

Strung Out On Analogies Of Everything

Are the Mathematical Metaphors in Popular Physics Books Intuitive?
Abstractions from research for an Open University MSc Science degree

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Here are six representative sets of scientists (no one more than once) and books which met the criteria for my science-as-language teaching research. For each set, one central source is identified (**The Books = B1–B7**).

Set 1

Robert Oerter
The Theory Of Almost Everything
B1: Stephen Hawking
A Brief History Of Time
John Gribbin
In Search of Superstrings

Set 2

João Magueijo
Faster Than The Speed Of Light
B2: Michio Kaku
Beyond Einstein
Paul Steinhardt & Neil Turok
Endless Universe

Set 3

Steven Weinberg
Dreams Of A Final Theory
B3: Lisa Randall
Warped Passages
Brian Greene
The Elegant Universe

Set 5

John Barrow
New Theories Of Everything
B5: Paul Davies
The Goldilocks Enigma
Leonard Susskind
The Cosmic Landscape

Set 6

Lee Smolin
The Trouble With Physics
B6: Peter Woit
Not Even Wrong
David Lindley
The End of Physics

Set 7

Robert Laughlin
A Different Universe
B7: David Deutsch
The Fabric Of Reality
Seth Lloyd
Programming The Universe

Over 50 popular science paperbacks were surveyed before The Books (above) were selected. Here are the selection criteria:

- Written (or co-written) by practising academic scientists no earlier than Hawking's (1988).
- Explaining fundamental physics concepts of relativity and quantum theory, and attempts at their unification, without formal mathematics (but often with pictures).
- Referring to string and/or superstring theory as a potential theory of everything (ToE).

While the general research was equally informed by all members of Sets 1–7, samples of popular science language for teaching were drawn exclusively from The Books (B1–B7, cf Hubbuck in *Mulberry* 59 forthcoming).

NB: Set 4 is empty by (counter-intuitive?) design.

Preface

'To discover the right style is to discover what you are really trying to do.'

Bernard Williams

The general research began with my distance learning of science communication, via the UK's Open University (OU). Most instructive to me, as a teacher of English for Academic Purposes (EAP) in Japan, were questions about the role of language in both the construction and communication of 'scientific' knowledge. I was particularly struck by Medawar's argument that the scientific paper is 'a fraud'¹.

Why, when science progresses as often through the right metaphor² as through replicable experiment or successful equation, do peer-reviewed journals demand a style devoid of rhetorical figures and interpersonal pronouns? It wasn't always so. The sociolinguistic segregation of science from the humanities was a 20th Century development, an elitist mystification which led to a deficit in the public understanding of science. By the 1990s, in

democracies worldwide, a more authentic discourse was being demanded—one in which *all* citizens might aspire to some assessable level of scientific literacy. Ultimately, this meant communicating ‘science-as-language’ in 21st Century environments, where the political climate was planetary, not national. My EAP experience had found a new calling.

Since Stephen Hawking wrote *A Brief History of Time* in 1988, a surge of popular science books has appeared globally in English. Do they address the pedagogical demand for science as-language? Their style seems increasingly authentic to communication among scientists worldwide, since the Internet took control of the means of publication away from their journals. But can the metaphors which The Books use to avoid mathematics (because each equation halves sales!) be ‘true’ to the mathematical ‘realism’ of fundamental physics?³ Not if those metaphors make the cognitive deficit between *genius* and *idiot* seem irreparable, by romanticising the difficulty of maths (as if Einstein didn’t have to learn from quite simple mistakes!).

To constructivists, scientific knowledge-transmission should not be directed and fixed (*genius*→*idiot*), but reciprocal and fluid (*scientist-citizen*↔*citizen-scientist*).⁴ The most creative scientists—both professional and popular—are flexible, multidisciplinary roleplayers. *Experts* in one narrow specialisation, they cheerfully relinquish authority to become *novices* in others—often by reading other experts’ popularisations (*producer*↔*consumer*). In all their democratic interactions, we should recognise patterns of lifelong learning for technological citizenship. Experimental groupwork in ICT-enhanced science-as-language classes should follow.

The Open University MSc Writing Guide (SUP 79674 2) says writing in Science Studies can be fun, a motivating ideal I try to maintain for my EAP students. So I’ll try to keep my style here edutaining, copying the genre I’ve been studying. Just as The Books avoid offputting equations, these abstractions avoid citations nested in hedges⁵. Register varies with personal pronouns. In instructional mode, I might transmit some information (*writer*→*reader*), then assess *my* success by testing *you* (*teacher*→*learner*). Or, let’s deconstruct the conduit metaphor *we* just used as a scaffold, and channel *our* intuitions into more creative analogies (*thinker*↔*thinker*).

It seems ironic that peer-reviewed journals are losing their power to alienate scientists from the humanities—to a machine! Is this just because citizens are converging with scientists in their everyday use of computers (e.g. to avoid doing maths)? Or is a more intelligent transition taking place at some *carbon*↔*silicon* interface? Certainly, ICT metaphors/analogies now proliferate across all the old science/humanities domains, and in their popularisations.⁶ Their interdisciplinary and multimodal translations may emerge to confuse you in this report ...

... and that's just in English, not the only natural language of science!

1. Introduction

'The gods in the beginning are not the cause but the effect of man's intellectual confusion.'

Karl Marx

1.1 A theory of everything real?

Let's start with an intuitive overview of how science gets done in The Books. I'll map B1–B7 to six stages in a theoretical physicist's career through his or her ToE paradigm. (B4 must give us pause to dream in!) If this makes Stephen seem permanently at the genesis stage, Lisa always establishing herself, only David ever making it through to revelation; remember: a productive analogy suppresses as much contradiction as it generates insight! The Books' authors progress and regress in their careers, wear different hats⁷ for different jobs, multitask at different stages simultaneously. Plus, each Book plots many career-trajectories, from Copernicus's to Witten's. Enjoy the reductionist overview, but please don't forget how complicated *everything* really is!

Stage 1: Introduction to ...

Dreaming of the cutting edge of his field, our young physicist must first get to grips with its prior knowledge traditions. It's hard going. It helps if he has the eternal enthusiasm (if not the infinite patience!) of a schoolboy.

