Brain Physiology's Connection to Teaching Algebra

Edward D. Laughbaum, *The Ohio State University (retired)*

Abstract: *The common pedagogy and algebra curricula have issues with facilitating understanding and long-term memory in many students. This article offers ideas on using common core brain function in teaching and curricular processes related to algebra.*

Keywords: *teaching algebra, brain-based learning, neuroscience in education*

1 I Had a Dream

The author has been retired from teaching mathematics for 14 years. The reason this is important is because after all these years, one might not expect to have a dream about teaching. So surely, a strange dream, yet true.

2 The Dream

In the author's dream, he was teaching a remedial algebra class, on the slope-intercept form of the linear function. He wrote $y = mx + b$ on the board and then proceeded to explain that m is the slope of the graphical representation of the equation and b is where the graphical representation crosses the y-axis. Of course, this was followed with an explanation of what slope is and how to calculate it; and this was followed with a few examples and drawings of slope and the y-intercept. He assigned practice homework, and this was the end of class. Just a note: the author's conscious brain prefers the words symbolic representation of a function to the word equation, since function covers more extensive concepts than does equation (Laughbaum, 2006). That is for example, an equation is simply one representation of a function. The concept of an equation may be okay for engineers and scientists, but equation has a lessor meaning from a conceptual perspective.

Anyway, the next day a student came to the author's office and said he had absolutely no idea of what the author had talked about in class, and he did not understand much of anything said in the explanation. At this point the author woke up and was rather distressed. In an awake state, he started to think about what he had done and spent the next two hours lying awake thinking of how he actually taught the point-slope form of the linear function later in his career.

The author, in the dream, did not have knowledge of what research in core brain physiology tells us about understanding with long-term memory (learning). The corrections below are fully referenced from neuroscientific research in the published articles listed in the Supplemental Readings section. Thus, each statement in this article is founded in the neuroscience of core brain function. In addition, the Supplementary Example Activities section contains a list of published articles that include examples of learning lessons that implement the concepts described below. However, one must take care when analyzing a sample lesson since the reader does not know what content/concepts preceded the lesson. That is, the samples are based on a curriculum with function representation and function behaviors as a common connective theme.

2.1 The First Dream Correction: Explain/Sample/Practice-Based Learning

Common thinking is that teachers often teach as they were taught. This thinking is to be expected for math teachers as we likely learned math because we were motivated and interested in mathematics. The issue is that we often think if the method helped us learn, it would help everyone. So, the author was teaching as he was taught in his dream using the explain/sample/practice method, while some students can learn from this method, experience and remediation data shows that it fails for many.

2.2 The Second Dream Correction: Capitalizing on How the Brain Works

The second issue with the author's teaching dream teaching was that he was teaching point-slope as an individual lesson with no connections to previously taught algebra and there was no use of a real-world context to teach the concepts of slope and initial condition (y-intercept) – just like he was taught. This is a problem because this approach places what was learned directly into short-term memory (see reference below). In addition, there are no known direct neural processes in the explain/sample/practice method that causes understanding of the math taught—except for a few who have outside influences. This may seem like a bold statement and is simply the author's opinion; however, there are many scientific research references in published papers that fully support why the statement is not an opinion.

For example, the seminal work of Nobel Laureate Eric Kandel shows that: "Short-term memory results from strengthening existing synaptic connections [from practice], making them function better, whereas long-term memory results from the growth of new synapses [from making connections]" (Kandel, 2018, p. 114). What this implies is that practice only strengthens the existing synaptic connections. So, practice alone does not necessarily involve connections that would create new synapses. The question is: "How can teachers teach to increase the likelihood of students actually understanding what is taught and how can long-term memory be in play?" Below are two options.

