

This is a post-peer-review, pre-copyedit version of an article published in *Journal on Multimedia User Interfaces*.  
The final authenticated version is available online at: <https://doi.org/10.1007/s12193-020-00318-y>

**TITLE:** Mapping for Meaning: the Embodied Sonification Listening Model and its Implications for the Mapping Problem in Sonic Information Design.

**AUTHORS:** Stephen Roddy and Brian Bridges

<p><b>Stephen Roddy,</b> Electronic and Electrical Engineering, Trinity College Dublin, Dublin 2, Ireland.</p> <p><a href="mailto:roddyst@tcd.ie">roddyst@tcd.ie</a></p> <p><b>orc id:</b> 0000-0001-8491-3031</p>	<p><b>Brian Bridges</b> School of Arts and Humanities, Ulster University, Magee Campus, BT48 7JL, Northern Ireland.</p> <p><a href="mailto:bd.bridges@ulster.ac.uk">bd.bridges@ulster.ac.uk</a></p> <p><b>orc id:</b> 0000-0002-3988-7855</p>
--	---

**Abstract:**

This is a theoretical paper that considers the mapping problem, a foundational issue which arises when designing a sonification, as it applies to sonic information design. We argue that this problem can be addressed by using models from the field of embodied cognitive science, including embodied image schema theory, conceptual metaphor theory and conceptual blends, and from research which treats sound and musical structures using these models, when mapping data to sound. However, there are currently very few theoretical frameworks for applying embodied cognition principles in a sonic information design context. This article describes one such framework, the Embodied Sonification Listening Model, which provides a theoretical description of sonification listening in terms of Conceptual Metaphor Theory.

**Keywords:** Auditory Display; Sonification; Conceptual Metaphor; Image Schema; Conceptual Blending;

**Acknowledgements**

This publication has been funded by an Irish Research Council Government of Ireland Postdoctoral Fellowship Award. This publication has emanated from research supported in part by a research grant from Science Foundation Ireland (SFI) and is co-funded under the European Regional Development Fund under Grant Number 13/RC/2077.

## Mapping for Meaning: the Embodied Sonification Listening Model and its Implications for the Mapping Problem in Sonic Information Design.

### Abstract:

This is a theoretical paper that considers the mapping problem, a foundational issue which arises when designing a sonification, as it applies to sonic information design. We argue that this problem can be addressed by using models from the field of embodied cognitive science, including embodied image schema theory, conceptual metaphor theory and conceptual blends, and from research which treats sound and musical structures using these models, when mapping data to sound. However, there are currently very few theoretical frameworks for applying embodied cognition principles in a sonic information design context. This article describes one such framework, the Embodied Sonification Listening Model, which provides a theoretical description of sonification listening in terms of Conceptual Metaphor Theory.

**Keywords:** Auditory Display; Sonification; Conceptual Metaphor; Image Schema; Conceptual Blending;

### 1 Introduction: Sonic Information Design and the Mapping Problem

*Sonic information design* refers to the application of design research, as defined by Faste and Faste [1], to *sonification*, an auditory display technique in which data is mapped to non-speech sound to communicate information about its source to a listener. A key challenge in sonification is *the mapping problem*, first introduced by Flowers [2], who stated that meaningful information does not necessarily arise when complex data sets are submitted to sonification. In fact, due to cognitive–perceptual dimensional entanglement (such as the ecological intermingling of what had traditionally been considered to be discrete auditory dimensions, e.g. pitch and amplitude), this may rarely be the case [3]. Similar concerns have been raised within sound studies and practices, notably Truax [4], who criticised the overreliance on the ‘energy transfer model’ of sound (asserting that a psychophysical approach does not account for many aspects of sound’s communicative affordances), O’Callaghan [5], a philosopher of sound, and sound artists and sound studies theorists Kahn [6], LaBelle [7] and Cox [8]. The relationship between arts practices and the sonification mapping problem is further discussed by Roddy and Bridges [9,10]. From a design–centered perspective Worrall [3,11,12] presents a similar argument: that the software tools used in sonification parameterise sound using the basic parameters of Western tonal music (pitch, duration, loudness and timbral identity/difference), an example being the *PMSon* mapping of pitch, loudness, duration and timbre to unique data [13]). These parameters, Worrall argues, fail to account for the embodied aspects of sound and sound production, which he sees as critical to meaning–making in the context of sonification.

From this perspective, then, the mapping problem becomes a design challenge that must be addressed anew whenever one attempts to create a sonification. The sonic parameters we choose when designing a sonification determine how well the sonification communicates information and how well the listener can interpret it. As Ryle [14], Searle [15] and Harnad [16] have variously shown, meaning cannot be

1 generated for a listener without providing sufficient context because, as Dreyfus [17]  
2 and Polyani [18] point out, objects of meaning require a background context against  
3 which their meaning can be assigned, and, as such, auditory display solutions must be  
4 designed with this critically important constraint in mind. We argue that the mapping  
5 problem can be addressed by adopting models of sound which draw from  
6 contemporary theories of embodied cognition to refine the more traditional  
7 perspectives of psychoacoustics and formalist/computationalist models of cognition.  
8 This, in turns may provide designers with new higher-level parameter mapping  
9 strategies that allow them to map data in ways may be better suited to providing  
10 sufficient context by which the symbolic component sounds of sonification might  
11 become meaningful and informative to a listener.  
12  
13

