The Use of Visuals in Undergraduate Neuroscience Education: Recommendations for Educators

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Abstract

Introduction: There is a history of overlap between art and science education, particularly in anatomy and other related medical specialties. Technological advances have increased exposure to visual images and creation and sharing of image-based content is commonplace. Statement of the Problem: The use of visual content and activities in education typically declines after early childhood, after which most teaching and learning relies heavily on text-based curricula. Incorporating visual content into education makes optimal use of human cognition; visual and verbal processing channels can operate independently, so using both allows for dual coding and enhanced memory. Literature Review: In this paper, we review the literature on the use of visual techniques in teaching undergraduate neuroscience. Teaching Implications: Image-based content can offer learners an additional cognitive resource and also engage English language learners and those with reading challenges, which might not benefit as much from a solely text-based approach. Conclusion: We recommend educators consider the use of (1) learner-generated drawing, (2) 3-D modeling, and (3) infographics to improve learning outcomes among undergraduate neuroscience students. We provide resources and practical suggestions for implementing the aforementioned techniques.

Keywords

visual literacy, drawing, infographic, 3D model, neuroscience education

Smartphones and computers have made creating and sharing pictures and videos easy with the widespread use of GIFs, animations, and emoticons to enhance text-based communication. Some social media platforms are designed to facilitate image-sharing; the popularity of social media platforms Instagram and Snapchat highlight this. The power and influence of images for conveying meaning has emphasized the importance of visual literacy, which can be understood as “an evolving concept best defined as the ability to think and learn in terms of images” (Kaplan & Mifflin, 1996, p. 107). For example, a McIntosh apple missing a bite automatically triggers an association with the Apple brand. This single image conjures up thoughts of the company history, product value and cost. As such, marketing has effectively adopted the use of visual imagery to convey large amounts of information to consumers (Manic, 2015). However, simply being exposed to visual information does not guarantee visual literacy (Brumberger, 2011). As such, visual literacy education is important to develop skills required for comprehending information presented in our visual-based world.

Educators have an opportunity to explicitly teach visual literacy skills to capitalize on the benefits of visual learning. Clark and Paivio’s (1991) dual coding theory highlights the benefits of using visual in conjunction with verbal information. It proposes that we have we have distinct neural “channels” for processing these types of information. Using both of these channels to learn new material leads to better comprehension than using either one alone. Mayer and Anderson (1992) further supported Clark and Paivio’s (1991) dual coding theory in their experiments investigating problem solving ability and retention of the mechanics of a bicycle tire pump or automobile brakes among students who were given animations or narrations alone, animations and narrations simultaneously, or no instructions at all. Participants presented with animations and narrations performed best on tests of problem-solving ability. Their study demonstrated the efficacy of employing multimedia in teaching increases when words and pictures are presented concurrently (Mayer & Anderson, 1992).

Using visuals in content delivery supports learning for students with reading difficulties, particularly dyslexia (Lyon

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et al., 2003). Despite their challenges with text-based information, individuals with dyslexia have superior visuospatial abilities, particularly in visual comparisons and holistic visuospatial processing (Schneps et al., 2007; von Károlyi et al., 2003). Thus, the use of visual information may be a powerful tool to engage these learners that might otherwise become alienated in the text-based environments of mainstream schooling.

Visual learning can also aid English language learners in their understanding of course material, as visual elements can provide contextual information from which to infer meaning (Rousseau & Tan, 1993). Visuals allow learners to employ the dual coding theory to visualize the abstractions of language. Gersten and Baker (2000) note that because of the fleeting nature of the spoken word, visualization like mind-maps, graphic organizers, story maps, and word banks allow learners to increase their understanding of words by allowing them to pause, process, and reflect on the meaning. The visual nature of IKEA furniture instructions provides a salient example of the use of visuals to communicate ideas across different languages.

