WHY JUST TEACH ART: THE DEVELOPMENT OF THE HIPPOCAMPUS

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ABSTRACT

That we intuitively feel a need to teach children what we consider the rudiments of education, approximately as soon as they are socially adept enough to attend school is not unjustified (eg. the "core curriculum standards" adopted by US public schools). However, there is a deeper technical issue to be considered, one that proves remarkably simple. Though the role of the hippocampus, within the larger function of the brain, is hardly well understood, there is ample evidence of its role in a particular aspect of memory, namely metacognition*, or "knowing about knowing." More neurologically informed consideration for the distinct memory systems that contribute to cognition revels that these rudiments may be entirely artificial and based on "adult-centric" conceptual frames. Moreover, given that the hippocampus is only fully formed by early adulthood, this would indicate that our educational itinerary may easily be fundamentally flawed, and at least warrants radical reconsideration.*

KEYWORDS

art education, concept development, hippocampus, memory systems

1. INTRODUCTION

It is impressive that that the documentation and subsequent theorization of human developmental stages by Jean Piaget are extremely consistent with neurological studies primarily only available to us decades later. Piaget's insights are certainly very familiar in the field of education, but are often misrepresented or absent in discussions regarding the web. Because web technology generally wields far more influence than child development for scientists of other disciplines, such as computers and even philosophy, the topic easily becomes convoluted as it is passed from various experts to laymen. Ordinarily, a lack of understanding might be easily overlooked. However, it so happens that the Piagetian model also has relevance, well beyond child psychology, to the study of nonhuman minds (ethology) and cognitive science. Understanding the broader significance can be thwarted by a certain academic xenophobia. Nonetheless, addressing a neurological mechanism for a greater understanding of effective learning requires us to delve into a wider range of topics.

2. CONSTRUCTIVISM[1]

In particular, we initially need to address the most influential of Jean Piaget's theories, better known as Constructivism, which he had originally called *Genetic Epistemology*. Constructivism

1. I will assume most readers will be rather familiar with Piaget and his influential Constructivist theories, as well as Constructivist practices in the classroom. We merely discuss aspects here that pertain directly to the current thesis. However, for interested readers more comprehensive introductions regarding education and (mostly primate) cognition respectively are offered in …

* Catherine Twomey Fosnot, (Ed.) (2005) *Constructivism: Theory, Perspectives, and Practice*. New York, NY: Teachers College, Columbia University
* Langer, Jonas and Killen, Melanie (Eds.) (1988) *Piaget, Evolution and Development*. Georgia State University and Mahwah, NJ: Lawrence Erlbaum and Assoc.

can be viewed from two distinct perspectives. In a philosophical sense, epistemology refers to the nature of ideas, and how they might occur in the mind. Constructivism offers a plausible explanation about what ideas actually are, that stands as an alternative to Platonism. Platonism is deeply rooted in the sciences, that ideas do not obey any physical law, but do exist beyond the mind in a perfect abstracted form. These ideas are somehow acquired by the mind, and in doing so are subject to degrees of corruption. No physical explanation is given as to how this might take place, though it is common to scoff at René Descartes' suggestion, in the primitive days of neurology, that this is accomplished by the pineal gland. However, without an alternative suggestion, Platonism remains entirely a matter of faith, even for scientists who adamantly object faith play any part in scientific evidence.

2.1. Two Ways to Consider Constructivism

In the Constructivist scheme, essentially no idea need exist in the a priori universe, that ideas are the net result of ongoing construction within the mind only. A ramification may prove illustrative. A traditional orthodox notion is that there exists an entity that is perfect English, with a perfect grammar, and comprehensive list of all vocabulary therein, where slang might be compared to and rejected on the basis that it is not included in this ideal list. Now imagine that 100 minds store 100 slightly imperfect copies of this entity, in order to implement it for the sake of communication. Constructivism states that there is no entity English, that there are only configurations within individual minds that result in English being manifested. There exist at least the number of cognitive/motor strategies with the result of English as individual minds. The desire to communicate encourages each individual to coordinate these results with other individuals. The fact that there are an enormous number of encounters during which individuals wish to communicate, ensures that their linguistic strategies will be similar.