## 14 **2 Embodied Cognition Guiding Sonic Information Design**

15 Embodied cognition researchers approach the problem of how to describe cognitive  
16 processes and conceptual systems from the perspectives of the physical and  
17 perceptual affordances of the human body [19]. To this end, the field has introduced  
18 a number of theoretical cognitive faculties that complement our traditional  
19 computationally-based understanding of cognitive faculties. *Image schema theory*  
20 [20] posits that the building blocks of thought are derived from frequently-  
21 encountered structures within sensorimotor experience; according to this theory, we  
22 draw upon image schema to lend structure to both our thinking and perceptual  
23 activities. One way in which we may do this is through conceptual metaphors. A  
24 *conceptual metaphor* [21] is the cognitive process by which image schemas in a  
25 familiar domain of thought are leveraged to make sense of an abstract domain of  
26 thought. A common example is highlighted in the phrase “Love is a Journey”. In that  
27 phrase the familiar logical structure of a ‘journey’ is mapped to frame the more  
28 abstract domain of ‘love’. Inferences can then be made about the concept of ‘love’ on  
29 the basis of this logical frame. For example, it can be inferred that, just like a journey,  
30 love has a beginning, middle and end and is typified by forward motion along that  
31 linear path. The image schema involved here is the *SOURCE-PATH-GOAL* schema  
32 [20]. In addition to providing a structure for logical inference, conceptual metaphors,  
33 within this theory, are also assumed to structure experience on the perceptual and  
34 sensorimotor levels. Here they frame an unfamiliar perceptual or sensorimotor  
35 domain in terms of a more familiar one. For example the desktop metaphor in human  
36 computer interaction (HCI) frames what would otherwise be an unfamiliar and  
37 abstract virtual space in terms of an office desk space. This structures how a user  
38 understands, reasons about and interacts with the virtual space.  
39

40 *Conceptual blending* is another process by which familiar conceptual content is  
41 integrated to generate new hybrid conceptual content [22]. Conceptual blending and  
42 its relationship to sonic information design is explored elsewhere [9], and design  
43 approaches informed by embodied cognition have been successfully applied in the  
44 context of HCI [23, 24, 25, 26] In a similar fashion, embodied approaches to  
45 interactive sonic information design have been developed, informed by Dourish’s [27]  
46 introduction of the concept of embodied interaction; see (Serafin *et al.*, 2011). In  
47 recent years, more broadly embodied models of sound have become increasingly  
48 prevalent in sonification. Diniz *et al.* [28, 29] apply principles from embodied music  
49 cognition to the design of a multilevel interactive sonification and Dyer *et al.* [30, 31],  
50 drawing from similar principles in the design of sonification mapping strategies for  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 motor skill learning. Peres *et al.* [32] explore embodied approaches to sonification in  
2 the design of a real-time sonification for surface electromyography (EMG).

3  
4 Whilst these approaches have provided productive connections between theories of  
5 embodied cognition and mapping strategies, we argue that a consideration of  
6 embodied perspectives drawn from music theories and practices may be helpful in  
7 further extending sonic information design. There is an extensive body of literature  
8 which has investigated the structures of Western tonal music in terms of embodied  
9 image schemas, conceptual metaphors and blending [33, 34, 35, 36, 37]. In particular,  
10 these models provide perspectives on the *temporal dynamics* of listening via  
11 embodied metaphors. A crucial factor for our present purposes is that the strategies  
12 which underpin music's evocation of apparent causality may inform more complex  
13 and dynamic sonic information design approaches. Beyond pitch-based musical  
14 structures, a number of researchers within the field of electroacoustic music have  
15 investigated embodied theories of timbre and sound-structural organisation. Kendall  
16 [38, 39] describes electroacoustic music on the basis of image schemas, conceptual  
17 metaphors and conceptual blending, and Graham and Bridges [40, 41] describe how  
18 Smalley's theory of spectromorphology [42, 43], a model of how sound textures and  
19 'gestures' within electroacoustic music may relate to one another,  
20 can be seen as compatible with image schema and conceptual metaphor theory.  
21 Similar work by Godøy [44] highlights the implied embodied underpinnings of Pierre  
22 Schaeffer's concept of the sound object (itself an antecedent of Smalley's theories  
23 [42, 43]). Further work in this domain [45] argues that an influential three-  
24 dimensional parametric model of timbral relationships—[46], with primary  
25 dimensions for spectral centroid, synchrony of start times, and presence/absence of  
26 attack transients—is compatible with dynamics drawn from embodied image schema  
27 and conceptual metaphor theory (verticality schemas, tension/projection/linearity  
28 dynamics of movement and spatial presence/diffusion).

### 35 **3.1 Theoretical Frameworks and the Embodied Sonification Listening Model**

36 The mapping problem could be said to arise when we fail to account for the  
37 idiosyncrasies of human perception and cognition. Sonification designers are broadly  
38 aware that they must work within the limits of human perception and that  
39 psychoacoustic constraints have a very large impact on how we represent data to a  
40 listener using sound. Furthermore, beyond the psychophysics of perception, we must  
41 account for the cognitive constraints of the listener in terms of working memory and  
42 cognitive load, etc. Embodied cognition suggests that there is both another layer of  
43 constraints for which we must account and another layer of possibilities that we can  
44 exploit in the design of effective sonification and auditory display solutions. The  
45 theory posits that we think, reason and understand, at least in part, on the basis of  
46 image schemata, conceptual metaphors and conceptual blends and as such we must  
47 account for them in our design solutions. The problem is that we do not yet have the  
48 theoretical tools with which to analyse, discuss and address these in the context of  
49 sonification listening. We present one such theoretical model below.