Respect for the founding fathers (e.g. Galileo, Newton and Einstein) is nurtured through first hand experience of their methods and equations; and comes naturally anyway—they were all iconoclasts in *their* day. Originally counterintuitive developments *our* hero must make time for will include (briefly): Greek geometry, Renaissance astronomy, the schism between science and religion; Newton’s gravity, Maxwell’s electromagnetism; Einstein’s relativity, singularity; Heisenberg’s uncertainty, wave/particle duality; the atom bomb⁸; the big bang, black holes; success of the standard model, failure of quantum gravity; supersymmetry, string theory (super or not) and the ultimate promise of M-theory (which he won’t understand).

Stage 2: Courtship of ...

Eager to make his mark, our young radical will intuitively fixate on one or two self-evident holes (multi-loop amplitudes?) in an established theory (e.g. of string fields). Even if his exciting new solutions violate relativity, he’ll identify with the young Einstein, blaming Heisenberg for the atomic bomb. He’ll expect the *old* Einsteins of the establishment to accord his new ideas equal courtesy. In so doing, he may confuse self-consciousness with the *real* measure of a scientist (like Wigner⁹). Only if his *results* prove unreasonably effective can he expect to make a name for himself (below Einstein’s!). Then he’ll be potentially useful, and the ToE community will recognise *that* with a probationary job offer.

Stage 3: Establishment in ...

Her position uncertain, our new member of the science establishment will network hard *within* her chosen paradigm. Allying with equally insecure peers, she’ll collaborate to associate her name with theirs, and gather momentum through the powerful authorities they cite. Anxious to be institutionalised, once would-be radicals often overcompensate: our heroine *must* prove herself in *everything* her colleagues can do! Fortunately, she’s still energetic enough to put many of them to shame. But she’ll have to tunnel that restlessness into ever-narrower dimensions, if she’s to expand prior thought in her school *without* undermining its seniors. Success in science is a social

equation, in which being popular counts as much as being productive. If she makes it, work will never be that mental again. For physical challenges though, she'll have to hike deserts and climb mountains.¹⁰

Stage 5: Reaching out ...

Ensnared in a salaried practice on which his family depends, what does our once youthful hero do for theoretical excitement? By this stage, administrative duties will have forced him to network *outside* his chosen paradigm (e.g. in economics). So he'll've acquired skills in the courteous translation of its central ideas, both across to other sciences, and out to nonscientists. Reciprocally, ideas from far-flung domains will have mapped themselves onto his own. He'll feel driven to incorporate them, or else abandon his pretention to know *everything*. Our sympathetic humanist's 21st Century ToE must now extend *at the very least* to: artificial intelligence, biogenesis, consciousness, dark matter/energy, evolution, final cause, genes, intelligent design, life, mind, paradoxes, qualia, teleology, virtual reality and (most vitally!) water.¹¹

Stage 6: Reaction against ...

His securities besieged by a new generation of school-shifting Einsteins, our anti-hero worries his way through a mid-career crisis. To simultaneously 1) keep faith with the profession he's known by, *and* 5) heed the intuitive call of truth from outside, is irrational (and splits an infinitive!). Science is suddenly a question of *moral* intelligence. Should he defend his vested interest with all his authority; *or* embrace change and be shifted back to career stage one? It isn't an easy decision.¹² Analogies with old heroes (e.g. young Einstein) no longer lend him their favourable aura. At stake is *everything* he has worked hard to achieve, including the support of family and friends. Oh, but just to feel righteous again for the first time in ages!

Stage 7: Escape from ...

Whither by accident or intelligent design, some scientists find themselves doing cutting-edge research (e.g. quantum computation and cryptography)

in a well-established institution (e.g. Oxford University). If also gifted with that alchemical blend of humility and arrogance which makes great communicators, they'll emerge unifying metaphors across generations and knowledge-domains¹³, in a language free of the principal stultifications of reductionist science. They may appear, in *one* career, to experience *everything* that workers worldwide dream of, both professionally (salaried recognition, job satisfaction) and personally (a happy family, their love and respect). Appearances can be as deceptive, however, as the harmony of Kepler's spheres; today's visionary profession may become yesterday's evolutionary dead-end job. In which case, go back to Stage 1.

1.2 A theory of everything psychological?

My course through the Lakoff School of conceptual metaphor followed that school's chronological development by George: from his little 1980 book with Mark Johnson (*Metaphors We Live By*), through his pre-millennial bipolar tensions with Gentner et al. (a dubious analogy?), to his newfound pre-eminence in *The Cambridge Handbook of Metaphor and Thought*. As Gibbs, the latter's editor, notes:

research on metaphor is now as multidisciplinary, and interdisciplinary, as perhaps any topic being studied in contemporary academia. (2008: 4)

Which makes metaphor some kind of ToE (and vice versa). Lakoff's School should therefore have something to say about The Books. So let's target six sources from my metaphor studies, heading pedagogically back towards The Books. With our blank slates so 'overwritten',¹⁴ we'll then have to play andragogy in the *Review* (2.1–2.7).

Course 1: A brief philosophy of language

I first heard of Lakoff in EAP, where 'hedging' is attributed to him. Later, I discovered George was a major combatant in 'the linguistics wars', over whether Noam's colourless green syntax was actually meaningful. Pinker disputed irregulars with Lakoff, who became an ally of Deutscher in the latter's evolutionary leap beyond the LAD.¹⁵ So while I wasn't surprised that the metaphor Lakoff first lived by was ARGUMENT IS WAR, I *was* at his

old-school philosophy: No corpus data, just handwritten intuitions in print (with no index!). Before entering Lakoff's School, I sought a more corporeal approach to The Books, off-campus. Using Open University search engines, I found David Banks (2.1).

Course 2: Beyond literature

In *Metaphors We Live By*, Lakoff & Johnson started a cognitive science argument:

Your claims are *indefensible*.

He *attacked every weak point* in my argument.

