

The Necessity of Ordinary Experience

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Abstract

I argue in this paper that ordinary experience is not only a nice part of everyday life; it is a necessity for the development of human knowledge. I begin by looking at why the particular biological machinery that defines our nervous system matters. I then examine the particular machineries that constrain but also foster the development of human knowledge. Finally, I examine the kinds of activities that foster the development of knowledge, given the constraints of the given machinery, and conclude that activities that are repeated often and that involve meaningful interaction with an inherently meaningful environment form a plausible basis for the formation of knowledge within the particular neural net machinery that evolution has produced for us.

Keywords: Learning; neural networks; embodied cognition; practice; education; development; instructional technology

Mind and world in short have been evolved together, and in consequence are something of a mutual fit.

(James, 1948, p. 4)

The Implementation Problem

The implementation question is the notion that once a system of knowledge has been completely and accurately articulated, it shouldn't matter in what kind of machinery the system is implemented. This was a major assumption of cognitive science for quite a long time, and to its credit it was a very useful and fruitful assumption. If we assume that there is no important difference between carbon-based machinery and silicon-based machinery, and this is a very reasonable assumption, we can investigate and test knowledge systems on silicon-based machinery, machinery which is much easier to control, much easier to completely specify, and much easier to manipulate in ethical ways. However, this assumption has two gaping holes in it: how does the knowledge get into the machinery (most biological organisms have no programmers to install useful data structures or programs, while most silicon-based machines do have programmers), and how does the knowledge get interpreted (most silicon-based machines have intelligent "users" to interpret the output; most biological organisms must interpret the knowledge for themselves).

If, instead of ignoring implementation, we examine how the actual machinery works, we find that there are many important constraints derived directly from the machinery that actually help us to understand how the knowledge gets incorporated into the machinery and how the "knowledge" in the system gets interpreted. This, of course, does not mean that a silicon-based machine couldn't learn and

interpret on its own (see (Brooks, 2008) for example); it only means that silicon-based machinery isn't necessarily constrained by the same physical qualities that constrain biological organisms. A lot of very interesting work in artificial intelligence, does examine cognition while taking biological constraints into consideration, and these lines of research have been extremely fruitful, which should help to support the idea that implementation does indeed matter. The embodied cognition paradigm already assumes, however, that implementation is a critical element of any intelligent system.

The Basic Machinery

That leads to the examination of the actual elements of the biological machinery from which the nervous system is constructed. There are, of course, very few elements in the biological machinery. The main element is an ordinary neuron, which is not too dissimilar from other cells in the biological organism. Like other cells in the biological organism the neuron is best at responding to elements in the immediate surroundings. In other words, the neuron is best at noticing what's in its immediate neighborhood and responding by secreting to its immediate neighborhood.

However, the neuron can take on very unusual shapes, and these shapes, make them particularly good for communicating with each other, by redefining what is meant by "its immediate neighborhood". The maximized surface area of the neuron (the dendrites) allows the neuron to receive multiple messages simultaneously from other neurons or from the environment. The other part of the neuron's unusual shape (the axon) can sometimes be quite a long extension of the cell body. The axon is the main tool that the neuron has at its disposal for communicating to other neurons or to the muscles. So just by changing its shape the neuron has the ability to get information from, and have an effect on, parts of the nervous system and ultimately parts of the body that are not apparently in its immediate neighborhood.

This is important because the main technique that neurons have for getting information, and for sending information, involves the idea of simple local processing. So it's important to note that "local" for the neuron has been redefined to include connections to quite distant elements of the nervous system and the biological organism. In fact, in the case of the photoreceptors, "local" involves light waves arriving in the immediate vicinity from potentially extremely distant locations. Simple local processing is the kind of processing that single-celled organisms developed at the very beginning of organized life, to detect things in their

immediate environment, and through very simple rules made decisions about how to act on their environment. The typical example is a bacterium floating through water. When it detects a particular toxin in the environment, it activates its flagellum and flaps away from the toxin. The cool thing about simple local processing is that when many organisms are using simple local processing at the same time, intelligent behavior can emerge at the level of the group or colony, without any programmer or leader or teacher.

