"); or the little trash

can shape in the corner of your computer screen (which is qualitatively rather like the one under your desk or outside your door). One way of describing an aspect of what musicians in many cultural traditions do is to say that they audibly signify embodied experiences (such as sounds or gestures) *iconically* (that is, using qualitative aural signs) in the music they make.

To choose at random an example from the history of Western music, Johann Sebastian Bach often signified particular emotions in his music by using certain motifs to make iconic reference to the human actions associated with those emotions. For instance, in the fifth recitative in his *Matthäus-Passion* (BWV 244), sung by an alto soloist, the continuous, four sixteenth-note plus eighth-note motif played by the two accompanying flutes musically portrays weeping or sobbing to support the sung text. In listening to this motif, it is not difficult to grasp that the pattern is iconic of human weeping owing to the similarity of the breathing and the musical phrasing the pattern involves with the physical act of sobbing. In Bach's composition, the motif is intended to reflect the actions of the woman who poured oil on Jesus' head (described in the Biblical book of Matthew 26: 6–7); the drops of oil are thereby likened to tears ("Tränenflüssen"). The same motif is not uncommon in Bach's other works, especially in his cantatas, and it appears only when his texts refer to weeping. Numerous examples could be cited just within the compositions of Bach.

More recently, in composing the score for the contemporary film *The Red Violin*, composer John Corigliano took advantage of state-of-the-art recording technology to manifest iconically one of the key points in the story (Corigliano, 1999). We learn by watching the film that the eponymous violin was made by craftsman Nicolo Bussotti in Cremona, Italy, in 1681, for his unborn son. But when his wife, Anna, died in childbirth, Nicolo worked some of her blood into the varnish he was applying to the violin, so that, in a certain sense, she would live on through the instrument. Corigliano chose to reflect this aspect of the story iconically by beginning his musical score with a solo vocal performance of the main melodic theme, sung by woman, that is gradually faded out as the sound of a solo violin simultaneously fades in to carry the theme forward. This compositional device gives the impression that the woman's voice is "becoming" the violin. For a listener who knows the story, the violinmaker's wife Anna's voice thus seems to live on audibly in the sound of the violin.

An infinite number of examples could be cited from the history of Western music, but it is important to realize that the practice of taking embodied sounds and manifesting them iconically in music also occurs in non-Western musical traditions. In describing his field work with the Kaluli people living in the rainforest of Papua New Guinea, a cultural group relatively untouched by modernity, anthropologist Stephen Feld undertook the difficult task of explaining how its members collectively understand the multi-timbral rhythmic and melodic sounds they make in their "musical" activities, despite the fact that they have no word conceptually equivalent to the Western notion of "music" in their language (Feld, 1982). He later described how he came to recognize the "pattern" or abstract coherence system that "metaphorically" links the sounds of the rainforest (e.g., birds, falling water) to the sentiments of their social ethos.

> Kaluli people think of themselves as "voices in the forest." They sing with birds, insects, water. And when Kaluli sing with them, they sing like them . . .

> To understand how Kaluli hear this world you have to get a handle on what they call *dulugu ganalan*, or "lift-up-over-sounding." This refers to the fact that there are no single sounds in the rainforest. Everything is mixed into an interlocking soundscape. The rainforest is like a world of coordinated sound clocks, an intersection of millions of simultaneous cycles, all refusing to ever start or stop at the same point.
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> "Lift-up-over-sounding" means that the Kaluli hear their rainforest world as overlapping, dense, layered. . . . People's [singing] voices layer like the trees of the forest canopy. Sounds of drums or axes arch up and out like tumbling waterfalls into swirling waterpools. (Feld, 1991, p. 3)

The field recordings Feld made during his first years living with and studying the Kaluli, excerpts of which are now commercially available, provide validation of his claims for interested listeners (Feld, 1991).

In all of the examples I have just described, the iconic sounds of embodied experiences are incorporated into the existing musical systems or conventions of the cultural groups that undertake them. But, from a complexity science perspective, it is even more notable that the musical systems or conventions of different cultures are themselves iconic of the abstract, culturally unique "coherence systems" of those for whom they have meaning.