His criticisms were *right on target*. (: 4)

They persuaded us that, undermining metaphor's use as a literary pretense¹⁶, were inferentially structured mappings between conceptual domains: from a *source* we know to a *target* we want to. In 2003, after their book had shifted the meaning of 'metaphor' (from linguistic device to multimodal concept), they admitted they'd reversed the polarity of *their* want of experience (: 265 WAR IS ARGUMENT?). In the restructured multidisciplinary Lakoff School, 'the essence of metaphor is understanding and experiencing one kind of thing in terms of another.' (: 5) Can it improve string-theory teaching? Let's ask Noah Podolefsky! (2.2)

Course 3: Warped paradigms

At the turn of the millennium, the cogsci establishment was making a schism out of a subtle distinction. While the Lakoff School had represented itself as 'The Contemporary Theory' at Ortony's multidisciplinary conference on *Metaphor and Thought*, it was still sectioned off from the real theory-changing science of 1993(: viii). Then, Gentner's 'Shift from metaphor to analogy in Western science' led by 2001 to *The Analogical Mind*; wherein 'Metaphor is like Analogy'—but with a structured career directionality which makes *analogy* the special case for hard scientists:

analogy is used in explanatory-predictive contexts, while *metaphor* can be used more broadly, in either explanatory-predictive or expressive-affective contexts. (: 236)

Interminological bipolar warguments (METAPHOR IS ANALOGY ↔ ANALOGY IS METAPHOR) dilated a Lakoff School pupil named Gedanken¹⁷. “Uncle Albert sent me here to learn some *proper* science!” she complained. And then along came Brown ... (2.3)

Stage 5: The Gödel, Escher, Bach enigma

a fictitious, unimaginably large book each of whose pages, on a one-by-one basis, contained exhaustive information on one specific neuron in Einstein’s brain. (Twentieth-anniversary Preface, P. –10)

That Carrollian book *was* imagined, by Douglas Hofstadter in his *metaphorical fugue on minds and machines: Gödel, Escher, Bach*. GEB was contemporaneous with *Metaphors We Live By*. Compare the two. Hofstadter drafted GEB on ‘one of the world’s earliest and best word-processing programs’, TV-Edit (: P. –12), for ‘one of the world’s first computer typesetting systems’ (: P. –13). It contained and continues to generate

a slew of profound and beautiful ideas in mathematics, physics, computer science, psychology, philosophy, linguistics, and so on. (: P. –9)

GEB rejects the bio-chauvinist view that any meaning in these ideas springs only from the organic chemistry, or perhaps the quantum mechanics, of processes that take place in carbon-based biological brains [...] the key is not the *stuff* out of which brains are made, but the *patterns* that can come to exist inside (: P. 3–4).

Pre-GEB, Hofstadter got his PhD in solid-state physics. Post-GEB, he worked in AI, founding the Fluid Analogies Research Group (FARG), in sympathy¹⁸ with Dierdre Gentner. He also translated Pushkin’s *Eugene Onegin*. (P. –21) Where does the romance and maths come from in Lakoff’s School? (2.5)

Course 6: Not necessarily right

Where Mathematics Comes From, Lakoff’s turn-of-the-millennium collaboration with Rafael Núñez (hereafter L & N, 2.5), took me right back to pre-exam nightmares¹⁹ at school. L & N’s explanations make good pedagogical sense, answering the questions my school teachers had failed to

(e.g. on the ϵ - δ approach to the limit of my understanding!). But when L & N denied me the romance of Mathgod²⁰, I felt wronged. Mathgod was my original motive for studying The Books.

Course 7: The real fabric of ideas

In *The Math Gene*, professional research mathematician Keith Devlin argues ‘mathematical ability is essentially just a new use of a mental faculty that gave us language—namely, off-line symbolic thinking.’ (2000: 285) Watching the ‘involuntary simulation behaviour’ of a sleeping cat, Jerome A. Feldman of the Lakoff School suggests an evolutionary adaptation to account for it:

Suppose that the mammalian involuntary simulation mechanisms were augmented by brain circuits that could explicitly control what was being imagined. (*From Molecule to Metaphor* 2008: 328–9)

Feldman’s *Neural Theory of Language* (NTL) promises to unify the grammar and syntax of language and thought, further incorporating multimodalities like intonation and gesture (: 302–3). Its mind/body mappings are ICT-analogues which depend on *computer* mathematics:

in the proof of the four-colour conjecture the use of the computer was absolutely essential—the proof hinged directly on it.²¹

Regarding *human* mathematics, will L & N’s minds be changed? (2.7)

2. Review

‘In the long history of humankind (and animal kind, too) those who learned to collaborate and improvise most effectively have prevailed.’

Charles Darwin

2.1 Grammatical metaphor

David Banks’ 2008 study of *The Development of Scientific Writing* is a model of sound methodology and precise reporting. No grandiose philosophical claims²², just an honest investigation of a restricted but significant historical corpus. Banks tracks changes in English science writing: from Chaucer’s

Treatise on the Astrolabe, through Bacon, via Newton, across three centuries of *Philosophical Transactions of the Royal Society* (1700–1980). These he divides into physical and biological sectors. A change he finds in the former is significant here:

In the physical sciences, a major development occurs at the turn of the twentieth century, when the focus moves from the experiment as such to mathematical modelling. (: 198)

Systemic Functional Linguistics (SFL) providing his necessary theoretical framework, Banks sets out to show that ‘language changes as a function of the context of scientific research in which it is produced.’ (: 4) He distinguishes his own *quantitative* methods (based on research writing) from the *qualitative* remarks (often based on ‘high quality popularisation’ (: 18)) of SFL’s founding father, Halliday: one of the few authors cited across both EAP and science education.²³ Unfortunately, as Wellington & Osborne noted:

Space here does not allow the kind of detailed insights provided by the work of the linguist Martin Halliday (Halliday and Martin 1993), to which the interested reader is referred. (2001: 81)

An SFL²⁴ concept the Lakoff school should make space for is grammatical metaphor, one of the phenomena Banks witnesses changing as twentieth century science progresses (: 123). With examples from Newton’s *Opticks*, he shows how the ‘usual or congruent’ verbalisation of processes (e.g. ‘was refracted’, ‘be reflected’) gets nominalised (‘the greatest Refraction’, ‘a total Reflexion’) (: 13); with both grammatical and semantic effects:

since nouns can be modified and qualified, the nominal groups could have additional Modifiers and Qualifiers [...]

that the process now has a nominal form means that it takes on some of the quality of an entity (: 14)

The historical nominalisation of processes like ‘experiment’, Banks believes (: 130–2), ‘is particularly appropriate to scientific writing’ (: 14). Indeed, he shows nominalisation increasing ‘in the creation of technical

vocabulary’ across his period of study. (: 135) Again, Banks’ sources and findings are relevant to problems Wellington & Osborne raised for science teachers, and may help the latter find solutions in EAP now: ‘constructing and deconstructing nominalisations and noun groups’, for instance.²⁵

Active	Passive	Nominalisation
How people make paper	How paper is made	Paper making
First, people fell trees	First, trees are felled	Felling trees is the first step
Then they remove the branches and leaves	Then the branches and leaves are removed	The second step is the removal of branches and leaves