We now zoom in our focus to address a more practical issue for the classroom, where Constructivism is a style of teaching. It is an alternative to traditional dictation. While developing minds can be told facts to recall, and required to regurgitate them accurately, it has become apparent that this does not indicate that the child understands the facts, nor can generalize them to other contexts. In Constructivism, rather than tell students the correct answer and ask for it to be repeated back, the teacher presents the problem, leaving it to the student(s) to solve. Obviously, one cannot expect students to spontaneously guess the optimal solution on the first attempt. The teacher's role is then to further break down the problem, such that the children recognize the insufficiency of this first solution, and thus must work out a more formidable one. While this process is justifiably criticized as being slow and tedious, the dictatorial alternative may be executed more swiftly, but with hugely disappointing results.

These two scales of Constructivism, the macro view of the epistemological philosophy and micro view classroom practice, are complimentary. In their separate terms, each scale describes a mechanism, by which the brain builds ideas internally resulting in what we call learning. A specific area of the brain that is integral to learning is the hippocampus. There are two descriptions of its function, generally the version discussed in (human) neurology and the version discussed in nonhuman animal behaviour. Considering these aspects together reveals that these are descriptions of learning differing primarily in semantics. The integration between episodic memory and conditioning can be understood as a strengthening coordination of mapping.

2.2. Pruning and Exuberance

There is a fairly consistent schedule of exuberance/pruning in the brain [1,2] during childhood. We are born with potential neural networks for a wide variety of un-honed skills, called *exuberance*. By two weeks the vast majority of unused, un-strengthened paths are abandoned.

Less extensive *pruning* occurs again around age two, then around age six, to lesser degrees, at longer intervals, throughout life. It remains speculative that we can do much to radically alter this schedule, though we do affect the process via continual encounters with novel experience. A famous example of this process, mentioned above, occurs when newborn babies, un-exposed to languages other than Japanese, are then unable to distinguish |r| sounds in adulthood [3,4].

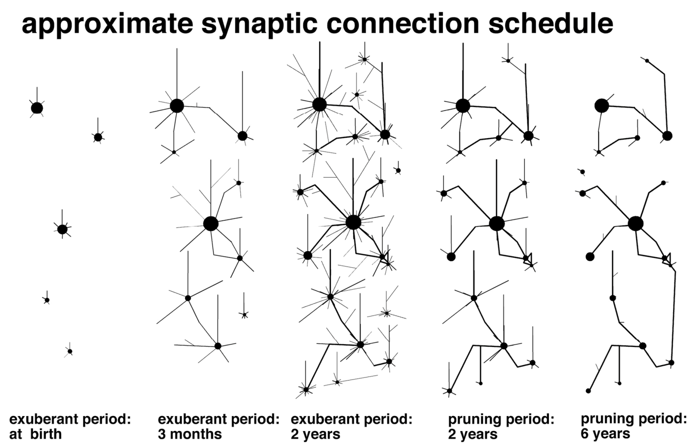


Figure 1: An approximate illustration of pruning and exuberance, showing how unused connections between neurons are lost drastically beginning after about two weeks.

We might also set our crucial learning deadlines according to Piagetian stages [5-7], which happen to be estimated during those same years, from about two to seven. Either way, there is likely a time period where the specific lessons learned by a child are not remotely as important as is the process by which the child learns to form concepts for themselves. Memorization of say multiplication tables are easily forgotten and often only understood insofar as they can be correctly – according to a teacher – regurgitated on tests. But, for instance, a child may discover a more fundamental notion in determining how much tea to make for all of the dolls to get a full cup.

Contrary to the idealization and oversimplification of the IC model for development, there is no universal way to learn. Each child merely follows interests to perform activities. Hopefully, the larger application of one of these games is understood. “Ah, the math problem 'three times six equals eighteen' is like if you had 6 dolls with 3 cups!” Obviously, this example is far too simple, and more accurately, realizations would build very gradually from much smaller steps. However, these steps do not always take the form of complete sentences or predication, and absolutely must be taken in the child's own terms, exploiting the strengths and weaknesses, of that child's idiosyncratic learning styles/intelligences [8].