50  
51 The *Embodied Sonification Listening Model* (ESLM) aims to describe the role of  
52 conceptual metaphor in the listeners' interpretation of a sonification. A model of the  
53 embodied meaning-making faculties active in sonification listening might help to  
54 guide the design of communicatively effective sonification mapping strategies.  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 Vickers and Hogg [47] make a similar argument: that the modes of listening proposed  
2 by thinkers like Schaeffer [48], Chion [49], and Gaver [50] are insufficient in  
3 describing sonification listening, and calls for a new paradigm that is exclusively  
4 focused on describing the richness and diversity of the sonification listening  
5 experience.  
6

7 The Embodied Sonification Listening Model (Figure 1) was originally introduced by  
8 Roddy [51] but is formalised and described in greater detail here. It uses Lakoff and  
9 Johnson's [21] conceptual metaphor theory to provide a theoretical description of how  
10 meaning might emerge in sonification listening, from an embodied perspective.  
11 Typically, a listener does not have direct access to the data or the original data source  
12 being represented during sonification listening. As a result, they must construct an  
13 imaginary model of the data on the basis of the cues provided by the sonification. In  
14 the same way that a sonification designer creates a mapping strategy from data to  
15 sound, the listener must create their own cognitive–perceptual mapping strategy from  
16 that sound back to an imagined data source. The embodied sonification listening  
17 model provides a theoretical explanation of the embodied meaning–making faculties  
18 involved in this process. It relies on the embodied meaning–making faculties  
19 discussed previously to describe the sonification listening process. The ESLM  
20 involves two novel *conceptual evaluation* schemes: the *embodied sonic dimension*  
21 and *embodied sonic complex*. These were devised to account for traditional  
22 dimensions of sound such as pitch, duration, amplitude and timbre, and also to  
23 account for the dimensionality of sonic aesthetics, and their role in framing and  
24 associated meaning–making in the context of sonic information design. These  
25 dimensions tend to be, generally speaking, too complex to be adequately described in  
26 terms of simple interactions of the traditional dimensions of pitch, duration, amplitude  
27 and timbre alone.  
28  
29  
30  
31  
32

33  
34 Examples of such dimensions might be a sense of narrative development over a  
35 sequence of sounds, felt emotional qualities conveyed by a sound, such as a sense of  
36 foreboding, tension as communicated in prosodic information of human vocalisations  
37 or the unique sense of place established by a specific soundscape. Smalley's  
38 spectromorphology framework [42,43], mentioned earlier, also describes a number of  
39 similar sonic dimensions such as motion and growth processes, behaviours and  
40 structural functions.  
41  
42

43  
44 These conceptual evaluation schemes are also intended to address the perceived need  
45 for dedicated theoretical descriptors for sonification [52]. (They were motivated by  
46 Koestler's concepts of the *holon* and the *holarchy* [53], a holon being something  
47 which is simultaneously a whole and a part of a larger whole while a holarchy is a  
48 hierarchical arrangement of individual holons). An embodied sonic dimension is  
49 defined here as any individual sonic aspect that a listener can attend to as a  
50 meaningful perceptual unit which remains identifiable while evolving in time along a  
51 continuous bi–polar axis. An embodied complex is defined as any perceptual  
52 grouping that contains multiple embodied sonic dimensions and can also be identified  
53 by a listener as a meaningful perceptual unit.  
54  
55

$$56$$
$$57 f(t): ((sC \rightarrow_{m1} dP) + (sD \rightarrow_{m2} dM))eK$$
$$58$$
$$59$$
$$60$$
$$61$$
$$62$$
$$63$$
$$64$$
$$65$$

Formula 1. Formalization of the Embodied Sonification Listening Model

At a given time  $t$  a listener attending to a sonification  $f(t)$  will associate the sound they are hearing (the sonic complex  $sC$ ), with the phenomenon of which they imagine the represented data to be a measurement (the data phenomenon  $dP$ ). This constitutes the first metaphorical mapping ( $m1$ ).

The second metaphorical mapping ( $m2$ ) involves the association of changes along dimensions within the sonification (sonic dimension,  $sD$ ) with changes in the original dataset (measurement dimension,  $dM$ ). These mappings are further constrained and modulated by the listener's embodied knowledge,  $eK$ . This contains the listener's understanding of the sound, the data, any instructions or training they have received regarding the sonification and any associations, conscious or unconscious, the listener draws between or to these elements. More broadly it encompasses a listener's everyday knowledge of their physical, social and cultural environments. This knowledge determines the cognitive mapping strategy a listener employs to map the sound back to an imagined data source during sonification listening. (A more detailed description of how embodied knowledge mediates a listener's interpretation and understanding of a sound is presented by Kendall [38, 39].)

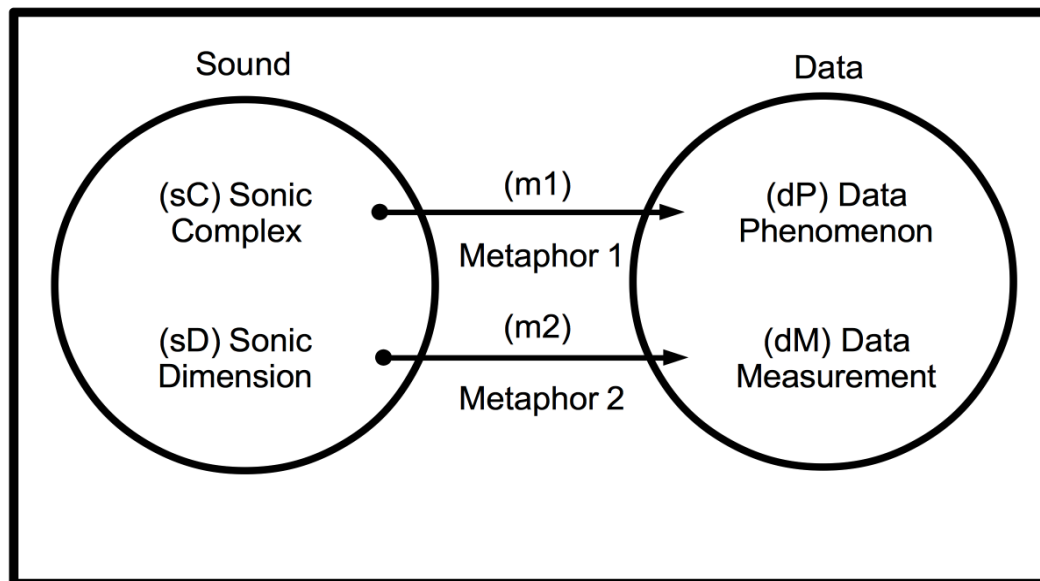


Figure 1. The Embodied Sonification Listening Model

As previously pointed out, there are two metaphorical mappings within the ESLM. In the first metaphorical mapping ( $m1$ ) the listener maps, or identifies, the sonic complex with the source of the data. That is to say that they associate the sounds they are hearing with the source from which the original data was recorded or measured. In the second metaphorical mapping ( $m2$ ), the listener maps or identifies changes in attributes of the sonic complex to the data set. This simply means that they associate changes in different attributes of the sound with changes in the data.