Drawing from their knowledge of the Javanese gamelan and the language and cultural traditions of Java, ethnomusicologist Judith Becker and linguist Alton Becker have shown how the members of one cultural group conceptualize their "music" as innate or "natural" owing to the iconicity of the tacit organizing principles of that "music" with the abstract coherence system that organizes their thought and behavior. (Like the Kaluli people mentioned earlier, most Javanese have not until recently had a word in their language that corresponds directly with the Western notion of "music.") The Beckers observe that *cyclic coincidence* is the most prominent and powerful attribute of the "music" produced by a Javanese gamelan ensemble, and they note that the conceptions of *time* that are evident in the Javanese language and calendar system are also characterized by cyclic coincidence.

More specifically, the Javanese and English languages differ in that Javanese is tenseless, it features reversed deixis (i.e., "here" is near the hearer, rather than the speaker), and the language lacks a copula (i.e., the verb *to be*). While time is organized by narrative order in a composed English text, a Javanese text typically includes "a series of overlays and simultaneous actions, in which a word has multiple and simultaneous etymologies, an event has multiple and simultaneous motives" (Becker & Becker, 1981, p. 206). Furthermore, the Javanese calendar designates a single day according to its occurrence within a number of simultaneous cycles (largely derived from agricultural traditions) each of which is of a different length. For the Javanese, days of coincidence in the calendar cycles have important cosmological and social meanings. In setting a wedding date, for example, a Javanese couple will typically seek the counsel of an astrologer for the purpose of finding a day with as many positively meaningful cyclic coincidences as possible. Dates of personal importance for the couple, such as birthdays and parents' anniversaries, are taken into account.

Just as the Javanese language involves simultaneous actions, etymologies, and motives, and the Javanese way of planning life events involves consideration of

the correspondences of the multiple simultaneous cycles in their calendar system, the "music" of the gamelan derives its power from the coincidences occurring in its cyclic organization of melodies. The Beckers assert the importance of this point in the following way:

> As pitches coincide at important structural points in gamelan music, so certain days coincide to mark important moments in one's personal life. One might say that gamelan music is an idea made audible …. (Becker & Becker, 1981, p. 210)

So, for the Javanese, the "naturalness" and power of the gamelan stems from its iconicity with their culturally shared, *cyclic* conception of time, which is also manifested in their language and calendar system. (The cyclical organization of the traditional Javanese gamelan can be heard in field recordings such as those made by R. E. Brown, 1971).

Likewise, musicologist Christopher Small has argued that symphony concerts in the Western Art music tradition are rituals that celebrate the "sacred history" of the Western middle classes, and, like all rituals, they represent an affirmation of faith in the values of the group "as the abiding stuff of life" (Small, 1987, p. 19). Specifically, Small argues that as individual audience members listen to performances of symphonic works written before and during the nineteenth century, they invariably, tacitly identify with the composer and participate in a "drama of the individual soul which is the symphonic work" through the medium of tonal functional harmony.

> [T]he music is highly dramatic in character, full of strong, even violent, contrasts of mood and emotion; its central technique, to which all others are subordinate, and which unifies all the music written between about 1600 and 1900, is that of tonal functional harmony, the arranging of chords in meaningful sequences by means of which the listener is led forward in time, his expectations being frustrated and teased but ultimately satisfied by the final perfect cadence in the home key (it is remarkable that there is scarcely a single piece written in the period that does not end in this fashion). (Small, 1987, p. 16)

Small explains that the emotional value of symphonic music is derived from the dramatic force of the struggle it signifies, and that symphonic works reflect a wide range of human experiences—including joy, pain, happiness in and loss of love, loyalty and treachery, heroism and patriotism—each work almost invariably concluding with the "triumph of the human spirit." However, Small observes, symphonic dramas are purely *abstract*, taking place solely in the minds of the participants, without their physical involvement; they are thus consistent with Western societal conventions that emphasize the importance of the minds or souls of individuals while denying the physical body.