Nonetheless, it is entirely sensible that one would want to take advantage of the child’s ability to “absorb” factual information [9], particularly because this ability is so astounding the younger children are. What is oversimplified though is the nature of the facts learned. The difference seems to hinge on *episodic* (remembered scenes) versus *semantic* (recalled facts) memory systems. For instance, a neonate might learn to fine-tune sensorial detecting processes (eg. French babies who learn to hear vowels, and Japanese babies who do not learn to hear |r|). However, a skill such as learning the violin or exposure to Mozart, is not generalizable, and does not result in a “smarter” baby, just one with an unusual skill/familiarity [10,11], possibly at the cost of redirecting important resources away from other, more crucial development [12].

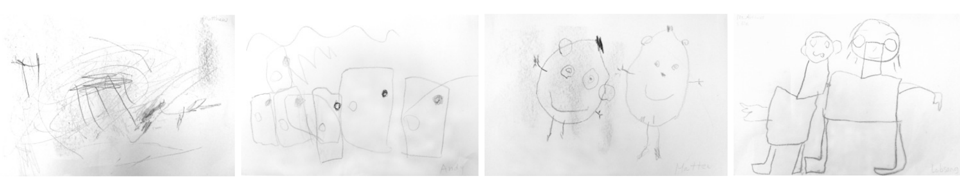
3. PROPOSED FUNCTIONS OF THE HIPPOCAMPUS

Though we are not yet certain about the role of the hippocampus in cognition, experimentation has yielded some indications. One thing is clear is that the hippocampus is involved in memory formation. However, lesion studies indicate these subsections (there are two) of neuroanatomy are not entirely crucial in the ways we might expect. For instance, mice can be trained by ordinary Pavlovian conditioning to press a lever to prevent a shock. The emotional trigger that encourages the animals' response has long been attributed to the amygdala, though not the association itself. Ordinarily, greater shocks induce more fervent lever pressing. Removal of a specific section of the amygdala does not appear to effect learning itself, but can diminish the enthusiasm with which the mice respond to varying conditioned stimuli [13].

Nonetheless, there may indeed be an unintuitive commonality between oft-noted hippocampal abilities, namely memory, navigation, spatial ability, *numerosity* (a sense of quantity). Specifically, these can all be thought of as increases in precision. A philosophical question to consider for the sake of this discussion, though it need not be answered conclusively, is whether the hippocampus offers a means to tighten focus on aspects of experience, or if reality is amorphous and vague, but humans project 'metrics' onto chaotic stimuli for the sake of cognition. In either case, we might imagine a scene filtered by varying degrees by this effect, leading us to consider the experience of the developing mind.

A conspicuous feature of planning is that it requires the processing of stimuli, which are not currently present. Planning is thus critically dependant on memory. While imagination can construct representations of events that have not, and may never, transpire, memories provide the raw material for these constructions. Many researchers have emphasized the importance of memory, and the neural substrates for memory in planning … Indeed memory of the past exists to promote successful behavior in the present…

While the inaccessible memories sufficient to support skills, like those needed for food processing or prey capture certainly prepare animals for behavioral needs, such memories probably cannot enter into planning as we normally think of it. Accessible memories appear to be subject to manipulation in flexible ways not evident with inaccessible memories… Such flexibility and manipulability would support the mental exploration of options to permit effective planning. [14]



Figures 2a-d. Four stages of kindergarteners' drawings observed by art teacher Meg Arthurs. (a) Marks on the page document gestural (and not visual or spatial) interpretations of haphazardly integrated concepts. (b) Shapes and designs replace gestures. (d) Shapes arranged as symbols, not yet according to visual stimuli. However, as in this example, the child does not have a holistic, adult concept of a person, but fragmented impressions. (d) The child begins to recognize a correspondence between the arrangement of symbols and visual (if only imagined) stimuli. The child begins to focus on holism of parts, but is not yet able to integrate the overwhelming number of details.

3.1. NAVIGATION AND SPATIAL ABILITIES

Many species of birds have been found to have far better numeric abilities in certain respects than most mammals, for instance in hiding and recalling the location of hundreds of caches of food over years [15]. But only humans count. Only humans put precise descriptions onto larger or smaller amounts. Human babies and nonhuman animals detect changes in quantity, distances, etc. [16] but only we adults put an exact number on things. This has fairly profound implications, especially for social coordination. Though the role of the hippocampus is still not well understood, it appears that numeric abilities, development in a comparable region corresponds to the advanced abilities found in birds, as well as differences roughly between sexes found in human hippocampi, occurs independently of precision elsewhere [17-20].