### 3.2 Applying the Embodied Sonification Listening Model

To better illustrate the operation of the ESLM let us consider a number of design strategies that a sonification designer can employ to present different kinds of data. For example considering a sonification developed for a flood monitoring and alert system the key data in question is water level. This is usually measured in meters and centimetres. For the sake of this illustrative example let's imagine that a designer chooses to represent this data using a pitch-mapped sine tone and that the polarity of the mapping is such that as the water level increases the pitch rises and as the water level falls the pitch falls too. This is a clear and direct mapping strategy. In this context the sine tone is the *sonic complex* (sC) of the sonification. It acts as a metaphor (m1) for our *data phenomenon* (dP). In this case the data phenomenon (dP) is the 'water', the level of which has been measured and recorded in the dataset.

This representation or substitution of the water with the sine tone is our first metaphorical mapping (m1). The second metaphorical mapping (m2) is between the *sonic dimension* (sD) and the *data measurement* (dM). In this example our sonic dimension (sD) is pitch and our measurement dimension (dM) is water level as recorded in metres or centimetres in the dataset. In this example the designer has mapped increases in water level to increases in pitch, and *vice versa*. (Whilst they could have inverted the polarity and mapped increases in data value to decreases in pitch, the original mapping polarity is in line with common practice in pitch-mapping sonification, one reason for which will be discussed below).

Our model suggests that these mappings are mediated by the listeners' *previous embodied knowledge* (eK) and that generally speaking, listeners come to a sonification with their own unique and vast history of such knowledge (eK).

This raises some important additional issues:

- (a) Which aspects of previous embodied knowledge do listeners draw upon when interpreting a sonification?
- (b) How do we design a mapping strategy that a listener can understand on the basis of their previous embodied knowledge?

We suggest that designers focus on the data here, and choose the strategy that best reflects the real-world, physical behaviours of the data phenomenon *and* the data measurement. In doing so the designer is leveraging the listeners' previous embodied knowledge of the data being represented. In the example above, the data phenomenon is water and it is probably safe to assume that from previous experiences the average listener knows that when you add water to a vessel, the overall level of the water within the vessel 'rises'. The polarity of this 'mapping' is therefore grounded within our direct, real-world experience of water. On this basis we can reason that when a listener perceives a rising pitch contour in a sonification of water level data they will interpret it as a rise in water level.

We can approach a sonification of a phenomenon like wind in a similar manner. For example, consider a sonification where wind speed data is mapped to the control the cutoff frequency of a filtered white noise generator. The white noise in this example is the sonic complex (sC). This provides a metaphor (m1) for the original data phenomenon (dP), which is the wind. The cutoff of the filter is the sonic dimension

(sD) and this in turn provides a metaphor (m2) for the data phenomenon which is the set of recorded changes in wind speed. Again, one might assume that, on the basis of past embodied knowledge (eK), an increase in cutoff frequency would be interpreted as an increase in wind speed. The reasoning here is that filtered white noise provides a good analogue for the sound of wind and increasing the cutoff increases the amount of perceptible activity in the frequency spectrum. As wind produces sound through friction when in contact with a surface, the higher the wind speed, the higher the frequency (e.g spectral centroid) of the resulting sound. As such, higher filter cutoff frequencies might coincide with higher wind speeds and *vice versa*, and the dimension and polarity of the sonic mapping is thus consistent with eK.

An interesting, but more demanding, example which nonetheless conforms to this model is the sonification of population data. Whilst still a measure of a physical phenomenon, population data (unless we are dealing with very small populations) is somewhat less immediately accessible than physical data like water levels and wind speed. However, if we consider a sonification where population data is mapped to control the number of individual grains in a grain cloud, the grain cloud (sC) becomes the metaphor (m1) for overall population (dP) and the density of the cloud (sD) becomes a metaphor (m2) for increases in the number of people in the population (dM). In this case, one might assume that on the basis of previous embodied knowledge (eK) increases in the density of the grain cloud would be interpreted as increases in the population number. The previous knowledge at play here can be quantified in terms of basic arithmetic or, from an embodied point of view, from simple everyday experience of adding and removing individual members from larger collections of physical objects; a conceptual metaphor of spatial *coverage* and *density versus sparseness*, which relates to Talmy’s [54] ‘states of consolidation’ (whereby spatial coverage may be compact or diffuse). Thus, in this example, the mapping is informed by a familiar, real-world, physical model (in this case, the behaviour of crowds), but is reinforced with reference to a more generic conceptual metaphor of spatial coverage/density.

The key point here is to focus on various aspects of common physical experiences that we can assume a listener is familiar with when designing a mapping strategy, and, furthermore, to design mapping strategies that are congruent with these familiar embodied experiences based on simple, directly-observable physical relationships (the first two examples) and, potentially, their reinforcement by more generic spatial conceptual metaphors (the third example).