> To the majority of the audience the drama…holds no real surprises, but the excitement generated by the music seems to be no less real than if it were the very first time that the work had been played. Because of the abstract nature of the music, [the audience] is not permitted to give physical expression to that excitement during the performance, and the whole response to the drama must be bottled up until the end, when it is likely to explode with a lack of moderation that would sometimes put a football crowd to shame. (Small, 1987, p. 17)

(For readers who would find it helpful to hear an example of what Small is describing, his points seem to be exemplified with particular clarity in the concluding

moments of the first movement of Beethoven's third symphony, *Eroica* (Op. 55), of which there are many recordings.)

On the basis of the Beckers' demonstration of iconicity between the "music" of the gamelan and the *cyclical* language structure of the Javanese, it can be inferred that the dramatic progression Small recognizes as being the essential basis of Western "tonal functional harmony" iconically manifests the *linear* organization of time inherent in English and other European languages, particularly the subject/predicate syntactical form at the root of these languages and the sequential, temporal order of narrative inherent in them. Whereas the Javanese language is tenseless, lacking the copula (the verb *to be*), the English language centrally involves verb tenses, allowing a speaker or writer to account in a linear narrative for her or his progression between different physical and mental "states" at different times. Thus, it seems reasonable to say that the musical systems or conventions of each of these cultural traditions are iconic of the abstract, culturally unique "coherence system" of those for whom they have meaning. (For a more detailed version of the preceding argument, see Goble (2006).)

An important additional point that also merits mention, of course, is that, in the Western Art music tradition (and in some other musical traditions), students must work through an intermediary process to learn to make music, actually dealing with *an abstract system of notation* that represents symbolically the sounds they are striving to make on their instruments (or with their voices) in ways consistent with the coherence system of the tradition. (Note that many musical traditions throughout the world have no attendant form of notation; most musical learning in such traditions is done by imitation.) Despite the predominance of traditional Western music notation in Europe and North America (and its increasing use in other parts of the world), many Westerners are not aware that there are, in fact, several other forms of music notation, including South Indian Classical or *Carnatic* music notation, the mnemonic notation associated with Tibetan sacred chant, and a number of different Chinese methods, to cite but a few examples. We might say that student musicians in these traditions learn to make music by interpreting an abstract notational system that manifests symbolically the abstract cultural coherence system from which it stems. Those who learn to make music primarily or exclusively through the use of such notation are an additional step away from experiencing and recognizing the sorts of embodied experiences that gave rise to the music they are practicing to perform.

Susan: Johannes Kepler's Treatise *On the six-cornered snowflake*:

There is a nice historical example of a mathematician acknowledging the embodied sources of the new mathematics he's creating. It comes from Johannes Kepler, a contemporary of Shakespeare's, a generation before Descartes, who lived during the turbulent times of the Renaissance.

In 1611, Kepler wrote a 24-page booklet, *On the Six-cornered Snowflake*, as a New Year's gift to his patron in Prague. This book has become famous as the first statement of a number of new mathematical problem domains, including the problem of close packing of identical spheres, some of the earliest work on crystallographic

structure and polyhedra, and an anticipation of work on phyllotaxis using the Fibonnacci sequence and the golden ratio.

What is particularly interesting about this book is its discursive style, which seamlessly combines mathematical conjectures with a narrative of Kepler's lived experiences and observations in and around Prague. He begins by talking about crossing the Charles Bridge in winter and noticing the sixfold symmetry of the snowflakes falling on his mittens and the lapel of his coat. Kepler wonders why snowflakes should all have a six-sided symmetry—what is it about water freezing into crystals that occasions this branching symmetrical structure? This reminds him of the frost he has seen on the high windows of the Turkish baths in Prague on a winter's day, which also has a six-fold symmetry that covers the surface of the window in a tiling pattern. This in turn leads him to wonder about the hexagonal prisms that bees build to form the cells of a beehive. Kepler wonders why it is that the bees build their hives in this shape. Is it the best shape to conserve materials (the beeswax), and does it help to give the bees maximum warmth from the shared body heat of their neighbours, and so help to keep the bees alive in the winter? Does the six-sided shape of the beehive cells have any relationship to the six-sided snowflakes and frost patterns?