As the hippocampus is also thought to coordinate memory systems, undergoing significant development from birth to adolescence, tends to explain the stereotypical lack of concept integration observed in childhood. It is more accurate to say that a feature of neurons is memory, rather "Memory is a feature of neurons rather than a function of brain systems." [21], but this There are different storage/memory schemes for experiences whether implicit (hippocampal) or semantic/episodic (regulated by the amygdala) [22]. While the latter scheme of storing memories-as-things (possibly ionic charges) of by rote memorized facts and names for things is enticingly intuitive, it is not so clear how the former scheme would store memories emotions, procedures and conceptualizations. This highlights a need for the brain to have a means by which dynamic concepts might be treated as static objects. Mediation provides this bridge.

Though we might argue that the ability to contextualize information, even symbolically, allowing for prediction, which increases fitness [12,20], it is not evident how envisioning a holistic world with a degree of detail would be essential to prediction of some isolated event, which could easily be conceptualized/detected independently [23]. A crucial distinction need be made between volition and execution, for instance in attributing "intelligence" to entities that appear animated. Computers manage the assembly of computers. But recursion is hardly sufficient. What is intelligent is that the execution is not an end, but a means concocted, with no explicit connection provided between the goal and the strategy. In this scenario, there is no reason to believe the computers coming off the assembly line are intelligent. The computer/manager is only routinely obeying code. Only the human who designed this system as a solution to a personal need shows actual intelligence. The managing machine cannot be said to have needs. But the attribution of personality traits to the inanimate computer/manager often fools not only those in search of evidence of artificial intelligence, but many of us who merely engage in tool-use during play.

3.2. NUMEROSITY

Particularly when considering the effects perception has on our interpretations of number [16,24,25], we are forced to consider the question: What aspect of our experience can we objectively determine is not yet another quale? Of particular relevance to our discussion, estimation is not a less accurate version of precise counting, but that subtizing is a quale that is often performed in tandem to the cognitive activity counting, Kadosh and colleagues findings speculate that this provides an explanation regarding competing perceptive cues in the *Stroop effect* [26]. Ordinarily, this effect is observed in slower response times when subjects identify words, such as "red," that are presented in say blue letters. The experiment suggests that a momentary hesitation is caused by a cognitive strategy for automatically resolving, though not always accurately, conflicts between two perceptive systems. Just as the automatic apprehension of colour can be over-ridden but not suppressed, so too an estimation quale is likely involuntary, but can be upstaged by another conscious intentional process. This appears consistent with.

Is brain-and-mind based mathematics all that mathematics is? Or is there, as Platonists have suggested, a disembodied mathematics transcending all bodies and minds and structuring the universe – this universe and every possible universe? … The question of the existence of a Platonic mathematics cannot be address scientifically. At best, it can only be a matter of faith, much like faith in God. That is, Platonic mathematics, like God, cannot in itself be perceived or comprehended via the human body, , and mind... The only mathematics that human beings know or can know is, therefore, mind-based mathematics, limited and structured by human brains and minds. [27]

What is actually meant when we ask whether an organism understands number [28-30]? This single word “number” is used to refer to distinct cognitive skills. What we are questioning here is that there is no actual non-subjective evidence that these integers are not simply a subjective description like that of colour, which exists only in the imagination, triggered by hardly-understood anatomical mechanisms. Though we do not absolutely discount the possibility of counting numbers, we also do not see any hard evidence of them ‘out there’ beyond species-specific perception. We mentioned previously the ability to re-perceive multiple quantities as groups, as in subtizing [31,32]. Though it would be difficult to verify experimentally, consistent evidence occurs indicating that humans can increase this limit with years of extensive training in specific domains. Adults at the supermarket surely do not count every other customers’ items precisely to determine which register line will move the fastest.