Because there is no programmer or leader or teacher to direct the nervous system this is an incredibly useful quality to include in any description or explanation of biological intelligence to account for the undoubtedly quite intelligent behavior of this leaderless system.

So, the basic elements of which our nervous system is composed consist of billions of very simple agents, performing simple local processing in which “local” has been redefined to include any “neighbor” to which a neuron’s unusual shape can give it access, including, for example, any light wave event within the visual vicinity of the amazing biological eye. This massively parallel system of simple agents acts without a leader, without a programmer, without a teacher; yet intelligent and useful behavior emerges over time. We turn next to the question of how knowledge, or intelligent behavior, can emerge in such a system.

How knowledge develops in such a system

While no single model of the human nervous system has been universally accepted, we have established the basic building blocks and parameters from which it must be built. Several of the basic mechanisms with which such a neural network could store knowledge have also been identified.

The first important mechanism was established about a hundred years ago by Pavlov (2009) and articulated more fully in the sea slug by Kandel and his colleagues (Hawkins, Greene, & Kandel, 1998, for example). The ability of the nervous system to associate a previously non-meaningful stimulus with an already meaningful stimulus may seem rather minor and non-cognitive when discussed within the context of dog saliva and sea slugs, and yet this is an amazingly useful mechanism. Association between a stimulus that is already meaningful and a previously meaningless stimulus can produce symbols, where a symbol means anything that stands for something else. Surely this is the basis of the nervous system’s ability to use language and, more generally, abstract symbols. Abstract symbols are, by definition, meaningless stimuli on their own which have taken on meaning by association with something already meaningful.

The second important mechanism was robustly established during the half century of American behaviorist research (Staddon & Cerutti, 2003). Operant conditioning increases the probability of a pattern of neural activity to reoccur if that pattern has proven to be useful (that is, if it has been reinforced). In a probabilistic network, this

couldn’t be more important. A relatively more predictable pattern of activation that is meaningful or important to the organism is pretty close to a basic definition of intelligent behavior, or knowledge. Again, operant conditioning may seem too basic and non-cognitive when discussed in the absence of a mind or within the context of training animals, as behaviorism often is; yet surely the ability to increase the probability of activating a useful pattern of neurons when it becomes clear that the pattern is, in fact, useful, could form the basis of an endogenous back-propagation system, the exogenous form of which is such an essential aspect of so many artificial neural nets (see, for example, McClelland and Rumelhart (1988)). Whether it forms the basis of the feed backward system or not, most would agree that knowledge that is more probable, rather than less probable, to become available at the appropriate time is the main point of learning and education.

The third important mechanism was hypothesized by Hebb sixty years ago (1949), and established more recently in empirical neuroscience research ((Isaac, Buchanan, Muller, & Mellor, 2009) for example). Hebb theorized that neurons that become activated simultaneously would be subsequently more likely to activate each other. This has been found at least in the case of the NMDA receptor, a receptor that requires simultaneous messages in order to allow permanent, structural changes to occur at the synapse (see (Isaac, et al., 2009) for example). This is perhaps a more general mechanism upon which both Pavlovian association and Skinnerian contingency are both built. Long-term potentiation has been the chief candidate for this process. Long-term potentiation involving the NMDA receptor requires more than one converging pathway to neural activation. Also important is the idea that this process is dependent on an overwhelmingly huge stimulus, or an often repeated activation before it makes permanent changes to the synapse. If long-term potentiation (or any kind of wiring) developed after every mere exposure the neural net would be in constant flux without the ability to store meaningful knowledge (something to keep in mind when considering so-called “smart” genes and genetic modifications). The ability of neurons to strengthen their association when they find themselves simultaneously activated over time is essential to both forms of conditioning, as well as learning to perceive and to act on any reliable invariance in the internal and external environment. Invariance in the environment, by definition, provides almost endless repeated activation in response to objects and events that are important, or, at least, enduring.