Kepler then talks about seeing cannonballs piled on the lawn of the castle, and fruit piled up in a market. He wonders whether there are various possible ways to pile the fruit, and if so, which would be the most efficient or stable. He wonders whether identical squashable spheres (say, peas) piled in different patterns and then compressed to form polyhedra would tend to form, say, cubes or hexagonal prisms. Which would give a maximally close packing of identical mutable spheres?

Throughout this little pamphlet, Kepler finds resonances between his awareness of pattern in his bodily, lived experiences and his conjectures of abstract patterns of number and shape, practical needs and causality. Abstractions are derived from and applied to a variety of diverse experienced phenomena, connected in the experiences and wondering mind of the mathematician.

How different this presentation is from the accepted format of mathematical speculation and proof in 2007, as found in academic mathematical journals. Although mathematicians like Whitely (2002), Taimina and Henderson (2006) acknowledge the importance of visualizations and bodily experience that inform their research work as mathematicians, the public face of mathematics is confined solely to the concise symbolism of algebraic proof, which allows no space for the human, the embodied, the wondering, for visualization of a tune, for a beehive or a walk across the Charles Bridge in the snow on New Year's Eve. The presentation of formal concise algebraic notation, with all the life boiled out of it, leaves very little space for the learner to play imaginatively, to "insert your face here." No wonder mathematics is considered cold, distant, inhuman.

SCOTT:

Just as many students learn mathematics via the "concise symbolism of algebraic proof," many student musicians in some musical traditions (including the Western Art tradition) learn to make music largely by interpreting an abstract form of

notation. In learning to make music in this way, they are indeed an additional step away from experiencing and recognizing the sorts of embodied experiences that gave rise to the music they are practicing for performance at a later time. In fact, many students in Western music conservatories spend a tremendous amount of time developing their instrumental or vocal technique (some practicing alone for eight or more hours each day) and far less time (if any at all) on experiential explorations of the origins of the music they are preparing for public presentation. Such disconnected experiences, which are not unusual for beginning music students and even many experienced musicians, have contributed to the widespread conception of music as a largely abstract art form.

However, numerous pedagogically oriented thinkers in the field of Music Education in the West have developed teaching methods to address this problem. Their methods serve to enable students to grasp and embody the original experiences and gestures that composers have sought to manifest iconically in their compositions. For example, Émile Jaques-Dalcroze (1865–1950) a Swiss musician and educator, developed a pedagogical approach to music teaching involving what he termed *eurhythmics*, a method by which students learn to reflect in the movements of their bodies aspects of the music they hear. In the Dalcroze approach, students enact iconically aspects of music being played (usually improvised) by a teacher at a piano. While individual students' movements differ somewhat, owing to their unique, individual interpretations of what they are hearing, their movements are also inevitably similar (iconic) in many respects. When the music the students hear is simple (say, a metrically consistent melody played at a steady tempo with little variation in loudness), their movements are correspondingly simple, involving walking and minimal gestures with the arms; when the music is more complex (say, involving complex meters and syncopation with wide dynamic variations and a variable tempo), the students arms move to reflect the meters while their feet step in syncopated patterns, and the size and speed of their movements varies to reflect variations in the music's loudness and speed. By this method, students are arguably aided in becoming physically responsive to what they hear, and they may thus more easily grasp a composer's intentions.

Zoltan Kodály (1882–1967), a Hungarian composer, ethnomusicologist, and educator, adopted a handsign system invented by John Curwen (1816–1880), an English Congregationalist minister and music teacher, and he incorporated it into an integrative teaching method intended to help student singers to overcome the challenges of developing musical literacy (i.e., the ability to read and perform from music notation). Curwen's handsigns are related iconically to the functions of the scale degrees they represent. Specifically, the handsign for each solfege syllable (*do*, *re*, *mi*, *fa*, *so*, *la*, *ti*, *do*) is placed in space vertically in relation to other "higher" or "lower" pitches, which allows students to enact physically the upward and downward movements of a melody, while also making a specific, outwardly visible hand gesture for each distinct pitch. For example, *do* is the tonal centre of all musical pieces in "major" keys, and its corresponding hand sign is a fist (made with the palm pointing down), which reflects its strength and stability. By contrast, the handsign for *so* is an open hand with the palm held parallel to the chest, which reflects its comparative openness or instability. The hand sign for the leading tone *ti*