Visuals are especially effective in the teaching and learning of scientific information (Bobek & Tversky, 2016; Stein & Power, 1996; Van Meter & Garner, 2005). Significant learning gains have been demonstrated with the use of visually based learning modules in chemistry and geology (Dangur et al., 2014; Gagnier et al., 2017). Gurnon et al. (2013) argued that blending art and science creates a unique opportunity to foster curiosity and a motivation to learn about science in university students who would be otherwise less engaged in “pure” science courses. In addition, the science, technology, engineering, art, and math (STEAM) initiative proposes that art should be integrated into math and science to provide the essential creativity and innovation piece required to transition concepts and ideas into applicable real-world settings (Land, 2013). Nobel laureates, the greatest scientists in their respective fields, are more likely to engage in artistic pursuits than other scientists, suggesting that artistic ability and creativity may promote the innovative ways of thinking that lead to academic success and scientific breakthrough (Root-Bernstein et al., 2008). Integrating science and arts benefits science learning by leveraging the curiosity and creativity of artistic ways of thinking.

Historically, medical specialties like neurology and neurosurgery have relied on the visual presentation of the complexities of the nervous system through drawing or painting (Geranmayeh & Ashkan, 2008; Lorusso, 2008). Physicians specializing in these neuroscience-focused fields were required to possess some artistic ability. Furthermore, some of the most prominent artists in history, like Michelangelo and Leonardo DaVinci, engaged in human dissection and depicted their direct observations through art. The Creation of Adam by Michelangelo, arguably one of the most famous art works of all time, can be interpreted as a coded representation of the brain and parts of the nervous system (Meshberger, 1990). In addition, caricatures of neurological conditions and facial expressions were used to convey the physical manifestations of illness and how the mind expressed emotion (Lorusso, 2008). Visual representations of anatomy, surgical techniques, and neurological disorders by these early physicians and artists have served as a powerful educational tool for aiding the understanding of those seeking to learn more about the mechanisms of the nervous system and the mind (Geranmayeh & Ashkan, 2008; Lorusso, 2008).

Most Introductory Psychology textbooks show Wilder Penfield’s body maps of the motor and somatosensory cortices, most commonly displayed as body parts superimposed upon their corresponding areas of cortex. 3D sculptures created from these maps to show the distortion of the body’s representation in the brain and are amongst the most recognizable images in the undergraduate neuroscience teaching (Griggs, 1988). Despite the widespread use of these famous images as teaching tools, there are few experimental studies on the use of visually presented information in teaching undergraduate neuroscience (Arantes et al., 2018; Chudler & Konrady, 2006). The objective of this paper is to review the available research on visual neuroscience education to argue for the application of visual learning techniques in the teaching of undergraduate neuroscience. Specifically, we recommend that educators implement (1) learner-generated drawings, (2) 3-D modeling, and (3) infographics in the teaching of undergraduate neuroscience courses to increase understanding and promote active learning.

Visual learning techniques easily allow for students to use active, rather than passive, strategies for learning science (Chi, 2009; Freeman et al., 2014; Michael, 2006). Active learning involves participation in activities that encourage learners to critically reflect on information (Collins & O’Brien, 2003). The advantages of active learning in undergraduate teaching are supported by a meta-analysis of 225 studies showing better performance on assessments and lower failure rates in undergraduate STEM courses when active learning practices were employed (Freeman et al, 2014). Active learning strategies used in these studies varied widely, so it is not possible to assess if visual learning techniques specifically enhanced student performance. However, techniques such as learner-generated drawings necessarily involve more learner action than a traditional didactic lecture and are therefore more engaging. In fact, Poh et al. (2010) showed that arousal, measured via skin conductance, dips substantially during lectures comparing. Interactive learning goes even further by encouraging collaboration with other people or systems which can provide learning opportunities through exposure to
differing perspectives. Interactive activities are better for learning than constructive activities, which in turn are superior to active activities. Engagement in active learning in STEM (science, technology, engineering, and math) disciplines increases examination performance, particularly in small classes. (Freeman et al., 2014).

**Recommendations**

**Learner-Generated Drawing**

Active and constructive learning can be incorporated into neuroscience education through drawing. Scientists practice drawing daily through data visualization, experimental design, and science communication (Ainsworth et al., 2011). Drawing is a constructive activity that requires the student to organize their background knowledge to create a cohesive visual representation. While engaging in drawing, learners are using a variety of learning processing simultaneously (Wu & Rau, 2019). Drawing activates verbal and text-based representations of a concept, which must then be mapped onto visual representations, thereby activating the dual coding process previously shown to aid learning (Clark & Paivio, 1991). The accuracy of learner-generated drawings is predictive of performance, indicating that drawings serve to confirm or facilitate comprehension, or both (Van Meter & Garner, 2005). Drawing also facilitates model-based reasoning, helps students become better writers, and increases affect and motivation for science learning (Ainsworth et al., 2011; Quillin & Thomas, 2015; Van Meter & Garner, 2005). However, simply instructing students to draw without clarifying what or how to draw may be insufficient (Van Meter & Garner, 2005). For optimal application of learner-generated drawing, educators should provide support and adequate instruction.