<b>Metaphor 1 (m1)</b>			<b>Metaphor 2(m2)</b>		
<u>Sonic Complex</u> (sC)		<u>Data</u> <u>Phenomenon</u> (dP)	<u>Sonic Dimension</u> (sD)		<u>Data</u> <u>Measurement</u> (dM)
Sine Tone	>>	Water	Pitch	>>	Water Level
Filtered White Noise	>>	Wind	Filter Cutoff Frequency	>>	Wind Speed
Grain Cloud	>>	Population	Grain Density	>>	Pop. Number
Heartbeat (sound)	>>	GDP	Heart/Pulse Rate	>>	GDP Changes



Table 1. Example mappings based on prior embodied knowledge (eK)

However, not all data have clear connections to physical experience. For example, consider changes in the gross domestic product (GDP) of a country. We cannot experience an economic phenomenon like GDP in the same direct manner that we can experience physical phenomena like water and wind. When representing data of this type, we don't have previous embodied knowledge of the data source that we can draw upon to inform our sonification mapping strategy. In these cases we suggest choosing *sounds* (sC) which themselves have proven to have familiar embodied associations for a listener. If we cannot derive a suitable background of embodied knowledge from the original data, we can import one by representing and framing the data with sounds for which the listener has sufficient previous embodied experience, developing a new 'narrative' through this new metaphorical connection which are nonetheless based on established metaphors from eK.

An example of this type of approach would proceed as follows.

- (1) Identify linguistic conceptual metaphors which are associated with the data set. White [55] argues that there is a clear conceptual metaphor underpinning the concept of an 'economy': that economies are often conceptualised as living organisms and are thought and reasoned about in those terms.
- (2) As such, a sonification designer would consider a biologically-inspired sonic complex (sC) in order to represent changes in an economic metric such as GDP. For example, a heartbeat sound could be used as a parameterised auditory icon to represent the data phenomenon (dP) in question: GDP.
- (3) The sonic dimension (sD) in this case could be the pulse or heart rate and the data measurement (dM) could be the changes in GDP, whereby increases would map to an increased pulse/heart rate and decreases could map to a decreased pulse/heart rate. (These types of mapping example are summarised in table 1, above.)

It must be noted here that we are making some assumptions about embodied knowledge in the previous examples. In practice, embodied knowledge is a critical aspect of this model as it mediates how exactly a listener will interpret a sonification, this is complicated by the fact that embodied knowledge (eK) can vary wildly from person to person and from culture to culture. Such factors must be taken into account during phases of design by adopting user-centric design and evaluation methodologies to produce systems which are better adapted to the specific embodied knowledge (eK) of expected user groups.

As discussed previously, the listener's background of embodied knowledge contains their understanding of the sound, the data and any instructions or training they have received for the sonification. This knowledge is grounded in the listeners' embodied experience through embodied schemata and these embodied schemata determine how the embodied sonic dimensions are mapped to data. A similar phenomenon is referred to by Walker [56] as *polarity*. For example, when the speed of a train is mapped to the sound of flowing water, an increase in the speed of the water flow (embodied sonic dimension) is likely to coincide with an increase in the speed of the train as both share a common measure, speed, which is structured by the Fast-Slow schema [20]. When

1 the depth of a submarine is mapped to pitch, a decrease in pitch (embodied sonic  
2 dimension) is likely to correspond to an *increase* in depth. This is because both depth  
3 and pitch are structured by a common Up–Down (*verticality*) schema [20, 36]. For  
4 depth however, an increase in the data means downward motion and so a decrease in  
5 pitch might be interpreted as an increase in data. In this case, the listener’s embodied  
6 knowledge of the data determines their experience of the sonification.  
7

### 8 9 10 **3.3 Sonification Metaphor and Culture.**

11  
12 Lakoff and Johnson [21] argue that all linguistic cultures that they have considered  
13 employ embodied knowledge and create and use conceptual metaphors based on  
14 embodied experience; however, the metaphors created are often specific to that  
15 culture. Taking this a step further, Kövecses [57] illustrates a class of conceptual  
16 metaphors that, while still rooted in embodied experience, have a predominantly  
17 cultural basis. As an example, he points to the idiom ‘Time is Money’ and argues that  
18 it can only result from, and make sense in a capitalistic culture in which profit can be  
19 equated with the time required to produce a product. This is an important point for  
20 sonic information design and suggests that when applying a model like the ESLM,  
21 which relies heavily on conceptual metaphor, the designer must be aware of the  
22 culture in which the listener is embedded and base their design on metaphors with  
23 which these users are accustomed. Consider the sonification of economic data. Since  
24 its inception sonification has proved a useful tool for representing economic and  
25 market data [3]. However, research by Chung [58] has suggested that Chinese, Malay  
26 and English speakers use different conceptual metaphors for markets. The results  
27 show that Chinese and Malay speakers tend to use more metaphors based on  
28 ‘competition’ than English speakers when conceptualising markets. By contrast  
29 metaphors used by English speakers tend to focus on the ‘fall’ of a market. A related  
30 study compared the use of conceptual metaphors across financial reports written by  
31 native English speakers with those written by native Spanish speakers [59]. The  
32 results showed that while both groups conceptualised the economy as an organism  
33 (similar to our earlier GDP example), Spanish reports used more metaphors based on  
34 psychological mood and personality while reports in English showed a tendency  
35 towards more nautically based metaphors. These differences in the conceptualisation  
36 of markets and economies across cultures are important and they call for unique  
37 approaches to the sonification of market and economic data for the groups in question.  
38 Accounting for these differences can result in systems that are more inclusive overall  
39 as well systems that are developed specifically for users of a certain culture.  
40  
41  
42  
43  
44  
45  
46

47 How listeners interpret the meaning of a given sound in a sonification context is,  
48 undoubtedly, highly dependent on cultural factors. Polli [60] points out that  
49 approaches to sonification reliant on the Western harmonic music system fail to  
50 account non-Western listeners. She argues that listening to the soundscape is an  
51 experience more commonly shared across cultures, though the content of those  
52 soundscapes can differ radically over time and geographical space. Jeon et al. [61]  
53 showed that in the representation of emotional state data in auditory display, Koreans  
54 listeners showed a stronger preference for either auditory icons (real-world sounds) or  
55 earcons (Westernised musical sounds), whereas U.S. listeners showed more  
56 distributed preference between the two categories. These results are suggestive of  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 cultural differences between listeners. Vickers and Hogg [47] also comment on  
2 cultural differences in auditory display suggesting that spectromorphology (discussed  
3 previously), has the advantage of being less culturally specific than some Westernised  
4 alternatives as it is chiefly concerned with the sonic gestures discussed earlier.  
5