(the least stable of all the scale degrees), is an index finger pointing up, which shows iconically the tendency of *ti* to resolve upward to the tonal centre *do* in the Western scale. (The function or tendency of all other scale degrees are reflected iconically in their corresponding handsign as well.) The effectiveness of this kinesthetic method for developing nascent singers' ability to read and perform from music notation "at sight" (and without the aid of another, supporting musical instrument) has been confirmed by years of instructional application and supported by systematic research (DeVries, 2001, p. 24).

Japanese music educator and theorist Shin'ichi Suzuki **(**1898–1998) sought to develop a method of musical instruction consistent with his understanding of language learning, thereby arguably bridging the gap between embodied experience and abstract music notation. His "talent education" method (which he originally developed for teaching the violin, but is now applied to other instruments) involves children in listening, observing, imitating, and repeating (i.e., learning by rote) long before they are given instruction in how to read music notation. The method arguably allows students to more easily grasp and embody the original experiences and gestures manifested in musical works owing to its great emphasis on observation and imitation. However, the method has been heavily criticized because many Suzuki students never learn to read and interpret written music well, and this prevents them from being able to perform complex orchestral music proficiently with other players.

Finally, most professional schools of music require that all students, instrumentalists and singers alike, take classes to develop facility with conducting technique, whether they plan to become conductors or not. Notably, the practice of conducting requires one to communicate physically and visibly important musical events one beat prior to the beat on which each such event is to occur, in order that players and singers will be able to respond to the gestures with perfect simultaneity and qualitative concurrence. The most highly regarded conductors tend to be those who go beyond mere technical proficiency to reflect well the embodied bases of music in their physical gestures and thereby effectively motivate (or "inspire") the players and singers they are leading to play with interpretive conviction; their effective personal embodiment of the musical content is thus paramount. Furthermore, some highly effective conducting teachers incorporate in their instruction aspects of mime and martial arts disciplines to encourage students' development of body awareness and physical expressiveness. All of these methods—Dalcroze eurythmics, Kodály / Curwen handsigning, Suzuki "talent education," and conducting instruction—contribute in their own way to facilitating music students' awareness and recognition of the embodied bases of what might otherwise seem to be a largely abstract art form.

Susan: The end of our bedazzlement with notation?

Up to about a hundred years ago, the most concise ways to record and express our awareness of the generality of mathematical patterns was through writing and algebraic expressions, possibly accompanied by a diagram. Likewise, musical patterns were best recorded in musical notation. Patterns found expression in

conventional systems of symbolic marks on paper, which took years of training to encode and decipher. A fascination with and perhaps an exaggerated respect for these ingenious systems of abstract symbolization often led to an assumption of the primacy and superiority of these systems to the experienced patterns they represented.

In very recent times, perhaps the past five years, our relationship to these symbol systems has changed in our new environment of converging networked electronic technology. It has suddenly become very easy to make digital multimedia presentations of ideas and expressions and to make them instantly accessible practically worldwide.

Brian Rotman, a lapsed mathematician and cultural critic, has written about this in an article, "The Alphabetic Body" (2002). Rotman predicts the demise of alphabetic literacy as a predominant mode of communication in the presence of networked multimedia. Given the easy availability of digital video, audio, and photography and interactive animation on uploadable and downloadable network sites, we have the immediate option of communicating in sounds and images. Why would a person choose, for example, to write out a set of instructions in words, when it may be more direct and comprehensible to send a video example of the instructions?