Generalizing

> Most algebra curricula tend to not use pattern generalization as a daily staple—if at all. "Yet this ability to generalize is a key to learning" (Dehaene, 2020, p. 23). Instead, explaining a concept or skill has become the norm. The problem is that "human beings have only a weak ability to process logic, but a very deep core capability of recognizing patterns" (Kurzweil, 2012, p. 38). As Sean Carroll observes, "we are pattern-recognizing creatures" (2016, p. 39). Jeff Hawkins makes the significant point: "Correct predictions [generalizations] result in understanding" (2004, p. 89).
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> (Laughbaum, 2022, p. 42)

So, Hawkins gives us that a method for developing understanding; it is to have students generalize a pattern. Due to the nature of mathematics, mathematics teachers have the perfect opportunity to capitalize on this basic neural functioning that produces understanding of concepts/skills taught. Teachers must create pattern building activities so that students will generalize each concept/skill we need them to understand and have a long-term memory of. Various pattern-building activities are included in the Supplemental Readings list.

Visualizations

> A second known method for creating understanding is through the early use of visualizations. "Visualizations (graphs) used early in the teaching process capitalize on the brain's visual system that relate to memory and understanding [Pinker, 1997; Schacter, 2001; Lynch & Granger, 2008]" (Laughbaum, 2014, p. 126). Further, cognitive scientist Steven Pinker concludes that "Thanks to graphs, we primates grasp mathematics with our eyes and our mind's eye. . . . vision was co-opted for mathematical thinking, which helps us see [understand] the world"
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> (Laughbaum, 1997, p. 360)

Reform mathematics textbook authors Bert Waits and Frank Demana used the motto "The Power of Visualizations" in promoting their work where dynamic visualizations were integral to their curriculum. They also promoted their work using the message "...and Confirm Graphically." Historically, common thinking was that visualizations promoted mathematical understanding, but we have to wonder if neuroscience has anything to add relative to visualizations producing understanding. It does. The issue is that as commonly used, the timing is not optimal.

Using visualizations to confirm an algebraic concept already taught has less impact on understanding and memory than it has when using visualizations at the beginning of a lesson. Further, not using any visualization may impact negatively on student understanding an algebraic concept or skill. Neuroscience shows that when designing a lesson, teachers should do something eventful during the early moments of the memory encoding process as this will influence the fate of the new memory. That is, "...more elaboration during encoding generally produces less transient memories. ...these studies [fMRI] managed to trace some of the roots of transience to the split-second encoding operations that take place during the birth of a memory" (Schacter, 2001, p. 27). The catch is this; normally functioning brains find abstract symbols to be of low value (Hofstadter & Sander, 2013); especially the brains of students who have little interest in algebra; this indicates that an algebra lesson should not start with symbolic work. But the proper use of visualizations adds attention through motion, that is, "...because we have visual, novelty-loving brains, we're entranced by electronic media" (Ackerman, 2004, p. 157). This suggests that visualizations should be placed first, and they should be dynamic—as found on a graphing calculator.

2.3 The Final Dream Correction: Connections to Understanding and Long-term Memory

"We understand something new by relating it to something we've known or experienced in the past" (Restak, 2006, p. 164). Further, "The most important property [of auto-associative memory] is that you don't have to have the entire pattern you want to retrieve in order to retrieve it. ...The auto-associative memory can retrieve the correct pattern, ...even though you start with a messy version of it" (Hawkins, 2004, p. 30). So, science suggests that teachers create connections to previous algebra taught to improve the understanding and memory of the new lesson. "Memory recall almost always follows a pathway of associations. One [neural] pattern evokes the next pattern, which evokes the next pattern, and so on" (Hawkins, 2004, p. 71). In teaching factoring of polynomials, one would connect the new math being taught to the previously taught concept of zeros of a function. Using hand-held technology, it is relatively simple to find zeros of polynomial functions expressed as rational numbers. By connecting the two processes, when students are asked to factor a quadratic polynomial at a later time, they are likely to think of zeros first (because of the visual methods used in teaching), followed by the pencil and paper factoring process.