Evidence supporting drawing as a powerful learning tool shows that it alters the brain and improves memory. One study investigated the impact of post-retirement activities on the stabilization of well-being and development of associated neural networks (Bolwerk et al., 2014). They showed that producing art during a 10-week visual art class resulted in greater functional connectivity between the frontal and parietal cortices to the posterior cingulate cortex compared to participants who only cognitively evaluated art (Bolwerk et al., 2014). This change in functional connectivity was associated with psychological stress resilience. Drawing has also been associated with improvements in memory when compared to writing; when participants are asked to draw or write words, those in the drawing condition perform better on a memory task (Wamme et al., 2018). Older adults seem to be more sensitive to the memory benefits of drawing, but these findings hold true across different measures of memory for adults of all ages (Meade et al., 2018). Interestingly, even the practice of preparing to draw benefits memory through engagement of the elaborative processes required to generate a drawing (Wamme et al., 2018).

Because drawing is accessible and easy to implement, much of the research on the use of visuals in neuroscience education has focused on this tool. Slominski et al. (2017) conducted a study in which they asked undergraduate neurophysiology students to draw and label representations of synaptic signaling, which was helpful in revealing gaps in knowledge that could then be more specifically targeted by subsequent interventions. An earlier study by Hay et al. (2013) asked individuals at various stages in academia (undergraduate to principal investigator) to draw a neuron and subsequently had a different group sort the drawings based on the creator's experience level and not the quality of the drawings. They found that undergraduate students’ drawings were more likely to resemble textbook representations of neurons, while expert drawings were more simplistic and naturalistic, perhaps reflecting the experts’ own thoughts and hypotheses about neurons. After they incorporated an intervention to make students physically act out the mechanism of a neuron, the undergraduate students’ drawings began to resemble the experts’ depictions.

Educators could incorporate learner-generated drawings into the teaching of neuroscience, especially where neuroanatomy and physiology are involved. Neurons are the building blocks of the nervous system, so understanding their structure and function is fundamental knowledge in neuroscience. There are several ways to incorporate neuron drawings in an undergraduate curriculum, depending upon the nature of the class. If a class allows for tutorial time, a drawing of a single neuron could be used as a formative assessment to determine students’ understanding of neuronal structure. A drawing can be assessed quickly by an instructor or teaching assistant and provides opportunity for incorporation of feedback. This approach can be scaffolded so that once the structure of a single neuron is mastered, the next formative assessment could focus on how two neurons form a circuit. Similar learner-generated drawings could then be used as summative assessments, although would require manual grading. If auto-grading is the only option (e.g., multiple choice exams for large class enrollments), students could answer questions based upon a neuron image to demonstrate their knowledge. Images have better resolution in an online environment compared to traditional paper exams, and colour can be used effectively without the added cost of colour printing.

The class sizes of many first-year courses at larger post-secondary institutions usually rely upon automated exam grading, which makes it challenging to incorporate drawing-based assessments. The Introduction to Psychology and Neuroscience course at our own university has an enrollment of 1000 students, so we encouraged neuron drawings with an art contest. The Neuron Art Battle is a voluntary bonus activity that requires students to submit an original drawing of two neurons communicating for a chance to win a small prize (see Figure 1). A large class can produce a large number of submissions, but it takes little time to assess errors in an image, and common misconceptions can be communicated to the class as a whole. For a complete description of the Neuron
Students are incentivized to deepen their understanding of the relationship between structure and function by creating a drawing that is not only anatomically correct, but also shows how the structures work together to facilitate synaptic transmission. Furthermore, interactive tasks that require students to work together to represent a neuroscience concept through drawing facilitate collaboration and reflection through discussion and strengthen comprehension. Students may also start by creating individual drawings and then later group together to discuss similarities and differences. Educators could also encourage the use of learner-generated drawings outside of class as active studying tools.