EAP recognises how difficult it is for non-native students to unpack grammatical metaphors. Since this language lost most of its inflections, change from one part of speech to another is intuitive. Consider how ‘green’ has switched from adjective to noun (‘a green field’, ‘the village green’) to verb (‘let’s green the city’): which of these uses still feels like a living metaphor? In scientific English, native speakers face comparable confusions. Consider ‘experiment’: is its literal use now nominal or verbal? Based on corpus data, learner dictionaries put ‘experiment=noun’ before the less frequent (but etymologically prior) ‘experiment=verb’.²⁶ But in the specialised physical sector of Banks’ scientific corpus, even that nominalised usage ‘waned as mathematical techniques begin to be used in the twentieth century.’ (: 133)

More confusing technicalities emerge when we study science in more than one language. Banks shows that, in Motte’s 1729 edition of Newton’s *Principia*, ‘the nominalised processes of the English translation are directly derived from the original Latin text.’ (: 63) Can questions about Latin’s influence on scientific English (or vice versa) be empirically resolved from the surviving evidence (none of it aural)? Circumstantially, Newton nominalised less frequently when describing mathematics than in his accounts of experiments, seemingly anticipating the decline of ‘the experiment’ in twentieth century mathematical physics. Now, would quantum theories be

better described in a verb-rich, noun-poor Algonquian language?²⁷ Here's a non-reifying conclusion from Banks:

I am not so much concluding my subject, as abandoning it at this point, and floating it off to a reading public. (: 198)

2.2 Teaching physics

Noah Podolefsky's pragmatic survey of the physics education literature on analogy, with personalised examples from University of Colorado websites (FERMIONIC CONDENSATES ARE DANCERS (: 2)), nicely sidesteps the old philosophical stance that 'scientific language should exist free from metaphor and analogy.' (: 6) Instead, the Lakoff school's notion 'that analogies form a part of our conceptual system' (: 6) is given scientific pedigree, through Maxwell's exemplary use of a 'fluid' analogy (: 2). Further study of Maxwell's muscular metaphors²⁸ would support Podolefsky's findings that 'analogies may be both communicative and generative' (: 3); and that 'effective teaching strategies' require analogies groundable in students' prior knowledge and culture: 'the analogy cannot be too abstract.' (: 16)

Podolefsky uses Rutherford's planetary model of the atom as an example in three ways:

1. to illustrate 'a subtle distinction' (: 2) between Lakoff's 'metaphor' and Gentner's 'analogy';
2. to demonstrate that Lakoff and Gentner's terms are, for effective teaching purposes, 'interchangeabl[e]' (: 2);
3. to show how the generative analogy of a paradigm can remain communicative after it shifts.²⁹

Re. 3., Rutherford's planetary model generated better explanations of experimental results than Thomson's competing 'plum pudding'; since the ascendance of wave-mechanical models, Rutherford's is nonetheless still used 'to communicate an introductory atomic model to physics students'. (: 3). Here's how Podolefsky represents it as a Lakoffian metaphor, but with Gentner's term 'base' for the source domain.

The Planetary Model of the Atom

Solar System (Base Domain)	Atom (Target Domain)
Sun	Nucleus
Planets	Electrons
Sun attracts planets	Nucleus attracts electrons
Sun is more massive than planets	Nucleus is more massive than electrons

‘With a formalism more familiar to mathematicians’ (: 5), Podolefsky presents Gentner’s *Structure Mapping Theory*³⁰ as a more *abstract* and *empirical* model of ‘analogy’ (the term Podolefsky prefers to ‘metaphor’ by 82 to 17 uses). Here’s Podolefsky’s figure of Gentner’s model of Rutherford’s analogy:

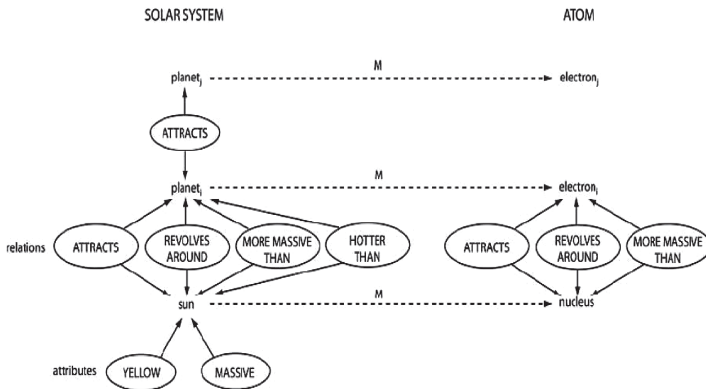


Figure 1. Structure-map for the Rutherford analogy: “The atom is like the solar system.”

Among Gentner’s domain comparisons, *analogy* is differentiated from *literal similarity* thus: single-input *attributes* (HOT(sun)) may be compared across two domains (HOTTER THAN), but are less likely to be *analogically* mapped than dual-input *relations*, eg:

$$(\text{ATTRACTS}(\text{sun}, \text{planet}) \rightarrow (\text{nucleus}, \text{electron})).$$

This formal notation aspires to Gentner’s third category of domain comparison, *abstraction*, wherein ‘the base domain is an abstract relational

structure' (: 6). As an expert physicist, Podolefsky knows novices must learn how to 'think in terms of abstractions' (: 15), eg:

(\rightarrow ACQUIRE(*metarepresentational competence*) (: 8)).

However, prior research seems to indicate that, in Gentner's terminology, the *analogy* leads to conceptual change more readily than the *abstraction*. (: 15)

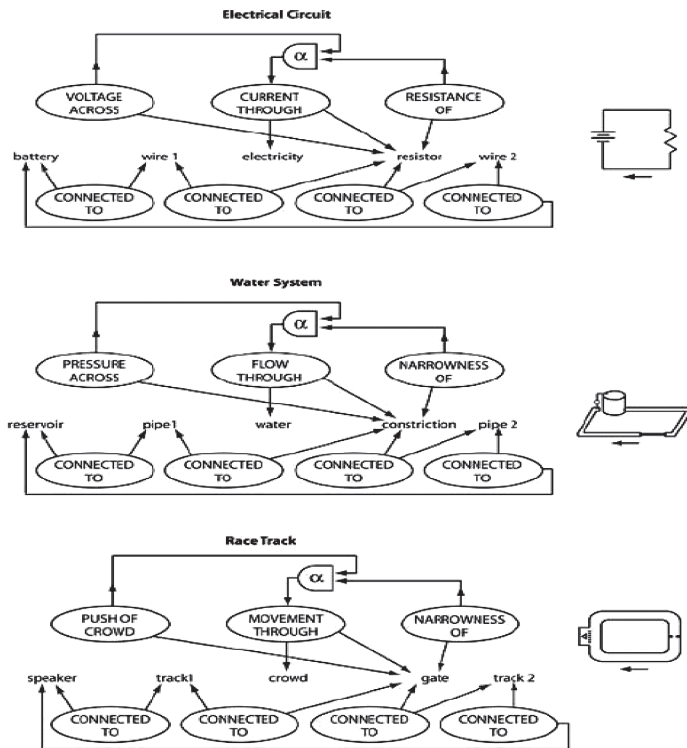


Figure 2. Structure-map for electric circuit and water system, adapted from Gentner's original paper.