The qualitative shift in effortful attention [33,34] between subtizing and counting also indicates that this reflex applies more broadly to amounts than merely numbers. For example, we can consider the gradual learning progression in Western music from a non-musician primarily oblivious to the chords heard, the novice musician painstakingly determining such chord spelling with mixed success, and the master musician with years of experience who, upon hearing the pitches, apprehends the harmonic structure, with near-perfect accuracy and no intentional effort. Other animals demonstrate varying abilities here [35]. For instance, pigeons show a remarkable ability to recognize quantities, though most mammals do not [36]. As adults, developed from infants, we do not replace our ability to estimate, but it appears that we sometimes enhance it.
In contrast, we also have an ability, that tends to require a bit of effortful attention, to use precise counting, which is generally only reliably testable in language-using subjects. Delving more deeply into why this should be so, involves thinking about the way brains construct conceptualizations from linguistic cues, termed *conceptual metaphor* [37-40], which differs radically from language determining how we think about things, such as numbers. Learning does take place without language, for instance to ride a bicycle. But often learning can be aided by utilizing concepts we already understand, in ways that that happen to recognize by their verbal role, namely embodied metaphor.

Integration of learning/interpretation schemata requires a robust hippocampus. Finger-counting is an example of children developing personal, embodied method of understanding *numerosity* (a closely related notion is described by Stanislas Dahaene as a “number sense”) [24,41]. In presenting novel stimuli to be comprehended, it would be fool-hearty to try to restrict the way the child from constructing a highly customized means to understand the stimuli presented. And yet teachers often do prohibit finger counting in the classroom, as if one might skip this step to reach generalization of numerosity. Anna Sfard describes a related conceptualization puzzle [42,43]. Children, who may be remarkable adept at transactions as cashiers in real-life markets, may have no idea how to perform the same calculations in class [44]. There is much speculation that cognition in children is limited due less to an ability to apprehend information, but to underdeveloped skills for coordinating framing schemes.

3.3. The Effect of the Hippocampal Developmental Schedule

Babies are born with a functioning hippocampus [45]. However, the brain continues developing during childhood. The hippocampus is perhaps one of the slowest sections to fully form. One reason for this is that a full sized brain would require a full-sized head, which would be much larger birth canal, such that women could not walk upright on two legs. Clearly, the way evolution operates cannot address this architectural problem. Rather, the organ simply does not stop growing with birth, but continues to increase in the number of neural cells, each adding a tiny mass, from conception throughout childhood. Organisms, most conspicuously our species, tend to make the best of such constraints. In fact, it is speculated that learning of a first language is facilitated by underdeveloped cognition [12,46,47].

A general finding … has been that younger children exhibit broader, more diffuse brain activation for cognitive control tasks as compared to adults. During development, these brain areas mature and the brain activity that correlates to task performance abilities (such as reaction time and accuracy) become more focal and fine-tuned. [48]

4. ART THERAPY

Though art therapy is primarily considered correctively, as a medicinal practice for patients suffering from some lack, this narrow limited view is hardly intrinsic to the process. While the word "therapy" brings with it negative connotations, cases illustrate ways that the practice of art making can enhance learning and cognition. A typical example was performed by Hendrixson [49] where a patient with the inability to form new memories is given a weekly art lesson, and creates a self-portrait using various media. The immediate solutions to goals (ie. how to apply paint to a canvas using a brush) are at first difficult. Though the patient has no memory of portraits from week to week, the patient tends to exhibit both an increased adeptness at the skill of applying paint, as well as signs of increased self-esteem and confidence for trying new things. This is obviously not universally true, but the point remains that the actual art-object created is incidental to the neurological effect produced. In less extreme cases, young students, with not-yet-fully-developed brains, are given problems in the form of artistic assignments, that are open-ended and thus customizable to each student's current cognitive skill. The aim of art class is hardly to create art, though this is certainly a conspicuous and even celebrated by-product. The aim is to exercise individual minds with appropriate tasks. By and large, curricula focused on closed-ended tasks, with there are correct answers, are often ineffective to a large degree in this respect.