6 The ESLM has been consciously designed to accommodate a broad range of sounds.  
7 The sonic complex can just as easily be a soundscape, or a section of a raga, as it can  
8 be a sine tone, melodic pattern or rhythmic pulse. The key point is to choose a sonic  
9 complex and sonic dimension that creates the right conceptual metaphorical mapping  
10 for a given listener allowing them to interpret the sonification on the basis of a  
11 familiar domain of embodied experience for them. It is critical that designers account  
12 for cultural factors, taking care to choose sounds and mapping strategies that are  
13 consistent with the metaphors employed by the user, whilst also seeking to better  
14 understand how cultural factors may be at play in the construction or modification of  
15 these metaphors.  
16  
17  
18  
19  
20  
21

### 22 **3.4 ESLM Re-iterated**

23  
24 To summarise in plain English, listeners attend to the sound as though it *were* the data  
25 during sonification listening. Thus, the sound is experienced as a metaphorical  
26 representation of the data. There are two metaphors involved in this process. In the  
27 first, the sound heard is identified with the original data source. In the second, and  
28 arguably more critical, metaphorical changes in the sound are identified as changes in  
29 the data recorded from the original source. Crucially, this entire process is mediated  
30 by the listener's background of embodied knowledge, which determines how exactly  
31 metaphorical mappings take place. However, where the data is more complex, more  
32 broadly embodied models of sound, through which multivariate data series can be  
33 represented using conceptual metaphors, blends and a wider range of timbral/textural  
34 changes (informed by the treatment of timbre's component dimensions via embodied  
35 dynamics), may be helpful.  
36  
37  
38  
39

40 The ESLM is proposed as a tool for guiding the design of sonifications that can  
41 exploit the embodied aspects of meaning-making during sonification listening. The  
42 ESLM connects a number of research strands in embodied cognition, sonification and  
43 music composition to describe how sonifications can be parameterised in terms of  
44 image schemas, conceptual blending, and conceptual metaphor theory. Research of  
45 the kind explored in this article is important for sonic information design because it  
46 shows that both sound and music can be modelled in terms of embodied cognitive  
47 processes. Rather than parameterising sound and music on the basis of listeners'  
48 abilities to discern changes in pitch, amplitude and timbre, the present article  
49 proposes the parameterisation of sound on the basis of their ability to detect, track and  
50 interpret changes based on image schema and conceptual metaphors and blends. This  
51 is arguably crucial to sonic information design because it allows the designer to map  
52 data to more complex sonic dimensions (and combinations of dimensions) that are far  
53 better suited to communicating information to a listener, and to which the listener,  
54 based on ecological-embodied experience, is adapted to making sense of.  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

#### 4 Discussion and Concluding Remarks

The ESLM has far-reaching implications for the field of sonic information design. There are strong cultural and historical precedents in the West for conceptualising sound in either psychophysical terms, (i.e. pitch, loudness and timbre) or Western musical terms (i.e. rhythm, melody etc.). This approach has proven to be less useful for sonification, where the mapping problem imposes hard limits on how data can be represented with these auditory dimensions. The ESLM provides a novel framework for thinking about and working with sound in the context of sonification. It differs from standard approaches in that it is specifically intended to account for sonification and it provides this account in terms of conceptual metaphor theory so as to address some of the embodied aspects of sonification listening. In doing so the ESLM serves as an explanatory framework for how given groups of listeners might interpret a sonification. Crucially, it provides a framework for thinking about, and better understanding, the processes by which listeners might relate a specific sound to a data source when listening to and interpreting a sonification. The ESLM allows a designer to work with sounds from a wide and varied range of sources in a systematic manner. The model can be applied if a sound can be parameterised with a sonic complex (sC) that can represent the data phenomenon (dP) and a sonic dimension (sD) that is mapped to the data measurement (dM) in the original data set via a relevant conceptual metaphor informed by, and adapted to, the listeners previous embodied knowledge (eK). This model, with its novel sonic and conceptual dimensions, introduces more degrees of freedom for representing data with sound. This expanded possibility space gives the designer the opportunity to choose sounds and mapping strategies which might better represent their data to the listener. The conceptual metaphors involved in the model, and the need to choose metaphorical mappings from data to sound that make sense to a listener, help to constrain this possibility space to only those mapping strategies that are meaningful and can be interpreted by a listener. In doing so, the ESLM provides a useful tool for addressing the first design challenge posed by the mapping problem: the question of how to design a meaningful data to sound mapping strategy [2]. The ESLM also helps to address another design challenge posed by the mapping problem: the issue of dimensional entanglement encountered in traditional approaches to sonification as the use of a sonic complex (sC) to represent a specific data phenomenon (dP) and a sonic dimension (sD) to represent changes in the measured data (dM) allows the designer to make clear delineations between different sounds in a sonification and the data sources they represent. Another crucial component here however is the embodied knowledge (eK) that a listener draws upon to interpret a sonification. While this doesn't unequivocally solve the mapping problem, which remains a design problem that must be solved each time a designer creates a sonification, it does offer a framework in which to address it.