Marshall McLuhan, the Canadian theorist of technology and culture, used a tetrad of effects to study any new technology or medium of communication (McLuhan & McLuhan, 1992). One of the four kinds of effect of any new technology in McLuhan's theory is that it obsolesces a previous technology and turns it into an art form. That is not to say that the old technology disappears—but it ceases to be the predominant mode within a culture, the "water in which we swim," and becomes instead a matter of artistic choice, an art form, visible to us because it is in some sense obsolete. (For example, when cars became the dominant transportation technology in North America, horses and carts ceased to be simply the way people got around and became optional, a conscious choice, an art form, so much so that people would pay large sums of money to ride in a horse and carriage around Stanley Park as a romantic retro experience.) Rotman's assessment of the obsolescence of the alphabet (and perhaps of other forms of written notation as well) is very much in the mode of McLuhan's thinking about culture and technological change. If Rotman is right, then educators' ideas about literacy need a radical rethinking, and soon.

Here is a simple example of this phenomenon from mathematics education. I was recently talking with a friend who is a Montessori elementary school teacher about the many different ways that multi digit multiplication can be taught, aside from the algorithm that is typically used in schools. A number of these methods have recently been posted to YouTube as brief silent home videos. So rather than attempting to write out verbal descriptions of the several versions of lattice multiplication, I sent my friend links to the YouTube videos. Why would I want to write out a verbal description, which would be difficult to write and to interpret, when such an elegant and beautiful little home video is easily available to explain the whole thing without words? My friend showed the videos to her Grade Three students, who immediately began to grasp the similarities of these lattice methods

to the area grid representations of multiplication they had just learned. This whole communication, among the maker of the video, the two teachers, and the students, completely bypassed alphabetic symbolization in favour of new and already pervasive technologies.

A similar musical example: I play traditional British folk music in several small bands. Some of my musical colleagues read music, and others will have nothing to do with those "little black dots on the page." Traditional musicians have always learned by ear and by example "at the elbows" of other musicians, and since the advent of sound recording a century ago, could also learn from recordings of performances. Now, with digital music and video so readily available, members of my band who don't read the little black dots often send out email links to recordings and videos of other traditional musicians performing versions of tunes we like. The availability of these recordings means there is less need to depend exclusively on a symbol system which abstracts features of sound to visual marks on a page. The option to learn more directly from the sound of a recorded performance has become increasingly available, and written music has become less predominant—though it too is available on the web.

With a turn towards our contemporary technoculture, we have moved from a concept of embodied experience as simple and uncontestable immediate physical presence into a more fraught and nuanced concept of multiple bodies, virtual bodies, and a fairly new form of embodied experience that moves fluidly amongst virtual, physically present, and more abstract pattern-noticing modes. Teenagers particularly seem to have quickly become adept at this multi-bodied, multitasking culture, and you can observe kids at any high school simultaneously or sequentially engaged in conversations on cell phones, taking and sending digital photographs, playing online social games directing an avatar, and talking about game strategies or homework, while also shooting some baskets, eating a snack, and practicing skateboard moves.

Using McLuhan's tetrads, we can say that electric and electronic technological surrounds have made physical bodies themselves obsolete, optional, an art form. That is not to say that humans are not physical creatures, but rather that we have suddenly realized the importance of our physicality because physical embodiment has become optional, an artistic choice, rather than "just everything." Physically embodied existence is no longer "the water in which we swim." McLuhan said that when we are "on the telephone" or "on air" on radio or television, we are all angels—disembodied beings who can be simultaneously in several places in the world at once. Since the beginnings of electric communications with the telegraph in the late 19th century, we have become accustomed to a more problematized relationship with our physical embodiment, but this process has been greatly accelerated by the introduction of personal computers, computer networks, and converging electronic technologies in the past twenty years. It is no coincidence that theoretical concerns with embodiment issues emerged with personal computers in the 1980s, along with a widespread cultural shift in treating our physical bodies as art forms, ranging from tattoos and piercings to cosmetic surgery and physically embedded medical technologies. If we are to avoid simply moralizing after the fact of technocultural change has irreversibly affected us all, in effect, "shutting the

barn door after the horse has gone," we need to focus our attention on that thing that is very hard to bear noticing: and that is the way our own technologies have already changed our sense of our physical bodily experience and its relationship to abstraction and virtual bodies.

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