5. CONCLUSION

… [C]hildren choose to attend or emphasize different attributes from adults, due to limited experience or lack of knowledge of culturally appropriate functions and their correlated form attributes. In such cases, children will form categories that are not isomorphic to adult categories, even though young children's beliefs concerning the basis for initial category formation are based on the same principals as adults' beliefs…Even a verbal explanation of why the new label is appropriate seldom results in change in the child's categorization system. Explicit feedback indicating that the child's label is incorrect, … also is unlikely to lead to change in the young child's categorization system…Older children, like adults, do not always accept the expert opinion. However, n contrast to the very young child who often is comfortable ignoring a contradictory adult label, the child who acknowledges he expert principal cannot simply ignore contradictory input. [50]

Though it is highly unpredictable when a particular child will have cognitively developed sufficiently to generalize abstract concepts such as mathematics, and apply them to practical concrete problems, or rather develop a culturally expected projection impulse, it is likely that this sufficient cognitive development for integration does not occur prior to about third grade [51.52]. Dictation may be effective for post-pubescent minds, as in learning from books. However, force-feeding younger children data, for instance requiring that children attend classes in mathematics, is almost certainly a waste of time and resources for both the schools and the children. In a few cases, children may develop faster, providing evidence to educators that dictation at this age should be viable. Rather, what many children do learn, because emotion learning develops earlier, is to associate academic environments with a feeling of disapproval.

However, weighing the consequences, regardless of whether this belief is justified, we propose the following. Given open-ended art lessons as problems, where the child has absolute freedom to employ whatever cognitive tools are at hand, insofar as the child is interested in solving the problem (lesson) the child will exercise those tools to the best of the child's abilities, pushing them further, just as a weight lifter trains muscles because there is a desire to do so. Children who have developed sufficient hippocampal abilities are certainly not at all harmed by this practice. In fact, they too benefit in the very same way. The benefits however are seldom recognizable to, and differ profoundly from those imposed by adults. On the other hand, many students will wind up discouraged, even by friendly teachers who insist on helping the child meet well intended but needless expectations.

Of course, in practice, in actual schools, one is also faced with deeply concerned, though not always well-informed parents, the intuitions and traditions of other educators. Even one hundred years after John Dewey's publications, the practicality of transformation from dictation in education is intimidating to many. However, it is evident enough that we are in a crisis situation regarding education. We do not have the luxury of conservatism. In the worst case, were this scheme outlined above implemented, a large number of children may 'lose' about three years of schooling. However, in the current state, many more children are apparently losing decades, avoiding education as much as possible. A pedagogue of copying and listening likely ensures that a few children learn a lot, and most children learn nearly nothing but perhaps a disdain for institutions and authority. Whereas in the proposed scheme, we can fairly be assured that by adopting a pedagogue of making and doing, the worst-case scenario would be that nearly all children learn a little. However, evidence points toward a much more positive outcome, not just for the children, but also practical financial pressures, where children will tend to have the cognitive tools necessary for later learning, without the psychological barrier built from past discouragements

REFERENCES

[1] Lise Eliot (1999) What's Going On in There?: How the Brain and Mind Develop in the First Five Years of Life, New York, NY: Bantam Books, pp. 27 – 32.

[2] Joseph LeDoux (2002) *The Synaptic Self: How Our Brains Become Who We Are*, New York, NY: Penguin Books, pp. 478 – 483, 516 – 517.

[3] Steven Pinker (1993) *The Language Instinct*, New York, NY: WW Norton, pp. 263 – 165.

[4] Katherine Yoshida, John Iversen, Aanirudh Patel, Reiko Mazuke, Hiromi Nito, Judit Garvain, & Janet Werker (2010) "The development of perceptual grouping biases in infancy: A Japanese-English cross-linguistic study", *Cognition*, 15, pp. 356 – 361.

[5] Morton Hunt (1993) *The Story of Psychology,* New York, NY: Doubleday, pp. 360 – 361.

[6] Jean Piaget (1955) *Language and Thought*, New York, NY: Meridian Books, pp. 171 – 221.

[7] Lev Vygotsky (1986) *Thought and Language*, Cambridge, MA: MIT Press, pp. 12 – 57.

[8] Howard Gardner (1983) *Frames of Mind: The Theory of Multiple Intelligences*, New York, NY: Basic Books.

[9] Maria Montessori (1967) *The Absorbent Mind*, New York, NY: Henry Holt and Company, LLC.

[10] David Campbell (1997) The Mozart Effect: Tapping the Power of Music to Heal the Body, Strengthen the Mind, and Unleash the Creative Spirit, New York, NY: Avon Books.

[11] Kevin Dunbar (2008) "Arts education, the brain and language", *The Dana Consortium Report on Arts and Cognition*. Washington DC: Dana Foundation/University of Toronto at Scarborough, pp. 81–92.

