Formative Learning:

Effects of Visualizing Neuroplasticity on Implicit Theories of Intelligence

BY

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B.S., Indiana Wesleyan University, 2013

THESIS

Submitted as partial fulfillment of the requirements
for the degree of Master of Science in Biomedical Visualization
in the Graduate College of the
University of Illinois at Chicago, 2015

Chicago, Illinois

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This thesis is dedicated to those who love the seed of knowledge and cultivate the tree that grows from it.

ACKNOWLEDGEMENTS

I would like to thank my research advisor, John Daugherty, for his consistent support and encouragement as well as my committee, Andy Boyd and Annette Valenta for their assistance, support, and feedback. Thanks also to the BVIS faculty and student body for their incredible instruction and comradery throughout the process.

I would also like to acknowledge Mustafa Mir, Taewoo Kim, Anirban Majumder, Mike Xiang, Ru Wang, S. Chris Liu, Martha U. Gillette, Steven Stice and Gabriel Popescu for their work creating a time-lapse video of neuron growth, and thank them for permission to include it in my interactive module. I also acknowledge Xu Liu, Steve Ramirez, Petti T. Pang, Corey B. Puryear, Arvind Govindarajan, Karl Deisseroth, Susumu Tonegawa for their work optogenetically labelling the neurons involved in a single memory, and thank Nature Publishing group for permission to include the figure in my interactive module.

To my family and friends, thank you always. Your support is invaluable.

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SUMMARY

Medical illustration traditionally evaluates a successful illustration based on the effectiveness of information transmission: did the audience learn the material? This study expands that view of success by examining not only effective information transmission, but also the influence of the information on the audience's beliefs and behaviors by affecting their implicit theory of intelligence.

Implicit theories are the unexamined beliefs we hold about the world around us. Psychology research indicates that instruction on neuroplasticity can affect implicit theories of intelligence -- whether we believe intelligence to be a fixed or dynamic quality. Implicit theories have been widely shown to impact behavior and performance in conflict, challenge, and failure.

This study involved the creation of a visually rich interactive eLearning module teaching about the dynamic changes happening within the brain. The module was tested for both traditional learning outcomes (fact transmission) and formative outcomes (change in implicit theory) through a pre/post-test design. Subjects were recruited through Amazon's Mechanical Turk crowdsourcing platform.

The average knowledge test score went from 51% pre-test to 82% post-test ($n=47$, $p<0.0001$, Cohen's $d = 1.53$) and the average implicit theory score increased by 0.55 pre- to post-test ($n=47$, $p<0.0001$, Cohen's $d = 0.64$). These results strongly support the hypothesis. Not only did participants learn the material presented in the interactive, but it changed their implicit beliefs about the nature of intelligence.

I. INTRODUCTION

A. Implicit Theories of Intelligence

The term implicit theory was coined in 1955 to describe the unexamined assumptions that govern how we interpret the world around us; for example, many assume that someone who is kind is also generous, or someone who is tall is also trustworthy (Colman, 2008). These unconscious assumptions affect how we perceive others and ourselves. In addition to correlation between traits, implicit theories also include our assumptions about whether personality traits are static or malleable. There are two main implicit theories regarding change: entity and increment. An entity theorist holds that personality is a stable entity. An increment theorist holds that personality is incrementally changing.

As the implicit theory conversation began, researchers observed and described the ways that implicit theories govern our motivation, judgments, and behavior. This work continued through the 1980’s describing what dispositional inferences people make and when they make them (Ross, 1989; Dweck, Hong, & Chiu, 1993), all based on entity vs. increment implicit theories. That work allowed researchers to move into the next realm. They knew how implicit theories affected internal judgments, now it was time to study their effect on external outcomes.

The dispositional inferences studies found that entity theorists make broader judgments about themselves and others. As a result, they are more punitive when they believe someone is guilty. On the other hand, an increment theorist thinks there is more possibility for reform, and therefore are less likely to desire harsh punishment (Dweck et al., 1993). The same judgments of others also apply to the self. When an entity theorist fails, they feel they are a failure. When an increment theorist fails, they feel they need to work harder or work differently next time (Dweck, Chiu, & Hong, 1995). Increment theorists are less likely to seek revenge and more likely to negotiate in response to conflict (Yeager, Trzesniewski, Tirri, Nokelainen, & Dweck, 2011). Entity theorists will resort to revenge or manipulation (Kammrath & Dweck, 2006). Unlike entity theorists, increment theorists remain effective learners even when there is a strong chance of failure (Mangels, Buttterfield, Lamb, Good, & Dweck, 2006) because they persevere through problem solving in response to failure (Da Fonseca, Cury, Bailly, & Rufo, 2004). They are also more likely to seek out challenging situations, and even perform better in serious gaming (Lee, Heeter, Magerko, & Medler, 2012).