1 Adopting approaches informed by embodied cognition may support designers in more  
2 efficiently investigating and devising solutions to this problem. Frameworks such as  
3 the ESLM can help a designer to account for some of the embodied cognitive aspects  
4 of cognition involved in a listeners interpretation of a sonification.  
5  
6

## 7 **Acknowledgements**

8 Acknowledgements reserved to preserve anonymity.  
9

## 10 **References**

11  
12  
13  
14 [1] Faste, T., & Faste, H. (2012, August). Demystifying "design research": Design is  
15 not research, research is design. Presented at Industrial Designers Society of America  
16 Education Symposium, Boston, Massachusetts.  
17

18  
19 [2] Flowers, J. H. (2005). Thirteen years of reflection on auditory graphing: Promises,  
20 pitfalls, and potential new directions. *Faculty Publications, Department of*  
21 *Psychology*, 430.  
22

23  
24 [3] Worrall, D. (2019) *Intelligible Sonifications In Sonification Design: From Data to*  
25 *Intelligible Soundfields*. Springer.  
26

27 [4] Truax, B.(1984). *Acoustic Communication*. Norwood, NJ: Ablex.  
28

29 [5] O'Callaghan, C. (2007). *Sounds: A philosophical theory*. Oxford University Press.  
30

31 [6] Kahn, D. (1999). *Noise, water, meat: A history of sound in the arts*. MIT press.  
32

33 [7] LaBelle, B. (2010). *Acoustic territories: Sound culture and everyday life*. A&C  
34 Black.  
35

36 [8] Cox, C. (2011). Beyond representation and signification: Toward a sonic  
37 materialism. *Journal of visual culture*, 10(2), 145-161.  
38

39 [9] Roddy, S., & Bridges, B. (2016). Sounding Human with Data: The Role of  
40 Embodied Conceptual Metaphors and Aesthetics in Representing and Exploring Data  
41 Sets. In the Proceedings of the MusTWork 2016 The Music Technology Workshop.  
42

43 [10] Roddy S., & Bridges B. (2018) Addressing the Mapping Problem in Sonic  
44 Information Design through Embodied Image Schemata, Conceptual Metaphors  
45 and Conceptual Blending. *The Journal of Sonic Studies*. 17.  
46

47 [11] Worrall, D. (2013). Understanding the Need for Micro-Gestural Inflections in  
48 Parameter-Mapping Sonification. Georgia Institute of Technology.  
49

50 [12] Worrall, D. (2014). Can Micro-Gestural Inflections Be Used to Improve the  
51 Sonulatory Effectiveness of Parameter Mapping Sonifications?. *Organised Sound*,  
52 19(1), 52-59.  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 [13] Grond, F. & Berger, J. (2011). Parameter mapping sonification. In Hermann, T.,  
2 Hunt, A., Neuhoff, J. G., (Eds) *The Sonification Handbook*, (pp. 363–397). Berlin,  
3 Germany: Logos Publishing House.

4  
5  
6 [14] Ryle, G. (1949). *The concept of mind*. London, UK: Hutchinson.

7  
8 [15] Searle, J. R. (1980). Minds, brains, and programs. *Behavioral and Brain*  
9 *Sciences*, 3(03), 417-424.

10  
11  
12 [16] Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear*  
13 *Phenomena*, 42(1), 335-346.

14  
15  
16 [17] Dreyfus, H. L. (1965). *Alchemy and artificial intelligence*. Santa Monica, CA:  
17 The Rand Corporation, Research Report.

18  
19 [18] Polanyi, M. (2012). *Personal knowledge*. Routledge.

20  
21 [19] Varela, F. J., & Thompson, E. &E. Rosch. (1991). *The Embodied Mind:*  
22 *cognitive science and human experience*. Cambridge, Mass.: MIT Press.

23  
24  
25 [20] Johnson, M. (1987). *The body in the mind: The bodily basis of meaning,*  
26 *imagination, and reason*. University of Chicago Press.

27  
28  
29 [21] Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago  
30 Press.

31  
32  
33 [22] Fauconnier, G. & Turner, M. (2002). *The way we think. Conceptual Blending*  
34 *and the Mind's Hidden Complexities*, New York.

35  
36 [22] Imaz, M., & Benyon, D. (2007). *Designing with blends: Conceptual foundations*  
37 *of human-computer interaction and software engineering methods*. Mit Press.

38  
39  
40 [24] Hurtienne, J. (2009). *Image Schemas and Design for Intuitive Use. Exploring*  
41 *New Guidance for User Interface Design*. (Doctoral Thesis). Retrieved from Deposit  
42 Once TU Berlin Repository for Research and Data Publications. TU Berlin identifier  
43 opus3 2970

44  
45  
46 [25] Waterworth, J., & Riva, G. (2014). *Feeling present in the physical world and*  
47 *in computer-mediated environments*. London: Palgrave Macmillan.

48  
49  
50 [26] Bødker, S., & Klokmoose, C. N. (2016, May). Dynamics, multiplicity and  
51 conceptual blends in HCI. In *Proceedings of the 2016 CHI Conference on Human*  
52 *Factors in Computing Systems* (pp. 2538-2548). ACM.

53  
54  
55 [27] Dourish, P. (2004). *Where the action is: the foundations of embodied interaction*.  
56 MIT press.

57  
58 [28] Diniz, N., Deweppe, A., Demey, M., & Leman, M. (2010). *A Framework for*  
59

1 music-based interactive sonification. In *16th International Conference on Auditory*  
2 *Display (ICAD-2010)*.

3 [29] Diniz, N., Coussement, P., Deweppe, A., Demey, M., & Leman, M. (2012).  
4 An embodied music cognition approach to multilevel interactive sonification.  
5 *Journal on Multimodal User Interfaces*, 5(3-4), 211-219.  
6

7  
8 [30] Dyer, J., Stapleton, P., & Rodger, M. W. (2015). Sonification as concurrent  
9 augmented feedback for motor skill learning and the importance of mapping design.  
10 *The Open Psychology Journal*, 8(3), 1-11.  
11

12  
13 [31] Dyer, J., Stapleton, P., & Rodger, M. (2017). Transposing musical skill:  
14 sonification of movement as concurrent augmented feedback enhances learning in a  
15 bimanual task. *Psychological research*, 81(4), 850-862.  
16

17  
18 [32] Peres, S. C., Verona, D., Nisar, T., & Ritchey, P. (2017). Towards a systematic  
19 approach to real-time sonification design for surface electromyography. *Displays*, 47,  
20 25-31.  
21