3-D Modeling

Physical 3-D models of the brain help students visualize the complex arrangements of brain structures and their relationships with one another (Estevez et al., 2010). The ability to physically manipulate a 3-D rendering of a brain is associated with higher test scores on questions requiring 3-D mental rotation (Estevez et al., 2010). Neuroscience educators can encourage learners to use clay and other household items like pipe cleaners and beads to create labeled and colour-coded representations of the brain, neurons, or other sense organs that can be manipulated to model neurophysiological processes (Chudler & Konrady, 2006). These models can be used as study aids or as methods of evaluation graded through a rubric.

Digital 3-D modeling has emerged as an effective visualization tool for teaching neuroscience, and neuroanatomy in particular (Arantes et al., 2018). Most of what we know about the internal structures of the human brain is based upon anatomical analysis of 2-D brain slices, either from post-mortem samples or neuroimaging. The use of digital 3-D modeling tools improves understanding of neural structures and leads to better test scores, compared the use of cadaveric anatomical models (Allen et al., 2016; Drapkin et al., 2015). The benefits of digital 3-D models appear to be independent of students’ previous visuospatial abilities (Ruisoto Palomera et al., 2014). Therefore, viewing and manipulating 3-D models is a strategy that has great potential for use by all students regardless of their prior abilities.

Digital 3-D models are an accessible and affordable option for learners and educators, since initiatives like Brainfacts.org, HumanBrainProject.eu, and TheBrainObservatory.org allow manipulation of anatomically accurate 3-D human brain models for free (see Figure 2). These online platforms allow sophisticated views of the nervous system that include detailed views from multiple perspectives. One simple way to incorporate 3-D brain models is by using them in classroom lectures by projecting onscreen and manipulating them live, which would provide
Evaluators could incorporate manipulation of 3-D brain models into online learning modules and assignments, like a brain treasure hunt. Large structures like the hippocampus change in size, shape, and position along the anterior-posterior extent of the brain. A 2-D section through the brain will show a different perspective of this structure depending upon the plane of orientation. Students can manipulate 3-D brain models according to specific neuroanatomical directions and submit an image of the hippocampus from a specific perspective, demonstrating their knowledge of terms and structures. This would require manual grading, but this type of grading is much faster than grading written text answers. This activity could also be altered for auto-grading, so that students are given anatomical directions and must “hunt” for an image that matches one from several options. Although this may be cumbersome on a traditional paper-based exam, this approach works well in an online learning environment. For a complete description of a neuroanatomy treasure hunt activity, student and teacher instructions, and a sample grading rubric, see Stamp (2021a, February 6).

**Infographics**

Although the use of infographics in neuroscience specifically has not been studied to date, infographics are effective tools for engaging both learners and educators in the modern science classroom (Fadzil, 2018). Infographics are visualizations of data and information that convey a message in a concise, clear, and aesthetic fashion. They use graphs, charts, diagrams, icons, and pictures to weave a narrative about the data and clarify the “big picture” of a concept that may be difficult to grasp (Lamb & Johnson, 2014). Infographics promote greater academic achievement and learners believe that they also improve retention and comprehension of material, increase positive affect and confidence, and promote the acquisition of life skills (Shabak Arlwele, 2017). When students in an online post-secondary course were provided with instructor-created summary infographics, they stated that both comprehension and retention of course material were improved, and that the infographics served as a useful content summarization and reminder (Elena Gallagher et al., 2017). Fadzil (2018) found that pre-service science teachers that engaged in an infographic creation assignment not only perceived it as a meaningful experience, but also felt that their own conceptual science knowledge was increased. This provides evidence for the potential of infographics to engage educators as well as learners.