In addition to discovering the myriad ways that implicit theory determines behavior, psychologists also discovered that the theories themselves were capable of changing. Though individuals may have a dominant fixed or increment theory, they vary their response based on context, situation, and the trait in question. An individual may have a strong entity theory regarding moral character, but an increment theory of intelligence. This malleability in implicit theories of personality has led researchers to test their own ability to influence the theory of their research subject, especially implicit theories regarding intelligence. As an example, undergraduates in a pen pal program who were taught to write letters about how intelligence can get stronger like a muscle – an increment theory – enjoyed learning more and had higher GPAs as a result of the intervention (Aronson, Fried, & Good, 2002). Another group of researchers successfully induced either fixed or entity theories by presenting undergraduate students with fictitious science articles arguing for one of the two theories (Dweck et al., 1995).

There is no need for fictitious science to influence implicit theories, however. Researchers in the same lab used the actual science of neuroplasticity to influence implicit theory. They developed a curriculum for middle school students teaching about the brain and how it forms new synapses when learning, taught in short weekly sessions for eight weeks. Students who went through the curriculum earned higher grades, despite a previous downward spiral (Blackwell, Trzesniewski, & Dweck, 2007). That curriculum has since been developed into a computer-based intervention called "Brainology." Early results indicated it improves study habits and persistence (Dweck, 2008), and it is now being marketed for use in middle schools (Chandler, 2012).

This work suggests that if you believe your neurons are static, then you believe your ability is as well, especially your intelligence. On the other hand, individuals aware of the brains' remarkable plasticity across their lifetime (such as described by White, Hutka, Williams & Moreno, 2013) will possess a strong increment theory of personality. Furthermore, a common qualitative theme emerged from the Brainology pilot: "Many students reported picturing their neurons forming new connections as they studied and learned," (Dweck, 2008, p.392). This speaks to the power of visualizations to teach about neuroplasticity and subsequently influence implicit theory and change behavior.

B. Neuroplasticity

Neuroplasticity is an umbrella term describing how the brain is a deeply adaptive, dynamic organ capable of change at the functional, molecular, and cellular levels. A review by Bruel-Jungerman, Davis, and Laroche describes the four main processes by which the brain changes: long term potentiation, long term depression, synaptogenesis, and neurogenesis. Long term potentiation (LTP) is the process by which synapses get stronger as part of memory formation. Long term depression (LTD) is the process to weaken synapses. It serves to counter-balance LTP, but it also has its own independent role in memory formation through weakening non-active synapses, indirectly strengthening active ones by contrast. Both LTP and LTD occur through changes in the molecules present at the synapse surface. Synaptogenesis involves greater changes, both in size and shape of synapses as well as the growth of new synapses. Finally, neurogenesis is the process of new neurons being formed. Though it was once thought that neurogenesis stopped after early development, it is now known that adults form thousands of new neurons every day and learning is the process by which these new neurons become integrated into existing networks. Otherwise they die through apoptosis (Bruel-Jungerma et al., 2007). These processes of neuronal change demonstrate that the brain is constantly changing through the ongoing process of memory formation and recall.

Not only is the brain constantly changing through learning, but the rate of learning is influenced by what is already known. This happens through the formation of schemas, a neurobiological network of related memories (also the type of memory capitalized by cognitive load theory). One clear example is a study where rats had to learn the location of unique rewards scattered throughout a non-linear maze. The initial training took weeks of repetition; however, once they had developed a schema of the maze, a new reward and corresponding new location could be introduced and learned with only one exposure (Tse et al., 2007). Repetition was no longer necessary. Learning changes the brain’s structure in ways that make it easier to learn in the future.

In addition to learning, there are other ways people have influence over their own neuroplasticity. Exercise has been shown to profoundly impact cognitive function by influencing the four main process of neuroplasticity. It increases levels of molecular factors necessary for synaptic regulation (LTP and LTD), increases synaptogenesis, and increases neurogenesis (Ratey & Hagerman, 2008). Interestingly, though exercise increases the number of new neurons created, the same percentage will die (as compared to a non-exercise control) without the stimulation of learning. The connection between exercise and cognitive function is corroborated by a California Department of Education study showing that students with increased fitness levels also have increased test scores (Ratey & Hagerman, 2008).

By understanding neuroplasticity, users will know that their brain is capable of fundamental change at the molecular and cellular levels. They will know that learning not only increases knowledge, but it also increases the speed of future learning, and they will know that their actions influence the entire process.