Finally, with lots of neurons activated simultaneously in response to an event in the environment, distributed “representation” is possible: that is, a distributed set of neurons together form a concept. This is important as a storage mechanism, but it is even more important as a means of developing categories and abstract concepts. When lots of neurons, rather than a single neuron, become activated by a particular stimulus, and then another large group of neurons becomes activated by a slightly different

stimulus, any overlapping active neurons get twice the opportunity to wire together with each other, and so subsequently are even more likely to activate each other. This overlapping set comes to stand for (or “mean”) the precise similarity between the two stimuli, not as an analogy but as a literal overlapping commonality. This is a profoundly important part of our machinery if we want to be able to explain the human genius for categorization, abstraction, and creativity.

Very few psychologists admit that these crude mechanisms are useful for more than motor skill learning and perception. Yet, what other mechanisms have been identified in the nervous system to account for lasting changes? I am aware of none. So, leaving physical skill learning and perception aside for the moment (although they’re quite important) let’s examine, briefly, how verbal, spatial, or declarative knowledge could develop in such a system, although the research in this area is ongoing and not at all settled yet.

These mechanisms certainly do look better suited to the implementation of non-declarative knowledge than of declarative knowledge. Non-declarative knowledge can build up over time through normal interactions and perceptions, and even without conscious awareness or attention. But how do we explain the (seemingly) more cognitive, conscious and occasionally instantaneous category: declarative knowledge? How could declarative knowledge be implemented in such a system?

Unlike all other organisms, human beings have a rich set of verbal (as well as visual) symbols at their disposal. One possibility is that words become associated (through classical conditioning mechanisms) with “concepts” already established in the neural network through Hebbian synapses. In fact, Bloom and her colleagues found that as soon as children are reliably able to refer to objects in their environment, jointly with their caregiver, vocabulary suddenly blossoms (Lifter & Bloom, 1989). Goldin-Meadow found that as soon as learners were capable of gesturing appropriately during problem-solving, that the correct words almost immediately followed (2003). It seems that in humans, at least, language is produced almost simultaneously with the ability to identify and perceive a referent. If this is the case, this is a powerful addition to the simple machinery with which we have to work: to be able to have a word associated with each distinction we are capable of perceiving or acting upon.

Once a word is in place (associated with a meaningful distinction) the neural net can use the activation of a word in place of the primary experience: the word can initiate a cascade of neural activity that is very similar to the cascade that would be produced by the primary experience. At this point, a coach, or a teacher, or a friend, or a parent can use a word (“hot”) to produce the same neural activity that might have been produced by a similar (“hot”) experience, thus allowing learning to take place without the primary experience. Clearly the primary experience, or some critical conjunction of important partial experiences, must have

occurred at some point. But learning can quickly be produced in the absence of the primary experience once the word is in place. From here it is a not impossibly large leap to the nervous system supplying the words internally in the absence of an external coach, teacher, friend or parent. These internally activated words, then, could form the basis of explicit knowledge and rational thought.

Re-activation of sensory-motor cortex, followed by a cascade of neural activity similar to primary activation, has repeatedly been found to be the case with stored concepts (see, for example, the visual imagery work of Kosslyn (2005) and the motor imagery work of Jeannerod (1994)). The research on mirror neurons has even indicated that watching someone else’s behavior can trigger a cascade of neural activity that is similar to the neural activity involved in one’s own primary experience (Brass & Rüschemeyer, 2010).