How analogy selection effects conceptual³¹ change was tested by Gentners, with regard to understanding of electricity from two base domains: i) water and ii) moving object (race track). See Podolefsky's adaptation of Gentner's structure-map (above), but remember: neither analogy has 'all the correct

properties of electric circuits' (: 9). Others (bicycle chain?) may also fit. The Gentners predicted that i) the water analogy would generate better understanding of batteries, while ii) imagining crowds moving would yield better concepts of resistors. When high school students generated their analogies *spontaneously*, both predictions were confirmed; but when these analogies were pre-taught, the water system failed to produce better answers to questions about batteries.

Podolefsky makes the educational implications clear: if 'inferences people make on a certain topic vary according to the analogies they use' (: 8), then:
the success of an analogy-based teaching method depends on student knowledge of the base domain (i.e. prior knowledge), and student acceptance of the analogy. (: 12)

This in turn relies on teachers and textbooks intercepting common student misconceptions in intermediary steps, between grounded sense and targeted abstraction.

Lakoff's idea of layering may prove useful—students may develop the skill of abstraction by building upon lower level analogical thinking skills.' (: 15)

A good case study here would've been Arons' in(ter)vention of 'internal energy' to forestall common 'infelicities' in teaching the Work-Kinetic Energy Theorem:

introducing what amounts to the First Law of Thermodynamics right at the start. This can be done without excessive abstraction and without the more sophisticated mathematical apparatus usually associated with formal thermodynamics.³²

Do the intuitive directions of both Gentners' formally structured analogies AND Lakoff's experientially mechanistic metaphors look familiar in the following form?

BASE/SOURCE → LAYER₁... → LAYER_N → TARGET

Yes! It's that scourge of constructivist science communicators, the cognitive-deficit/transmission model (or conduit metaphor³³), in yet another authoritative disguise! Is it any wonder Podolefsky finds 'few studies have

examined spontaneous generation by students.’ (: 14) Indeed, when 31 of their 46 high school subjects spontaneously conceived of electricity in terms other than water OR moving crowd, the Gentners excluded them! (: 9) Outside the control boxes of research, however, Podolefsky thinks teachers should encourage nonlinear thinking:

Simultaneous domain comparisons may lead students to extract abstract structure and develop conceptual knowledge.’ (: 15)

We want our students to understand batteries AND resistors, don’t we?

2.3 Counter-intuitive embodied concepts?

In *Making Truth: Metaphor in Science*, practising scientist and science-administrator Theodore L. Brown seeks ‘a new perspective on the ways in which science gets done.’ (2003: 1) It should be inclusive of ‘public policy questions with important ethical and economic implications’; and address the fact that ‘the text materials used in science education are defective.’ (: 2) Brown begins with Polyani’s post-Popperian popularisation³⁴ of sleepwalking scientists, who only vaguely intuit their vision of a dynamic hidden reality:

The shifting character of that vision is determined for the individual scientist by the twin characteristics of intuition and imagination. (: 7–8)

These implicit epistemological processes being largely unconscious, artificial intelligence has so far failed to emulate them. (: 9) Brown’s new perspective on metaphor in science is consequently more 20th Century Lakoff than 21st Century Gentner.

In *The Books*, ‘relativity’ collocates significantly with ‘counterintuitive’. In the Lakoff School, this seems paradoxical. How, from physically grounded inferences, could Einstein have constructed ‘counterintuitive theoretical ideas that defied the evidence of the senses’? (: 10) Brown’s answer: young Einstein’s imaginings, while ‘counterintuitive in terms of a *Newtonian* conception of the world’, needn’t be so to *Einsteineans*:

the physical premises of the gedankenexperiment were extensions of Einstein’s everyday physical experiences.[...] His genius lay in thinking about those experiences in novel ways. (: 11)

Teach Special Relativity to children without prior layerings of Newtonian

prejudice, and you'll discover spacetime has always been a common sense preposition:

For in language—any language—no two domains are more intimately linked than space and time.³⁵

Space	Time
<i>from</i> London	<i>from</i> today
<i>about</i> the town	<i>about</i> midnight
<i>through</i> the jungle	<i>through</i> the month
<i>out of</i> Africa	<i>out of</i> term
<i>at</i> the door	<i>at</i> noon
<i>by</i> the window	<i>by</i> tomorrow

Quantum theory also

seems to spell trouble for the idea that science proceeds using models based on embodied experience with the macroscopic world. (Brown: 88)

A Rutherford, schooled in the physical forcefields of Newton and Maxwell, simply could not reverse-engineer the abstract mathematical models of a Bohr:

how does an electron decide what frequency it is going to vibrate at when it passes from one stationary state to another? (: 88)

It doesn't, answers Brown:

the transition occurs essentially instantaneously; there is no clear physical model (: 88).

Even if there was, any instrumental measures to test it would (like their mathematical interpretations) be 'representational metaphors'³⁶, of a world no human sense can never scale.

For example, the colour in scanning tunneling microscope pictures is added for visual effect; it is not inherent in the data. (: 98)

These constructivist paradoxes aside, Brown remains a committed scientific realist:

The images we obtain are indeed based on a stable, mind-independent reality. (97)

So what *is* the privileged status of science's relationship with it? Brown

says our instrumental readings of (and mathematical writings about) quantum scale events

are constructs that at their best represent reliable models of reality, with sufficient verisimilitude to serve as productive metaphors. (: 99)

Their productivity is usually technological, and often exaptive—unless television was the final cause of Thomson’s model-testing cathode ray tube!

Like authentic anecdotes in The Books, Brown’s case studies show scientific ‘seers’ often wonder what to *make* of what they’ve seen; more technically-minded ‘craftspeople’ have to show them.³⁷ Uncertain seers don’t produce the best pedagogical metaphors either.