Neuroscience educators could adopt the use of infographics in their teaching to help explain intricate studies and concepts. The complexities of the nervous system have led to a “neurophobia” among some learners who believe their neuroscience knowledge to be insufficient (Abulaban et al., 2015). Infographics could be a tool to dispel some of this neurophobia, particularly in first-year or lower-level courses where understanding the “big picture” of scientific concepts and literature is emphasized. Learners could be tasked with creating infographics for assessment, either in groups or alone, which would encourage them to work together to critically analyze, condense, and accurately pictorially represent content. This would work particularly well in teaching neuroanatomy, which is an inherently visual topic. Alternatively, instructors could provide learners with infographics to supplement their understanding of concepts or literature (see Figure 3). By being exposed to both the complete work and the low-text, condensed infographic version, learners could use these pairs as models for how to effectively summarize and condense literature. A final advantage for the use of infographic assignments is their accessibility. There are several user-friendly online programs

![Figure 2. Screenshots of an online 3-D model of a human brain from different perspectives, obtained for free at Brainfacts.org (Society for Neuroscience, 2017).](image-url)
(e.g., Canva, Piktochart, Venngage) that allow educators and learners to create infographics for free. For a complete description of a sample science infographic assignment, student instructions in written and infographic form, and a sample grading scheme, see Stamp (2021b, February, 6).

**Conclusion**

Before the modern era, being a neuroscientist necessitated engaging in art; drawings and visual representations of the brain were integral to the understanding of the field. In the contemporary scientific era, visual representations of science continue to serve as powerful tools, particularly for educational purposes. In this paper, we have reviewed the limited literature on the use of visuals for undergraduate neuroscience education.

We have recommended that neuroscience educators employ the use of learner-generated drawing (Ainsworth et al., 2011; Hay et al., 2013; Quillin & Thomas, 2015; Slominski et al., 2017; Van Meter & Gardner, 2005; Wu & Rau, 2019), 3-D modeling (Allen et al., 2016; Arantes et al., 2018; Chudler & Konrady, 2006; Drapkin et al., 2015; Estevez et al., 2010; Ruisoto Palomera et al., 2014), and infographics (Elena Gallaghher et al., 2017; Fadzil, 2018; Shabak Arlwele, 2017) in their instruction to improve student learning. Neuroscience educators should continue the practice of ancient neuroanatomists and neuroscientists of embracing the complimentary nature of art and neuroscience by using the recommendations outlined in this paper.

**Authors’ Note**

Qendresa Sahiti is now at the Faculty of Medicine, Dalhousie University, Halifax, NS, Canada.

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**References**

Abulaban, A. A., Obeid, T. H., Algahtani, H. A., Kojan, S. M., Al-Khathaami, A. M., Abulaban, A. A., Bokhari, M. F., Merdad, A. A., & Radi, S. A. (2015). Neurophobia among medical students. *Neurosciences (Riyadh, Saudi Arabia)*, 20(1), 37–40.

Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science, 333*(6046), 1096–1097. http://doi.org/10.1126/science.1204153

Allen, L. K., Eagleson, R., & de Ribauipierre, S. (2016). Evaluation of an online three-dimensional interactive resource for undergraduate neuroanatomy education. *Anatomical Sciences Education, 9*(5), 431–439. https://doi.org/10.1002/ase.1604

Arantes, M., Arantes, J., & Ferreira, M. A. (2018). Tools and resources for neuroanatomy education: A systematic review. *BMC Medical Education, 18*(1), 94–108. https://doi.org/10.1186/s12909-018-1210-6
Bobek, E., & Tversky, B. (2016). Creating visual explanations improves learning. *Cognitive Research: Principles and Implications, 1*(1), 27–40. https://doi.org/10.1186/s41235-016-0031-6

Bolwerk, A., Mack-Andrick, J., Lang, F. R., Dörfler, A., & Maihöhner, C. (2014). How art changes your brain: Differential effects of visual art production and cognitive art evaluation on functional brain connectivity. *PLOS One, 9*(7), e101035. https://doi.org/10.1371/journal.pone.0101035

Brumberger, E. (2011). Visual literacy and the digital native: An examination of the millennial learner. *Journal of Visual Literacy, 30*(1), 19–47. https://doi.org/10.1080/23796529.2011.11674683

Chi, M. T. H. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*(1), 73–105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

Chudler, E. H., & Konrady, P. (2006). Visualizing neuroscience: Learning about the brain through art. *Science Scope, 29*(8), 24–27. https://eric.ed.gov/?id=EJ758452

Clark, J. J., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*(3), 149–210. https://doi.org/10.1007/BF01320076

Collins, J. W., & O’Brien, N. P. (2003). The Greenwood dictionary of education. Greenwood.