The other aspect of declarative knowledge, the apparent ability of explicit knowledge to be examined consciously, needs more explanation, and probably a completely separate paper. Briefly, though, the main advantage of implicit, or non-declarative knowledge, is that it is so well integrated into the neural network that it is ready for use without any conscious reflection. That is of course its main liability as well, because without conscious reflection there is no room for “free will”, no room for new responses, and no room for transfer of knowledge to novel situations. How, then, does declarative knowledge gain this apparently conscious element? There is perhaps no hotter topic in philosophy of mind these days (see Metzinger (2009) for example), so I will not presume to solve this problem for all time. However, an intriguing possibility, and one that is in line with what is known about the biological constraints of the human nervous system, was put forth decades ago by Antonio Damasio (1989). He pointed out that a mechanism in the hippocampus allowed incoming messages to be, essentially, bounced back to the sensory store from which they had just come. Because incoming sensory information must reach the hippocampus in a cohesive timeframe, the bouncing back must also occur in tandem, restimulating the same sensory stores as the original experience. He did not discuss verbal stimulation in particular, but because we know that verbal information stimulates the same sensory store as heard language (Hubbard, 2010), this mechanism should work for verbal information as for any other sensory stimulation. What does this ability to bounce an experience back for re-experiencing buy us? Just this: it allows for the opportunity, as any multi-neuron synaptic junction would, for the original stimulus to be affected by other elements rather than triggering an automatic and unalterable cascade of activity. Implicit knowledge does not need to go through this bounce-back process because it’s already usable, and in many cases, already crystallized. Explicit knowledge, however, differs from implicit knowledge in the “second chance” it gives its network, and of course the environment, to affect the cascade of activity in a new or more subtle way. This explicit second chance may not result in fast, or

graceful, processing and activity (that is the strength of implicit knowledge), but it gives our neural net the opportunity to bring old symbols, old categories and old knowledge to bear on a new situation. The analogy I have used with students is very over-simplified, but may help to illustrate this distinction. If a sensory stimulus is like a pebble and our neural network is like a pond, then implicit knowledge is the set of waves that travel across the pond without hindrance when the pebble is dropped into its center, and explicit knowledge is the set of waves that results from the pebble's original waves encountering a partial barrier that bounces back some of the waves allowing them to interact again with the out-moving waves. The explicit is more complicated, more interesting, more filled with information (in the information theory sense), but the implicit is more graceful and efficient.

So, it's possible for both non-declarative and declarative knowledge to develop within the severe constraints built into the biological machinery about which we already know.

Activities that Foster Development

What kinds of activities, then, foster knowledge development in such a system, with so few clear mechanisms for plasticity? Imagine the elaborately connected human nervous system moving about in the environment with all of its electrical activity visible for observation. Notice that the nervous system is constantly active and that what changes is the relative activity of the system: relative both in time and space. This system does not passively await inputs, but constantly changes in response to the particular interactions it has with its environment. It should be clear at this point, that a system such as this one has no "input" device. It has, rather, the ability to make small adjustments in real time in response to real events. This system will only be as useful as the meaningful distinctions to which it can attend and respond. What activities will, naturally, produce patterned and intelligent behavior?

Perhaps obviously, the neural network will store reliable patterns detected in the environment: if a set of neurons is consistently firing together, they will begin to wire together, thus storing a united response to a unified set of stimuli. There are two major sources for such reliable patterns: the natural invariances in the physical world, and the sets of actions that produce reliable (or meaningful) results for the organism (contingent activities). Notice how perfectly these sources match our two major learning mechanisms: associative conditioning and operant conditioning.

Invariance in the Environment

Why does the physical world provide such a rich source of useful invariances (or correlations) for the nervous system? The short answer is "evolution". Because the particular physical environment in which we all develop is the product of multiple, simultaneous lines of successful evolution, within the same set of physical constraints based on the physical structure and physical laws of this particular planet,

the characteristics that tend to appear simultaneously tend not to be arbitrary co-occurrences, but rather quite meaningful and successful co-occurrences. In other words, if our nervous system happens upon a set of co-occurring characteristics in the natural world, they are extremely likely to be the product of a long and successful line of evolution, and therefore be the opposite of arbitrary or capricious.

All else being equal, then, the set of repeated co-occurrences we encounter will tend to be meaningful, not meaningless, co-occurrences, and therefore very useful for us to learn to perceive, "chunk" and to be able to act on. Our physical environment is full of non-arbitrary co-occurrences. The physical laws at work here are the same physical laws that have shaped our planet for billions of years and that have driven evolution of all the living species we encounter since life began on this planet. And the co-occurrences of living things in a particular environment are also non-arbitrary because these living things have had to survive within the same environment for millions of years. So the living organisms that we encounter have been successful not just in our particular physical environment, but in our particular ecological niche as well.