But it is clear that to put the uncertainty principle into terms that have meaning for most people, a simple physical metaphor *is* needed. (: 93, *italics mine*)

Figure this! Heisenberg’s gamma-ray microscope gedanken reformulated (in part)¹⁷

$$\langle p_x \rangle = \frac{h}{\lambda} \int_{\theta=0}^{\theta=\theta_0} \int_{\phi=0}^{\phi=2\pi} (1 - \sin \theta \cos \phi) \sin \theta \, d\theta \, d\phi$$

$$\times \left(\int_{\theta=0}^{\theta=\theta_0} \int_{\phi=0}^{\phi=2\pi} \sin \theta \, d\theta \, d\phi \right)^{-1} \quad (4)$$

and

$$\langle p_x^2 \rangle = \frac{h^2}{\lambda^2} \int_{\theta=0}^{\theta=\theta_0} \int_{\phi=0}^{\phi=2\pi} (1 - \sin \theta \cos \phi)^2 \sin \theta \, d\theta \, d\phi$$

$$\times \left(\int_{\theta=0}^{\theta=\theta_0} \int_{\phi=0}^{\phi=2\pi} \sin \theta \, d\theta \, d\phi \right)^{-1}, \quad (5)$$

Einstein was a seer who made good common sense. Heisenberg’s ‘gedanken’, on the other hand, doesn’t help Lakoff School teachers embody counterintuitive quanta. (: 92) Is it because:

Heisenberg’s thought experiments in the original form cannot be regarded as illustration of the uncertainty principle implied by the mathematical formalism of quantum mechanics?³⁸

If so, we need a better *non-mathematical* illustration, for all the reasons Brown has just shown us: uncertainty *is* fundamental to our best scientific reality; we can ‘see’ it *only* through representational metaphors; these *need* to be clear enough to teach to schoolkids; the existing educational texts *aren’t*.

Yet, if wave/particle duality describes the world humans and language evolved in, we must *always* have had novel³⁹ ways—beneath careful layerings of troubled denial—to re-spell it.

Imagine yourself at Einstein’s autopsy, watching them trying to gauge the full *measure* of the man, by cutting up his *brain*. Dead-certain of his body’s *position*, aren’t you *simultaneously* mystified about the *momentous* influence of Einstein’s *mind* across *fields* of knowledge? For even as you *observe* with *gravity* the *singular* end of their *originator*, Einstein’s thoughts are having a *forceful* effect *at a distance*. Through his language, countless persons are *virtually interacting* with Einstein the man; his *ideas* continuing to alter *reality* as if—*improbably*—still Einstein lives! As for you—one *particular* observer whose path just *collided* with a famous *decay*—isn’t your *individuality* now and forever caught up in *waves* of history? You’ll be moved *physically* and *mentally* in ways you’ll never completely *relate*, as the *media* outside the inquest *accelerate* the story—*eventually*, you’ll move others too!⁴⁰

2.5 Where mathematics comes from

However intuitive, science-as-language must do justice to an experimental reality which we know to be mind-independent, as it “kicks back” in a complex, autonomous way’. (B7: 223) Equally, science-as-language teachers must respect ‘the unreasonable effectiveness of mathematics’⁴¹ at accounting for that reality (B6: 194). Otherwise, they won’t be teaching the laws of physics, or communicating how physicists believe they know them.

Speak to physicists, and most of them will talk as if the laws are *real things*—not physical objects, of course, but abstract relationships between physical entities [...] relationships that really exist, ‘out there’ in the world, and not just in our heads. (B5: 12)

There’s much more evidence in The Books of what L & N call this ‘romance’ of mathematics. (2.7)

If we're to speak a language in which string theoretical ideas can make productive sense, we'll need to embody their mathematical meanings in it; i.e.

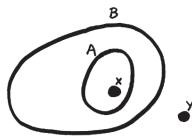
dispel the paradoxes and clear away the shrouds of mystery to reveal in full clarity the magnificence of those ideas. (L & N: 5–6)

Stuck in some Ordinary Level equations at school, I once complained to my genius friend, 'I don't know how to do this.' He looked at my paper and said, 'Yes you do, idiot; you've got the right answer!' I had, but I didn't *understand* why. How on Earth *did* he?

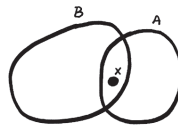
The meaning of mathematical symbols is not in the symbols alone and how they can be manipulated by rule [...] Ultimately, mathematical meaning is like everyday meaning. It is part of embodied cognition. This has important consequences for the teaching of mathematics. (L & N: 49)



(a)



(b)



(c)

L & N propose a courteous translation from the sensory-motor schemata in which maths is grounded (e.g. Source-Path-Goal: 37; Container: 32, pictured above), up into such multi-layered abstractions as $e^{\pi i} + 1 = 0$ (: 381–451); and back down again. If we want said translation (and its multimodal

illustrations) legitimised for science teaching, we must provide scientific evidence for the claims it's making. L & N take this bottom-up approach. They provide convincing support for the evolutionary and developmental origins of arithmetic in the subitising abilities demonstrated by animals and infant humans (who can all count up to 3, but get confused around 4!). (: 19–23) From plausible (if less established) evidence from cognitive science, L & N then argue 'the most fundamental mathematical ideas are inherently metaphorical in nature' (: xvi). Contemporary mathematicians⁴² are unlikely to be put out by any of this; physicists may await firmer proof of its neurological basis. In the meantime, will L & N help mathematical novices like me?

One of the principal results in cognitive science is that abstract concepts are typically understood, via metaphor, in terms of more concrete concepts. (: 39)

From this result came the linear SOURCE→TARGET mappings of the Lakoff School, such as the following, 'from the domain of physical objects to the domain of numbers' (: 55):

ARITHMETIC IS OBJECT COLLECTION	
<i>Source Domain</i> OBJECT COLLECTION	<i>Target Domain</i> ARITHMETIC
Collections of objects of the same size	→ Numbers
The size of the collection	→ The size of the number
Bigger	→ Greater
Smaller	→ Less
The smallest collection	→ The unit (One)
Putting collections together	→ Addition
Taking a smaller collection from a larger collection	→ Subtraction

'Object Collection' (above) is the first of L & N's four *grounding metaphors* (the 4Gs), which allow humans to extend numerical concepts beyond subitising 'while preserving the basic properties of innate arithmetic'

(: 77). The others are: ‘Object Construction, the Measuring Stick, and Motion Along a Line.’ (: 75) These seem like sensible beginnings for primary school shapes and sums. Nonetheless, an elementary problem is left over:

In our everyday experience, the result of taking a collection of seven objects from a collection of seven objects is an absence of any objects at all—*not a collection of objects*. (: 64)

In a manoeuvre reminiscent of unreasonable effectiveness in The Books, L & N fix this with ‘a metaphor that creates something out of nothing’ (: 64):

THE ZERO COLLECTION METAPHOR

The lack of objects to form a collection → The empty collection

But isn’t this an inference backwards from ABSTRACT→CONCRETE? It seems even at low-levels, *entity-creating metaphors* can be disorientational⁴³!