[12] David Bjorklund & Anthony Pellegrini (2001) *The Origins of Human Nature: Evolutionary Developmental Psychology*, Washington DC: American Psychological Association, ch. 4.

[13] Rudolf Cardinal, John Parkinson, Jeremy Hall, & Barry Everitt (2002) “Emotion and motivation: The role of the amygdala, vertral stratium, and prefrontal cortex”, *Neuroscience and Behavioral Reviews*, 26, pp. 321 – 352.
[14] Robert Hampton (2011) “Status of nonhuman memory monitoring and possible roles in planning and decision making” in Randolf Menzel & Julie Fischer (Eds.), pp. 105 – 119, *Animal Thinking: Contemporary Issues in Comparative Cognition*, Cambridge, MA: MIT Press, p. 112.
[15] Sara Shettleworth (1998) *Cognition, Evolution, and Behavior*, New York, NY: Oxford University Press.
[16] Edward Hubbard, Manuela Piazza, Philippe Pinel, & Stanislas Dehaene, (2009) “Numerical and spatial intuitions: A role for posterior parietal cortex?” in Luca Tommasi, Mary Peterson, & Lynn Nadel (Eds.), pp. 221 – 246, *Cognitive Biology: Evolutionary and Developmental Perspectives on Mind, Brain, and Behavior*, Cambridge, MA: MIT Press.
[17] Ultrich Nehmzow (1998) “’Meaning’ through clustering by self-organization of special and temporal information” in Chrystopher Nehaniv (Ed.), pp. 209 – 229, *Computation for Metaphors, Analogy, and Agent*s, New York, NY: Springer Verlag.
[18] Irwin Silverman, & Marion Eals (1992) “Sex differences in spacial abilities: Evolutionary theory and data”, in Jerome Barkow, Leda Cosmides, & John Tooby (Eds.), pp. 533 – 549, *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*, New York, NY: Oxford University Press.
[19] Alessandro Treves (2009) “Spatial cognition, memory capacity, and the evolution of mammalian hippocampal networks” in Luca Tommasi, Mary Peterson & Lynn Nadel (Eds.), pp. 41 60, *Cognitive Biology: Evolutionary and Developmental Perspectives on Mind, Brain, and Behavior*, Cambridge, MA: MIT Press.
[20] Jan Wiener, Sara Shettleworth, Verner Bingman, Ken Cheng, Susan Healy, Lucia Jacobs, Kathryn Jeffrey, Hanspeter Mallot, Randolf Menzel, & Nora Newcombe (2011) “Animal navigation: A synthesis”, in Randolf Menzel & Julie Fischer (Eds.), pp. 51 – 76, *Animal Thinking: Contemporary Issues in Comparative Cognition*, Cambridge, MA: MIT Press.
[21] Joseph LeDoux & Big Think (2010) “Big Think interview with Joseph LeDoux”, *Big Think*. June 24.
[22] Bernard Baars, & Nicole Gage (2010) *Cognition, Brain, and Consciousness,* San Diego, CA:Academic Press, pp. 325 – 330.
[23] Jeffrey Stevens (2011) “Mechanisms for decisions about the future”, in Randolf Menzel, & Julie Fischer (Eds.), pp. 93 – 104, *Animal Thinking: Contemporry Issues in Comparative Cognition*, Cambridge, MA: MIT Press.
[24] Stanislas Dehaene & Jean-Pierre Changeux (1993) “Development of elementary numerical abilities: A neuronal model”, pp.390 – 407, *Journal Cognitive Neuroscience*, vol. 5.
[25] George Lakoff & Rafael Núñez (2000) Where Mathematics Comes from: How the Embodied Mind Brings Mathematics into Being, New York, NY: Perseus Books.
[26] Roi Kadosh, Wim Gevers, & Wim Notebaert (2011) “Sequential analysis of the numerical Stroop effect reveals response suppression”, pp. 1243–1249, *Journal of Experimental Psychology: Learning, Memory and Cognition.* American Psychological Association. vol. 47, no. 3.
[27] *see ref. 25*, pp. 1–4.
[28] Deborah Schifter (2005) “A constructivist perspective on teaching and learning mathematics” in Catherine Twomey Fosnot (Ed.), pp. 80 – 98, *Constructivism: Theory, Perspectives, and Practice*, New York, NY: Teachers College Press.
[29] Anna Sfard (2008) Thinking as Communicating: Human Development, the Growth of Discourse, and Mathemetizing, New York, NY: Cambridge University Press.
[30] Giorgio Vallortigara (2009) “Animals as Natural Geometers”, in Luca Tommasi, Mary Peterson, & Lynn Nadel (Eds.), pp. 83 – 104. *Cognitive Biology: Evolutionary and Developmental Perspectives on Mind, Brain, and Behavior*. Cambridge, MA; MIT Press
[31] *see ref. 22*, pp. 485 – 487.
[32] *see ref. 25*, pp. 15, 17.
[33] Arne Dietrich & Oliver Stoll (2010) “Effortless attention, hypofrontality, and perfectionism” in Brian Bruya (Ed.), pp. 159 – 178, *Effortless Attention: A New Perspective in the Cognitive Science of Attention and Action,* Cambridge, MA: MIT Press.
[34] John Searle (2001) *Rationality in Action*, Cambridge, MA: MIT Press.
[35] John Pierce, (1999) “Consonance and scales”, in Perry Cook (Ed.), pp. 167 – 186, *Music, Cognition and Computerized Sound*, Cambridge, MA: MIT Press.