Contingent Activities

Held and his colleagues found quite a while ago that contingent experiences were necessary for the normal development of kittens (Held & Hein, 1963). In his elegant set of experiments, in which kittens were literally yoked during their daily visual stimulation and were able to move around the visual stimuli based on just one of the yoked kittens' movements, Held showed that kittens with completely equal visual stimulation, and deprivation, developed completely different visual capabilities depending only on whether the visual stimulation was contingent on the kitten's own activity.

Fox and Oakes updated Held's experiments by doing a similar set of experiments using undergraduates, instead of kittens, and video games, instead of a yoked carousel experience (Fox & Oakes, 1984). In this set of experiments, undergraduates were virtually yoked to each other while they played one of two versions of a video game. In one version of the game, the undergraduates' success at destroying elements of the virtual world was completely contingent on their motor behavior: if their aim and timing was good, they were able to blow up a lot of objects; if their aim and timing was poor, they had little success. In the second version of the game, undergraduates experienced the same (yoked) number of apparent successes, but the success had nothing to do with their motor behavior: it depended completely on the success of the undergraduate to which they had been virtually yoked. However, the second version of the game was designed to make it look like the success was contingent on the player's skill: elements were slowed or speeded up in order to make appropriate, successful, contact. When tested afterwards all of the undergraduates felt as though they had succeeded: consciously they felt like their actions mattered. But the undergraduates who played

the non-contingent form of the game were not as successful at a subsequent, unrelated, lexical decision task.

Notice that “contingent experience” is any experience in which the organism’s actions are related, reliably, to the feedback the organism receives, whether or not the organism is consciously aware of this reliable relationship.

Both Invariance and Contingency

Diamond and Rosenzweig and their colleagues looked at both elements at once. They found that rats that grew up in an environment with lots of new, physical and social interactions, developed more useful and heavier brains (Rosenzweig, Bennett, & Diamond, 1972). Interestingly, when the interaction was eliminated, by having rats near enough to watch but not interact with all the stimulation, the rats’ brains did not become as useful or heavy. Most importantly, however, these “enriched” lab rats had brains that were significantly less useful, heavy, and well-connected than rats raised in the wild (where both invariants, and contingency are much more widely available) (Huck & Price, 1975; Zhao, Toyoda, Wang, & Zhuo, 2009).

Flanagan (1996) showed that in a normal classroom setting, third graders who did an activity that involved contingent rather than non-contingent feedback for just fifteen minutes were subsequently significantly less likely to give up in a challenging but possible puzzle. Furthermore, third graders who used physical rather than virtual materials were significantly more likely to be able to build on that knowledge.

Natural feedback refers to feedback that is not dependent on a teacher, programmer or author, but that is instead inherent in the activity itself. So dropping objects of different weights does not require a teacher to give positive or negative feedback; the gravity of the physical world gives this feedback naturally. Most interactions with the natural world provide such feedback, but natural feedback is not limited to the natural or physical world: computer programming, for example, provides natural feedback because the programmer does not need a teacher or authority to provide positive or negative reinforcement – the programmed code either works or it doesn’t. All else being equal, though, the natural world is the safer bet since co-occurrences in the natural world are the product of evolution, and interactions with the natural world follow the laws of physics. Artificial, or authored, environments depend completely on the author, or programmer to provide meaningful co-occurrences, and to provide meaningful feedback – these must be deliberately incorporated, while in the natural world they are already an integral part.