> Mathematical connections typically come in two forms. The first and most important connection is to previously taught mathematics, in addition, "New information becomes more memorable if we 'tag' it with an emotion [like a familiar real-world context]" (Restak, 2006, p. 164). So, we also need to connect new math concepts to contexts that are familiar (evoke an emotional response) to students. For example, when teaching (not applying) the concept of the behavior of zero(s) of a function by modeling the amount of fluid remaining in an I.V. drip bag, this "tags" it with the real-world meaning of the zero—the bag is empty. The result of tagging a mathematical concept or process with an emotional connection is improved memory. It turns out that the more connections to a mathematical concept/procedure, the more likely the correct recall. That is: "In general, how well new information is stored in long-term memory depends very much on depth of processing, ...A semantic level of processing, which is directed at the meaning aspects of events, produces substantially better memory for events than a structural or surface level of processing" (Thompson & Madigan, 2005, p. 33).
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> (Laughbaum, 2011, p. 3-4)

3 Bayesian Thinking

The author formulated teaching and curriculum ideas based on his practice, education, and experience. Bayesian thinking implies revising core ideas as new information is processed (Carroll, 2016, p. 40-41). Some new experiences lead to a quantum jump in thinking and other experience/education added minor changes—all based on the credence of the experience/new learning. Learning sometimes leads to a lowering of credence of an established process/idea, as it did in the case of the author with mathematical standards. A lower credence implies a moving away from using the concept in teaching.

The author's experience started with traditional math education as a student, teaching based on this education, and standards teaching curriculum and pedagogy. When students demonstrated a need for a revision in the curriculum and pedagogy, Bayesian thinking required a change. That is, as student failures continued measured by the growth of remediation required in colleges, the credence kept dropping as time passed. This event initiated an extensive reading in the neurosciences on the how brain behavior of understanding and long-term memory is developed through core brain processes. These core processes now govern the author's thinking about learning.

4 Additional Resources

4.1 Supplementary Readings

1. Laughbaum, E. D. (2011). "The neuroscience of connections, generalizations, visualizations, and meaning." In C. Knights & A. Oldknow (Eds.), *Enhancing mathematics with digital technologies* (pp. 3-11). London, UK: Continuum Press. https://drive.google.com/file/d/0B8vZ3H3sC2ACV015SUlkTks3Rzg/view?resourcekey=0-f5YZlObNNDah47iEGU-vKw
2. Laughbaum, E. D. (2013). "Pattern building and modeling in beginning algebra." *Mathematics Teachers' Journal*, 64(3), 124-130. https://www.researchgate.net/publication/274959282_Pattern_Building_and_Modeling_in_Beginning_Algebra
3. Laughbaum, E. D. (2022). "Issues with the developmental algebra curriculum and resulting pedagogy." *MathAMATYC Educator*, 13(3), 40-45. https://www.researchgate.net/publication/360951449_Issues_with_the_Developmental_Algebra_Curriculum_and_Resulting_Pedagogy
4. Laughbaum, E. D. (2012). "Learning - Changing the Connections in the Brain." *The New Jersey Mathematics Teacher*. https://drive.google.com/file/d/0B8vZ3H3sC2ACeC16MEpjT2sxQUE/view?resourcekey=0-jpcoHPsZe1YJSE_VteBXfg

Further, the following articles provide the reader with examples in which brain science of connections, generalizations, visualizations, and meaning is used in various classroom applications.