Dangur, V., Avargil, S., Peskin, U., & Yehudit, J. (2014). Learning quantum chemistry via a visual-conceptual approach: Students’ bidirectional textual and visual understanding. *Chemistry Education Research and Practice, 15*(3), 297–310. https://doi.org/10.1039/C4RP00025K

Drapkin, Z. A., Lindgren, K. A., Lopez, M. J., & Stabio, M. E. (2015). Development and assessment of a new 3D neuroanatomy teaching tool for MRI training. *Anatomical Sciences Education, 8*(6), 502–509. https://doi.org/10.1002/ase.1509

Elena Gallagher, S., O’Dulain, M., O’Mahony, N., Kehoe, C., McCarthy, F., & Morgan, G. (2017). Instructor-provided summary infographics to support online learning. *Educational Media International, 54*(2), 129–147. https://doi.org/10.1080/09523987.2017.1362795

Estevez, M. E., Lindgren, K. A., & Bergeethon, P. R. (2010). A novel three-dimensional tool for teaching human neuroanatomy. *Anatomical Sciences Education, 3*(6), 309–317. https://doi.org/10.1002/ase.186

Fadzil, H. M. (2018). Designing infographics for the educational technology course: Perspectives of preservice science teachers. *Journal of Baltic Science Education, 17*(1), 8–18. http://www scientiasocia lis.lt/jbse/?q=node/636

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America, 111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Gagnier, K. M., Atit, K., Ormand, C. J., & Shipley, T. F. (2017). Comprehending 3D diagrams: Sketching to support spatial reasoning. *Topics in Cognitive Science, 9*(4), 1264–1279. https://doi.org/10.1111/tops.12233

Gerannmayeh, F., & Ashkan, K. (2008). Mind on canvas: Anatomy, signs and neurosurgery in art. *British Journal of Neurosurgery, 22*(4), 563–574. https://doi.org/10.1080/02688690802109820

Gersten, R., & Baker, S. (2000). What we know about effective instructional practices for English-language learners. *Exceptional Children, 66*(4), 454–470.

Griggs, R. A. (1988). Who is Mrs. Cantile and why are they doing those terrible things to her homunculi? *Teaching of Psychology, 15*(2), 105–106. https://doi.org/10.1207/s15328023top1502_13

Gurnon, D., Voss-Andreae, J., & Stanley, J. (2013). Integrating art and science in undergraduate education. *PLoS Biology, 11*(2), e1001491. https://doi.org/10.1371/journal.pbio.1001491

Hay, D. B., Williams, D., Stahl, D., & Wingate, R. J. (2013). Using drawings of the brain cell to exhibit expertise in neuroscience: Exploring the boundaries of experimental culture. *Science Education, 97*(3), 468–491. https://doi.org/10.1002/sce.21055

Kaplan, E., & Mifflin, J. (1996). “Mind and sight”: Visual literacy and the archivist. *Archival Issues, 21*(2), 107–127.

Land, M. H. (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. *Procedia Computer Science, 20*, 547–552. https://doi.org/10.1016/j.procs.2013.09.317

Lamb, A., & Johnson, L. (2014). Infographics part 1: Invitations to inquiry. *Teacher Librarian, 41*(4), 54–58. http://hdl.handle.net/1805/8589

Lorusso, L. (2008). Neurological caricatures since the 15th century. *Journal of the History of the Neurosciences, 17*(3), 314–334. https://doi.org/10.1080/09647040802132023

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53*(1), 1–14. https://doi.org/10.1007/s11881-003-0001-9

Manic, M. (2015). Marketing engagement through visual content. *Bulletin of the Transylvania University of Brasov. Economic Sciences. Series V, 8*(2), 89–94. http://webbut.unitbv.ro/Bulletin/Series%20V/Series%20V.html

Mayer, R. E., & Anderson, R. B. (1992). The instructive animation: Anatomical Sciences Education, *Series V*, 30, 297–310. https://doi.org/10.1037/0022-0663.84.4.444

Meade, M. E., Wammes, J. D., & Fernandes, M. A. (2018). Drawing as an encoding tool: Memorial benefits in younger and older adults. *Experimental Aging Research, 44*(5), 369–396. https://doi.org/10.1080/0361073X.2018.1521432

Meshberger, F. L. (1990). An interpretation of Michelangelo’s creation of Adam based on neuroanatomy. *JAMA, 264*(14), 1837–1841. https://doi.org/10.1001/jama.1990.03450140059034