Natural feedback is also less available in stereotypically female hobbies than in stereotypically male hobbies. Playing with water pistols provides natural feedback – either you get wet or you don’t. Many stereotypically female hobbies depend on the opinions offered by peers or authority figures: does this look pretty? Have I pleased you? Is this good? Dweck and her colleagues have found

that personal feedback rather than task-related feedback interferes with the mastery orientation of children solving challenging problems (Dweck & Leggett, 1988). Because of this difference in available stereotypically female and male after school activities, Flanagan and Canada provided school-age female students with one hour a week of after-school activities in which the students got natural feedback for both invariance in the environment and their own contingency (Flanagan & Canada, 2010). These students did computer programming (Scratch (Group) or Lego Mindstorms (Lab, 1999)) or building scale models (Google Sketch (Google, 2010) or physical craft materials) for eight weeks. At the end of the eight weeks the students had significantly better spatial reasoning skills than a similar control group, and felt significantly more confident about doing math and using computers.

Ordinary Experiences

In environments that consist of inherently meaningful co-occurrences and opportunities for consistently meaningful feedback the nervous system thrives. Repetition, or practice, in such environments should produce robust, well-organized, functional nervous systems. The practice effect is well-established, but shouldn’t be ignored: too often we turn to the conceptual or technological shortcut when mere practice in a meaningful environment would do more good. Imagine a basketball team that got an hour or two of lecture a week and then several readings in order to get ready to play the season; imagine an orchestra that got an hour or two of lecture a week and then had to read their musical scores as homework for getting ready for their concert season. This sounds ridiculous, of course. But we expect our students to learn more “cognitive” skills this way even though it shouldn’t work given the mechanisms available, and routinely fails to work (see (Sahiner, 1987) for example). If we accept the mechanisms we’ve been given, cognitive education should begin to look more like physical and musical education.

“Baby Einstein” media have recently been (finally) recalled because they probably do more harm than good (Lewin, 2009). As cognitive scientists we owe anxious parents the benefit of our expertise, and must point out that ordinary interactions with people and meaningful objects are better suited to the developing nervous system than “educational” consumer media. Because, (un)fortunately, constrained by the biological machinery with which we are born there is no magical input portal for pouring fully formed knowledge systems into the human mind: there are just a few simple mechanisms that must incorporate knowledge through lots of simple, ordinary, meaningful encounters over a long period of time.

Conclusion

The human nervous system is the product of millions of years of evolution within an ecology that has simultaneously been evolving. So it makes sense that the human nervous system should be optimized for operating within the

particular natural and physical world we call “earth”. Indeed when we look at the particular mechanisms actually available to the human nervous system for learning and developing a solid knowledge base, these mechanisms seem to be ideal for detecting and learning naturally occurring invariances in our ordinary environment, as well as for learning actions that turn out to be important and meaningful to the nervous system itself. These are the very elements that Lloyd argued were the minimum essential requirements for anything we would consider to be a “mind” (1989). Furthermore, these mechanisms work best when the applicable neurons are activated simultaneously over a significant period of time.

Activity that involves important co-occurrences that are meaningful for the organism over significant periods of time are more succinctly termed “ordinary” experiences and are the foundation of our solid and meaningful neural network. We would be wise to build on this framework rather than attempting to circumvent it. Practice in real environments in real time has long been the accepted practice in athletics and music. It is time for other human endeavors to follow the same advice.

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References

Brass, M., & Rüschemeyer, S.-A. (2010). Mirrors in science: How mirror neurons changed cognitive neuroscience. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 46(1), 139-143. doi: 10.1016/j.cortex.2009.04.005

Brooks, R. A. (2008). Intelligence without representation. In W. G. Lycan & J. J. Prinz (Eds.), *Mind and cognition: An anthology* (3rd ed.). (pp. 298-311). Malden: Blackwell Publishing.

Damasio, A. R. (1989). Time-locked multiregional retroactivation: A systems-level proposal for the neural substrates of recall and recognition. *Cognition*, 33, 25-62.

Dweck, C. S., & Leggett, E. L. (1988). A Social-Cognitive Approach to Motivation and Personality. *Psychological Review*, 95(2), 256-273.

Flanagan, R. (1996). Learning through direct vs. indirect experience: The role of interactivity and physicality in media effects. 57, *ProQuest Information & Learning*, US. Available from EBSCOhost psych database.