The conduit metaphor (SOURCE→TARGET), on which L & N’s conceptual metaphors were historically based, has oversimplified their presumed neurological substrate. Individual neurone outputs *are* unidirectional all-or-none signals; but each *one* is the sum of *many* excitatory and inhibitory inputs. (Natural language nodes reflect this, cf reference-ambiguity in my previous ‘their’). Moreover, L & N acknowledge that communication between brain regions involves a conflation of simultaneously-activated, multiply-networked neuronal links—

links that often result in conceptual metaphor, in which one domain is conceptualised in terms of the other. (: 42)

So to sustain the mathematical inferences generated by their dual-domain simplifications, L & N must inhibit otherwise self-evident (neurotic⁴⁴?) complexes. How else could the following metaphor masquerade as CONCRETE→ABSTRACT? (: 142)

THE NATURAL NUMBERS ARE SETS METAPHOR	
Source Domain SETS	Target Domain NATURAL NUMBERS
The empty set \emptyset	→ Zero
The set containing the empty set $\{\emptyset\}$ (i.e., $\{0\}$).	→ One
The set $\{\emptyset, \{\emptyset\}\}$ (that is, $\{0, 1\}$)	→ Two
The set $\{\emptyset, \{\emptyset\}, \{\emptyset, \{\emptyset\}\}$ (i.e., $\{0, 1, 2\}$)	→ Three
The set of its predecessors (built following the above rule)	→ A natural number

In L & N's terms, the above was a *linking* metaphor, different from a *grounding* in that:

both the source and target domains of the mapping are within mathematics itself. (: 142)

The result is a *metaphorical blend* of two distinct cognitive structures, whose entailments may include the creation of new entities in *both* domains (: 48). Try 'stretching the 4Gs' (: 89) up through layers of such blends to the next example, then ask yourself: which domain is more concrete, Source or Target? (: 263)

A SPACE IS A SET OF POINTS	
Source Domain A SET WITH ELEMENTS	Target Domain NATURALLY CONTINUOUS SPACE WITH POINT-LOCATIONS
A set	→ An <i>n</i> -dimensional space— for example, a line, a plane, a 3-dimensional space
Elements are members of the set.	→ Points are locations in the space.
Members exist independently of the sets they are members of.	→ Point-locations are inherent to the space they are located in.
Two set members are distinct if they are different entities.	→ Two point-locations are distinct if they are different locations.
Relations among members of the set	→ Properties of space

Answer: it depends on the order of your prior courses in maths! Gentner's abstract analogies *are* more fitting here than L & N's embodied metaphors.

(2.2) The 4Gs may well be part of ‘the cognitive unconscious’, arising from our ‘commonplace experience’ as children, and subsequently ‘extremely common in everyday thought and language’. (: 41) But you don’t need to rise to a very high consciousness of mathematics to get disoriented with regard to earthbound spacetime. Indeed, counterintuitive directions are now emerging at almost *zero*-level complexity in *computer* mathematics (e.g. Wolfram’s Rule 30 cellular automaton (2002: 27)). To fit the ICT-ecology of this new kind of Mathgod, Lakoff School principles of *human* mathematics may need revising.⁴⁵

The results of our inquiry should not change mathematics in any way, but they may radically change the way mathematics is understood and what mathematical results are taken to mean. (: 8)

2.6 The basic metaphor of infinity

∞

2.7 Back to zero!

Metaphor: LoveIsAJourney

Source Domain: Journey

Target Domain: Love

Mapping:

Travelers	→	Lovers
Vehicle	→	Relationship
Destinations	→	LifeGoals
ImpedimentsToMotion	→	Difficulties

Evokes:

Purposes Are Destinations Metaphor,
with Destinations = Self.Source.

Destinations

Purposes = Self.Target.LifeGoals

Difficulties Are Impediments to Motion

Metaphor,

With Impediments to Motion =

Self.Source.ImpedimentsToMotion

Difficulties = Self.Target.Difficulties

Lakoff's paper in the 2008 *Cambridge Handbook of Metaphor and Thought* devotes significant space to Feldman's NTL, 'a must-read for metaphor theorists'. (: 17) Under headings like 'Embodiment and Simulation Semantics' (: 18) and 'Neural Choreography' (: 20):

The NTL perspective provides a very different way of thinking about such complex metaphors (: 25)

as were analysed in THE OLD THEORY. (: 24–5) NTL notation (: 37, scanned & pasted above) evinces how AI models and fluid analogies are now changing Lakoff's minding⁴⁶ of natural language:

This is where we are in the neural theory of metaphor as of November 2006.

We have a reasonable early approximation to the kinds of computations that neuronal groups must perform to characterise [metaphors, blends, etc]. A parsing program to use these kinds of constructions is being constructed.

This computer-applied shift in Lakoff's old-School methodology must have implications for some of its human-theoretical principles.