Michael, J. (2006). Where’s the evidence that active learning works? *Advances in Physiology Education, 30*(4), 159–167. https://doi.org/10.1152/advan.00053.2006

Poh, M., Swenson, N. C., & Picard, R. W. (2010). A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. *IEEE Transactions on Biomedical Engineering, 57*(5), 1243–1252. https://doi.org/10.1109/TBME.2009.2038487

Quillin, K., & Thomas, S. (2015). Drawing-to-learn: A framework for using drawings to promote model-based reasoning in biology. *CBE Life Sciences Education, 14*(1), es2–es2. https://doi.org/10.1187/cbe.14-08-0128
Root-Bernstein, R., Allen, L., Beach, L., Bhadula, R., Fast, J., Hosey, C., Kremkow, B., Lapp, J., Lenc, K., Pawelek, C., Podufaly, A., Russ, C., Tennant, L., Vrtis, E., & Weinlander, S. (2008). Arts foster scientific success: Avocations of Nobel, National Academy, Royal Society, and Sigma Xi members. *Journal of Psychology of Science and Technology, 1*(2), 51–63. https://doi.org/10.1891/1939-7054.1.2.51

Rousseau, M. K., & Tan, B. K. Y. (1993). Increasing reading proficiency of language-minority students with speech and language impairments. *Education & Treatment of Children, 16*(3), 254–271.

Ruisoto Palomera, P., Juanes Méndez, J. A., & Prats Galino, A. (2014). Enhancing neuroanatomy education using computer-based instructional material. *Computers in Human Behavior, 31*, 446–452. https://doi.org/10.1016/j.chb.2013.03.005

Schneps, M. H., Rose, L. T., & Fischer, K. W. (2007). Visual learning and the brain: Implications for dyslexia. *Mind, Brain, and Education, 1*(3), 128–139. https://doi.org/10.1111/j.1751-228X.2007.00013.x

Shabak Alrwele, N. (2017). Effects of infographics on student achievement and students’ perceptions of the impacts of infographics. *Journal of Education and Human Development, 6*(3), 104–117. https://doi.org/10.15640/jehd.v6n3a12

Slominski, T. N., Molsen, J. L., & Montplaisir, L. M. (2017). Drawing on student knowledge of neuroanatomy and neurophysiology. *Advances in Physiology Education, 41*(2), 212–221. https://doi.org/10.1152/advan.00129.2016

Society for Neuroscience. (2017). *3D Brain*. BrainFacts.org. https://www.brainfacts.org/3d-brain

Slominski, T. N., Momsen, J. L., & Montplaisir, L. M. (2017). Drawing on student knowledge of neuroanatomy and neurophysiology. *Advances in Physiology Education, 41*(2), 212–221. https://doi.org/10.1152/advan.00129.2016

Stein, M., & Power, B. (1996). Putting art on the scientist’s palette. In R. S. Hubbard & K. Ernst (Eds.), *New entries: Learning by writing and drawing*. Heinemann.

Van Meter, P., & Garner, J. (2005). The promise and practice of learner-generated drawing: Literature review and synthesis. *Educational Psychology Review, 17*(4), 285–325. https://doi.org/10.1007/s10648-005-8136-3

von Károlyi, C., Winner, E., Gray, W., & Sherman, G. F. (2003). Dyslexia linked to talent: Global visual-spatial ability. *Brain and Language, 85*(3), 427–431. https://doi.org/10.1016/S0093-934X(03)00052-X

Wammes, J. D., Roberts, B. R. T., & Fernandes, M. A. (2018). Task preparation as a mnemonic: The benefits of drawing (and not drawing). *Psychonomic Bulletin & Review, 25*(6), 2365–2372. https://doi.org/10.3758/s13423-018-1477-y

Woollett, K., & Maguire, E. A. (2011). Acquiring “the knowledge” of London’s layout drives structural brain changes. *Current Biology, 21*(24), 2109–2114. https://doi.org/10.1016/j.cub.2011.11.018

Wu, S. P. W., & Rau, M. A. (2019). How students learn content in science, technology, engineering, and mathematics (STEM) through drawing activities. *Educational Psychology Review, 31*(1), 87–120. https://doi.org/10.1007/s10648-019-09467-3