4.2 Supplementary Example Activities

1. Laughbaum, E. D. (1998). "Multiplicity of Algebraic Methods Using Graphing Calculator Technology": A variety of ways of doing and teaching algebra. Unpublished paper presented at The First ICMI-East Asia Regional Conference on Mathematics Education, Korea National University of Education, Chungbuk, Republic of Korea. https://www.researchgate.net/publication/291022431_Multiplicity_of_Algebraic_methods_using_graphing_calculator_technology_A_variety_of_ways_of_doing_and_teaching_algebra
2. Laughbaum, E. D. (2001). "Teaching in Context: Enhancing the Processes of Teaching and Learning in Community College Mathematics." *Community College Journal of Research and Practice*, 25(5–6). https://www.researchgate.net/publication/233251085_Teaching_in_context_Enhancing_the_processes_of_teaching_and_learning_in_community_college_mathematics
3. Laughbaum, E. D. (2002). "Ideas on Teaching the Linear Function." Presentation at the NCTM's Central Regional Conference, Paducah, Kentucky. https://drive.google.com/file/d/0B8vZ3H3sC2ACNl9uR0RFRkNXRDA/view?resourcekey=0-IUUsmRd6dcNMhd_fxpbtAg

4. Laughbaum, E. D. (2006). "Why Use a Function Approach when Teaching Algebra?" *Texas Mathematics Teacher*, 53(1), 10–16. https://drive.google.com/file/d/0B8vZ3H3sC2ACN1FrRWFEM2FfYkU/view?usp=sharing&resourcekey=0-tWSlrzUiCjnPcUM4aTwsNg
5. Laughbaum, E. D. (2013). "Not Your Father's Equation Solving." *Florida Council of Teachers of Mathematics, Dimensions in Mathematics*, 33(2), 14–23. https://drive.google.com/file/d/160MUQGtyzpJS2c73vW5gphKtMSENKpP9/view
6. Laughbaum, E. D. (2014). "Pattern Building and Modeling in Beginning Algebra." *New York State Mathematics Teachers' Journal*, 64(3), 124–129. https://drive.google.com/file/d/0B8vZ3H3sC2ACTTVoS090VVplTEU/view?usp=sharing&resourcekey=0-lcVH-AKmAolWGT1UUqHEWw

References

Carroll, S. (2016). *The big picture: On the origins of life, meaning, and the universe itself*. New York, NY: Dutton.

Dehaene, S. (2020). *How we learn: Why brains learn better than any machine...for now*. New York, NY: Viking.

Hawkins, J. (2004). *On intelligence*. Times Books.

Hofstadter, D. & Sander, E. (2013). *Surfaces and essences*. New York, NY: Basic Books.

Kandel, E. R. (2018). *The disordered mind: What unusual brains tell us about ourselves*. New York, NY: Farrar, Straus, and Giroux.

Laughbaum, E. D. (2006). "Why use a function approach when teaching algebra." *Texas Mathematics Teacher*, 53(1), 10-16.

Laughbaum, E. D. (2011). "The neuroscience of connections, generalizations, visualizations, and meaning," 3-11. In *Enhancing mathematics with digital technologies* (C. Knights & A. Oldknow, Eds.). London, UK: Continuum Press.

Laughbaum, E. D. (2014). "Pattern building and modeling in beginning algebra." *Mathematics Teachers' Journal*, 64(3), 124-130.

Laughbaum, E. D. (2022). "Issues with the developmental algebra curriculum and resulting pedagogy." *MathAMATYC Educator*, 13(3), 40-45.

Kurzweil, R. (2012). *How to create a mind: The secret of human thought revealed*. Penguin Group.

Lynch, G. & Granger, R. (2008). *Big Brain: The Origins and Future of Human Intelligence*. New York, NY: Palgrave McMillan.

Pinker, S. (1997). *How the Mind Works*. New York, NY: W. W. Norton & Company.

Schacter, D. L. (2001). *The seven sins of memory: How the mind forgets and remembers*. Boston, MA: Houghton Mifflin Company.

Thompson, R. F. & Madigan, S. A. (2005). *Memory*. Washington, D.C.: Joseph Henry Press.

Ed Laughbaum taught remedial mathematics (and many other courses) at Columbus State Community College for 24 years and then moved to The Ohio State University as Director of the Ohio Early College Mathematics Placement Testing Program and Associate Director of the Teachers Teaching with Technology College Short Course Program. He is the former editor of the *Ohio Journal of School Mathematics*.