Flanagan, R., & Canada, T. (2010). Ordinary experience helps girls develop their spatial reasoning. Paper presented at the Association of Psychological Science, Boston, MA.

Fox, P. E., & Oakes, W. F. (1984). Learned helplessness: Noncontingent reinforcement in video game performance produces a decrement in performance on a lexical decision task. *Bulletin of the Psychonomic Society*, 22(2), 113-116.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA US: Belknap Press of Harvard University Press.

Google. (2010). *Google Sketchup*.

Group, L.-I. K. *Scratch Programming Language*. Cambridge, MA: MIT Media Lab.

Hawkins, R. D., Greene, W., & Kandel, E. R. (1998). Classical conditioning, differential conditioning, and second-order conditioning of the *Aplysia* gill-withdrawal reflex in a simplified mantle organ preparation. *Behavioral Neuroscience*, 112(3), 636-645. doi: 10.1037/0735-7044.112.3.636

Hebb, D. (1949). *The organization of behavior*.

Held, R., & Hein, A. (1963). Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology*, 56(5), 872-876. doi: 10.1037/h0040546

Hubbard, T. L. (2010). Auditory imagery: Empirical findings. *Psychological Bulletin*, 136(2), 302-329. doi: 10.1037/a0018436

Huck, U. W., & Price, E. O. (1975). Differential effects of environmental enrichment on the open-field behavior of wild and domestic Norway rats. *Journal of Comparative and Physiological Psychology*, 89(8), 892-898. doi: 10.1037/h0077160

Isaac, J. T. R., Buchanan, K. A., Muller, R. U., & Mellor, J. R. (2009). Hippocampal place cell firing patterns can induce long-term synaptic plasticity in vitro. *The Journal of Neuroscience*, 29(21), 6840-6850. doi: 10.1523/jneurosci.0731-09.2009

James, W. (1948). *Psychology*. Cleveland, OH: The World Publishing Company.

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences*, 17(2), 187-245.

Kosslyn, S. M. (2005). Mental images and the brain. *Cognitive Neuropsychology*, 22(3-4), 333-347. doi: 10.1080/02643290442000130

Lab, M. M. (1999). *Lego Mindstorms: The Lego Group*.

Lewin, T. (2009, 10/23/2009). No Einstein in Your Crib? Get a Refund, *New York Times*.

Lifter, K., & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior & Development*, 12(4), 395-423. doi: 10.1016/0163-6383(89)90023-4

Lloyd, D. (1989). *Simple Minds*. Cambridge, MA: MIT Press.

McClelland, J. L., & Rumelhart, D. E. (1988). *Explorations in parallel distributed processing: A handbook of models, programs, and exercises*. Cambridge, MA US: The MIT Press.

Metzinger, T. (2009). *The ego tunnel: The science of the mind and the myth of the self*. New York, NY US: Basic Books.

Pavlov, I. P. (2009). Conditioned reflexes: An investigation of the physiological activity of the cerebral cortex (1927). In B. F. Gentile & B. O. Miller (Eds.), *Foundations of psychological thought: A history of psychology*. (pp. 441-453). Thousand Oaks, CA US: Sage Publications, Inc.

Rosenzweig, M. R., Bennett, E. L., & Diamond, M. C. (1972). Brain changes in response to experience. *Scientific American*, 226(2), 22-29.

Sahiner. (1987). *A Private Universe: Harvard-Smithsonian Center for Astrophysics, Science Education Department, Science Media Group*.

Staddon, J. E. R., & Cerutti, D. T. (2003). Operant conditioning. *Annual Review of Psychology*, 54, 115-144. doi: 10.1146/annurev.psych.54.101601.145124

Zhao, M.-G., Toyoda, H., Wang, Y.-K., & Zhuo, M. (2009). Enhanced synaptic long-term potentiation in the anterior cingulate cortex of adult wild mice as compared with that in laboratory mice. *Molecular Brain*, 2.