[36] Roger Thompson & Cynthia Contie (1994) “Further reflections on mirror-use by pigeons: Lessons from Winnie-the-Pooh and Pinnocichio too”, in Sue Parker, Roccia Mitchell, & Maria Boccia (Eds.), pp. 392 – 409, *Self-Awareness in Animas and Humans: Developmental Perspectives*, Cambridge, MA: Cambridge University Press.
[37] Jerome Feldman (2008) *From Molecule to Metaphor: A Neural Theory of Language*, Cambridge, MA: MIT Press.
[38] George Lakoff & Mark Johnson (1980) *Metaphors We Live By,* Chicago, IL: The University of Chicago Press.
[39] R. Seyfarth (1984) “What do vocalizations of monkeys mean to humans and what they mean to the monkeys themselves”, in Rom Harré & Vernon Reynolds (Eds.), pp. 43 – 56, *The Meaning of Primate Signals*, Cambridge, England: Cambridge University Press.
[40] Lev Vygotsky (1986) *Thought and Language*, Cambridge, MA: MIT Press, p. 71.
[41] *see ref. 29*, pp. 32, 50 – 53, 183 – 185.
[42] Maurice Bazin & Modesto Tamez (2002) *Math and Science Across Cultures*. San Francisco, CA: Exploratorium Teacher Institute.
[43] *see ref. 29*, pp. 10 – 15, 148.
[44] *see ref. 29*, pp. 149 – 154.
[45] Charles Nelson, Kathleen Thomas & Michelle de Haan (2008) “Neural bases of cognitive development” in Richard Damon and Deanne Kuhn (Eds.), pp. 19 – 53, *Child and Adolescent Development: An Advanced Course*, Hoboken, NJ: Wiley and Sons.
[46] Jerome Bruner, (1975) “Nature and uses of immaturity”, in Jerome Bruner, Alison Jolly, & Kathy Sylvia (Eds.), pp. 28 – 64, *Play: Its Role in Development and Evolution*, New York, NY: Basic Books.
[47] Terrence Deacon (1997) *The Symbolic Species: The Co-evolution of Language and the Brain*, New York, NY: WW Norton and Co., pp. 159 – 164.
[48] *see ref. 22*, p. 497.
[49] Rick Garner (2012) “Neuro-arts education: Neuroscience and education”, *The Humanities Collection*, vol. 9, no. 10, pp. 1 – 10.
[50] Carolyn Mervis (1987) “Child-basic categories and early lexical development” in Ulric Nesser (Ed.), pp. 201 – 233, *Concepts and Conceptual Development: Ecological and Intellectual Factors in Categorization*, New York, NY: Cambridge University Press, pp. 207, 225, 227.
[51] Chip Wood (1994) *Yardsticks*, Turners Falls, MA: Northeast Foundation for Children.
[52] Judson Wright (2013) “Can you tell me how to get, how to get to e-learning: Development and complexity”, Eletti, Valerio (Ed.), *Journal of e-Learning and Knowledge Society: Complexity*, vol. 9 no. 3.

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