The physicists who may have been awaiting a firmer basis for metaphor/analogy in mathematics (2.5) might now be tempted into interdisciplinary meetings of minds. If human intuition (pattern recognition?) is anything to go by, the neural substrate of NTL is where the hardware and software of a quantum-computational fabric of reality might actually merge (B7: 194). I said 'merge', but the nominalisation (2.1) 'emergence' (: 32, B7: 362–4) would be a more productive word-level metaphor to map (graph-theoretically? (3.3)) across the cutting edges of both the Lakoff School and The Books. An even more precise topological⁴⁷ term for transdisciplinary corpus analysis (3.1) is 'symmetry'. Be courteous:

Symmetry is a sacred word to most physicists. One might conjecture that other communities value symmetry highly as well. [...] Spontaneous symmetry breaking is not only ubiquitous in physics, but is a prevalent feature of everyday life. **Lisa Randall** (B3: 191 & 205)

Neurones [...] involved in physical bodily functioning tend to fire more. For this reason, the metaphorical maps learned are asymmetric and tend to have physical source domains (though some have social source domains). **George Lakoff** (: 28)

In Gentner-style notation (2.2):

$$\text{TOE}_{\text{PHYSICAL}} \{\text{emergence, symmetry}\} \leftrightarrow \text{TOE}_{\text{PSYCHOLOGICAL}} \{\text{emergence, symmetry}\} \rightarrow \text{TOE}_{\text{BIG}}!$$

(a) (b)

Developmental considerations in NTL might also generate transdisciplinary insights. If ‘children pick up some general information about the sound patterns of their language even before birth,’⁴⁸ then the new Lakoff School may have to reverse the polarity of its old SPACE→TIME metaphor (as it did ARGUMENT↔WAR). Aural ante-natal experience of the mother’s biorhythms and intonations in time happens *prior* to visual-tactile, post-natal exploration of space. The multi-modality of NTL modelling (: 19) means the sensory-motor dimensions of our SPACETIME experiences might be unfolded from their compactifications in wombs and brains, and mapped across the creative braneworlds (B3: 50–4) of post-quantum physics.

Núñez’s paper in *The Cambridge Handbook of Metaphor and Thought* remains preoccupied with just such *human* dimensions of mathematical language. He gets stuck where I did too, in the nominalised ε – δ approach of mathematicians to the infinite continuities they intuit from limited iterative computation (: 343–349). Has he momentarily forgotten that the Basic Metaphor of Infinity (2.6) he co-developed for the Lakoff school should *not* be taken too literally?

We can observe that there is *no motion* whatsoever involved. No entity is actually *approaching* anything or moving *beyond* anywhere. So, why then did these respected Russian mathematicians use dynamic language to express static properties of static entities? (: 344)

I asked a Russian mathematician⁴⁹ to resolve Núñez’s linguistic confusion, and he pointed out that Núñez is already well on the way to doing so himself. Núñez’s studies of maths lecturers’ gestures show how a verbal grammatical metaphor (2.1) can coexist with and be complemented by a ‘forgotten dimension of thought and language’ (: 352) —one of the ones NTL is, even as we speak, encoding for the Lakoff School.

Núñez's 2008 paper re-emphasises his 2000 'romance' (with Lakoff) of *human* mathematics. I would appreciate L & N's pedagogy more if they devoted less obsessive spacetime to an ancient cognitive dissonance which, after Gödel⁵⁰, cannot ever completely be fixed. Of course, it's part of being human to *want* to put our fingers on mercurial ideals; but their philosophical reification is just a grammatical trick (2.1). They *will* move us again, as discourteous translations of the foundation stones we thought we'd overkilled for dead certain. *Nothing* we can do will forever stop the universe thinking! Consider these premises of the romance of mathematics, every one of which appeared false to L & N at the millennium:

- Mathematics is part of the physical universe and provides rational structure to it.
- To learn mathematics is to learn the language of nature, a mode of thought that would have to be shared by any highly intelligent beings anywhere in the universe.
- Machines can, in principle, think. (: xv–xvi)

Now compare the Lakoff School's new NTL syllabus.

- Mathematics is physically embodied in the neurochemistry of the brain.
- *Terrestrial* animals share that neurochemistry and thus the early stages of an evolutionary programme which developed into human arithmetic. (Watch this space for more from SETI and AI!)
- Computer simulations of human cognitive processes are beginning to generate meaningful results.

Surely, Lakoff School teachers can't continue refuting a 'romance' on which their most progressive lessons are self-evidently founded. To do so would mean returning to that *Philosophy in the Flesh* which Lakoff and Johnson once took great pains to leave behind (when according to Hofstadter, Mathgod already had). Is there a theory of EVERYTHING big enough to reconcile our reactionary human discomfort with the emergence of artificially-intelligent designs? It's getting harder even to ask the appropriate question!

We don't know what planetary common sense will emerge round the

current ICT-metaphorical twist. A theory of *anything* might prove exaptive, and in a school where playing with *everything* is positively encouraged, *anyone* might find stumble on *something* scientifically useful. So having got well and truly **strung out on analogies of everything**, we'll need to come gently back to an earth whose educational climate is fast-changing. How a language teacher made passable sense of such science-seeming abstractions will be the subject of my forthcoming paper in *Mulberry* 59 (2010), to include examples for teaching from The Books.

Endnotes

Preface

- 1 Medawar 1990
- 2 Bruner 1996: 95
- 3 Turney 1999: 132
- 4 Irwin 1999
- 5 Lakoff 1972 in Jordan 1997: 240
- 6 Brockman 1995

1. Introduction

- 7 de Bono 1999
- 8 Hawking 1989: ?
- 9 Kaku & Thompson 1995: 48
- 10 Randall 2006: 24 & 99
- 11 Davies 2007: Index
- 12 Woit 2007: xvii
- 13 Deutsch 1997: Praise for
- 14 Hubbuck 2006: 144
- 15 Hubbuck 2008b: 80–82
- 16 Martinich 2008: 469
- 17 Stannard 1998
- 18 Hofstadter 1995: 182
- 19 Freud 1999
- 20 Hofstadter 1995: 38
- 21 Devlin 1998: 156

2. Review

- 22 Lakoff & Johnson 1999
- 23 Hubbuck 2009: 150
- 24 <http://www.isfla.org/Systemics/>
- 25 Cox & Hill 2004: 229
- 26 Macmillan 2007
- 27 Peat 2008: 2
- 28 Cat 2001
- 29 Kuhn 1996
- 30 Gentner & Bowdle 2008: 109
- 31 Feldman 2008: 307
- 32 Arons 1997: III: iii
- 33 Reddy 1993
- 34 Fuller 2004: 59
- 35 Deutscher 2005: 134
- 36 Stahl 1987: 60
- 37 Smolin 2006: 308
- 38 Home & Sengupta 1983: 567
- 39 Stannard 1994
- 40 I couldn't determine this writer's real position.
- 41 Wigner 1960
- 42 Devlin 2000
- 43 Lakoff & Johnson 2003: 264
- 44 Borbely 2008: 414
- 45 Núñez 1995
- 46 Ryle 2000
- 47 Devlin 1998: 246
- 48 Feldman 2008: 311
- 49 Alexey Valer'evich Shchuplev, friend & colleague
- 50 Hofstadter 1999: 86

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