22  
23 [33] Cox, A. (2001). The mimetic hypothesis and embodied musical meaning.  
24 *Musicae Scientiae*, 5(2), 195-212.  
25

26  
27 [34] Brower, C. (2000). A cognitive theory of musical meaning. *Journal of music*  
28 *theory*, 44(2), 323-379.  
29

30  
31 [35] Adlington, R. (2003). Moving beyond motion: Metaphors for changing sound.  
32 *Journal of the Royal Musical Association*, 128(2), 297-318.  
33

34 [36] Zbikowski, L. M. (2002). *Conceptualizing music: Cognitive structure, theory,*  
35 *and analysis*. Oxford University Press.  
36

37  
38 [37] Larson, S. (2012). *Musical forces: Motion, metaphor, and meaning in music*.  
39 Indiana University Press.  
40

41  
42 [38] Kendall, G. S. (2010). Meaning in Electroacoustic Music and the Everyday  
43 Mind. *Organised Sound*, 15(1), 63-74.  
44

45  
46 [39] Kendall, G. S. (2014). The Feeling Blend: Feeling and emotion in electroacoustic  
47 art. *Organised Sound*, 19(2), 192.  
48

49  
50 [40] Graham, R., & Bridges, B. (2014). Gesture and Embodied Metaphor in Spatial  
51 Music Performance Systems Design. In *NIME* (pp. 581-584).  
52

53  
54 [41] Graham, R., & Bridges, B. (2014). Strategies for spatial music performance: the  
55 practicalities and aesthetics of responsive systems design. *Divergence Press*, 3,  
56 December 2014. University of Huddersfield Press/Centre for Research in New Music  
57 (CeReNeM). [Online journal article]. Available at: DOI: [10.5920/divp.2015.33](https://doi.org/10.5920/divp.2015.33). [last  
58 accessed 22 July 2016].  
59  
60  
61  
62  
63  
64  
65

- 1 [42] Smalley, D. (1996). The listening imagination: listening in the electroacoustic  
2 era. *Contemporary Music Review*, 13(2), 77-107.
- 3  
4 [43] Smalley, D. (1997). Spectromorphology: explaining sound-shapes. *Organised*  
5 *sound*, 2(02), 107-126.
- 6  
7 [44] Godøy, R. I. (2006). Gestural-Sonorous Objects: embodied extensions of  
8 Schaeffer's conceptual apparatus. *Organised Sound*, 11(02), 149-157.
- 9  
10  
11 [45] Graham, R., Manzione, C., Bridges, B., & Brent, W. (2017). Exploring Pitch and  
12 Timbre through 3D Spaces: Embodied Models in Virtual Reality as a Basis for  
13 Performance Systems Design. *New Interfaces for Musical Expression Proceedings*.
- 14  
15  
16 [46] Grey, J. M., & Gordon, J. W. (1978). Perceptual effects of spectral modifications  
17 on musical timbres. *The Journal of the Acoustical Society of America*, 63(5), 1493-  
18 1500.
- 19  
20  
21 [47] Vickers, P., & Hogg, B. (2006) Sonification ab-straitte/sonification concr`ete:  
22 An 'æsthetic perspectivespace' for classifying auditory displays in the ars musica  
23 domain. In 12th International Conference on Auditory Display (ICAD-2010). pp.  
24 210–216.
- 25  
26  
27 [48] Schaeffer, P., Reibel, G., Ferreyra, B., Chiarucci, H., Bayle, F., Tanguy, A., ... &  
28 Schwarz, J. (1967). *Solfège de l'objet sonore*. INA/GRM.
- 29  
30  
31 [49] Chion, M., Gorbman, C., & Murch, W. (1994). Audio-vision.
- 32  
33  
34 [50] Gaver, W. W. (1989). The SonicFinder: An interface that uses auditory icons.  
35 *Human-*
- 36  
37 [51] Roddy, S. (2015). Embodied Sonification. Doctoral Dissertation. Trinity College  
38 Dublin. Ireland.
- 39  
40  
41 [52] Walker, B. N., & Nees, M. A. (2011). Theory of sonification. *The sonification*  
42 *handbook*, 9-39.
- 43  
44 [53] Koestler, A. (1967). The ghost in the machine. London: Hutchinson & Co.
- 45  
46  
47 [54] Talmy, L. (2008). The Fundamentals of Spatial Systems. In: Hampe, B. (ed),  
48 (2008). *From Perception to Meaning: Image Schemas in Cognitive Linguistics*.  
49 Berlin: Walter de Gruyter.
- 50  
51  
52 [55] White, M. (2003). Metaphor and economics: the case of growth. *English for*  
53 *specific purposes*, 22(2), 131-151.
- 54  
55  
56 [56] Walker, B. N. (2002). Magnitude estimation of conceptual data dimensions for  
57 use in sonification. *Journal of experimental psychology: Applied*, 8(4), 211.
- 58  
59  
60  
61  
62  
63  
64  
65



1 [57] Kövecses, Z. (2010). Metaphor and culture. *Acta Universitatis Sapientiae,*  
2 *Philologica*, 2(2), 197-220.

3 [58] Chung, S. F. (2005, December). MARKET Metaphors: Chinese, English and  
4 Malay. In *Proceedings of the 19th Pacific Asia Conference on Language, Information*  
5 *and Computation* (pp. 71-81).

6 [59] Charteris-Black, J., & Ennis, T. (2001). A comparative study of metaphor in  
7 Spanish and English financial reporting. *English for specific purposes*, 20(3), 249-  
8 266.

9 [60] Polli, A. (2012). Soundscape, sonification, and sound activism. *AI & society*,  
10 27(2), 257-268.

11 [61] Jeon, M., Lee, J. H., Sterkenburg, J., & Plummer, C. (2015). Cultural differences  
12 in preference of auditory emoticons: USA and South Korea. Georgia Institute of  
13 Technology.

14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65