C. Educational Digital Interactives

Dynamic interactive visuals are gaining momentum as educational tools in the biological and health sciences. They are being used to teach research methods and statistics to nurses (Johnston, Boyle, MacArthur, & Manion, 2013), mental health literacy to young adults (Li, Chau, Wong, Lai & Yip, 2013), and molecular genetics to high school students (Marbach-Ad, Rotbain & Stavy, 2008), to name a few.

Merely being digital and interactive does not ensure success, however. A 2014 review by George et al examined all studies comparing eLearning to traditional learning published between January 2000 and April 2013. Of the qualifying studies that directly compared knowledge gain between traditional and eLearning, 28% found higher knowledge gain for eLearning, 56% found no significant difference, 8% had mixed results favoring eLearning, and 8% found higher knowledge gain with traditional learning. Combined, it makes a strong case for the equivalence of eLearning to traditional learning and alludes to the potential of eLearning to surpass traditional learning methods.

This leaves interactive designers with the question: what qualities distinguish the digital tools that surpass traditional learning from the tools that perform the same or worse? Though no work retroactively evaluating the quality of interactive media documented in past studies has been done, researchers and designers have begun to look to cognitive load theory to guide current interactive development.

Cognitive load theory (CLT) is based on the principle that effective learning happens when the learning experience corresponds with the learner's cognitive architecture. It focuses on developing the learner's mental schema (a form of memory that becomes automatic and, once formed, can easily receive new information) without exceeding the limited capacity of working memory. Khalil, Paas, Johnson, and Payer (2005) identify five CLT design principles to guide interactive development:

1. Learner Control: Allowing learners to control the pace decreases cognitive load and requires active processing, which is the key to schema formation.
2. Visual Grouping: Group information into small segments to avoid exceeding working memory capacity.
3. Modality Principle: Visual and verbal channels are processed separately by the learner, so using both decreases the cognitive load of each and promotes

integration of the two. Ideal modality use involves hearing the text narrated while seeing the visual, however, this limits the amount of user control compared to written text next to the visual.

4. Contiguity Principle: Corresponding information needs to be presented together either temporally (learner hears the information when they see the visual) or spatially (learner reads the information next to where they see the visual).
5. Signaling: Directing attention to relevant parts, such as through highlighting, decreases cognitive load and increases learning.

These principles have been used to create successful education digital interactives, such as the CLT-based 3D animations on the upper limb of Hoyek, Collet, Di Rienzo, De Almeida, and Guillot (2014) that significantly improved student test scores on questions regarding spatial anatomy as well as the interactive eye model of Allen, Bhattacharyya, and Wilson (2014) in use at Western University. Interestingly, when pediatric residents were asked what features they felt were important in a web-based interactive on pediatric rheumatology, their requests align well with CLT. All the residents requested pictures (Signaling and Modality Principles), 93.2% requested interactivity (Learner Control Principle), and 86.4% requested graphics and animation (Modality Principle) (Batthish et al., 2013).

In light of this evidence, digital interactives based in cognitive load theory are potent learning tools and should be effective in teaching about neuroplasticity and influencing implicit theories of intelligence.

II. RESEARCH QUESTIONS AND HYPOTHESIS

Research Question: Does a digital interactive on neuroplasticity increase factual understanding of the process?

Hypothesis: The digital interactive will improve understanding of neuroplasticity.

Research Question: Does understanding neuroplasticity affect implicit theories of intelligence?

Hypothesis: Understanding neuroplasticity will strengthen the increment theory of intelligence.

III. MATERIALS AND METHODS

A. Design Process

The digital interactive consists of five main segments: an introduction to synapses, molecular change, synaptic change, cellular change, and schema formation (Figure 1). The final product is a series of webpages coded with HTML/CSS using Adobe Dreamweaver CC 2014. Included within the webpages are illustrations and interactive scenes (see Appendix A for screenshots of full interactive). Illustrations were created using Adobe Illustrator CC 2014. A simple schematic style was chosen to reduce visual complexity.

Interactive scenes were created using the Unity4 game engine. Scenes were storyboarded (Figure 2) and then built. The 3D models and textures were created with Autodesk 3ds Max 2014. The backgrounds were rendered out of 3ds Max and composited in Adobe Photoshop CC 2014. The functionality was written in Javascript for Unity, also called UnityScript. The interactive scenes allow the user to dynamically change variables and see the effect, solidifying the concept for that section.

In addition to illustrations and interactive scenes, the module also ties in real-world data with a photo of a memory by Liu et al (2012) and a time lapse video of a neuron network forming by Mir et al (2014), used by permission of the original authors (Appendix E). These tiers of complexity combine to form a robust learning environment. Schematic illustrations visualize each piece of information. Interactive scenes allow for user to dynamically practice the material, reinforcing the main ideas. Microscopic imaging connects the ideas to reality and provides a sense of accurate scale and complexity.

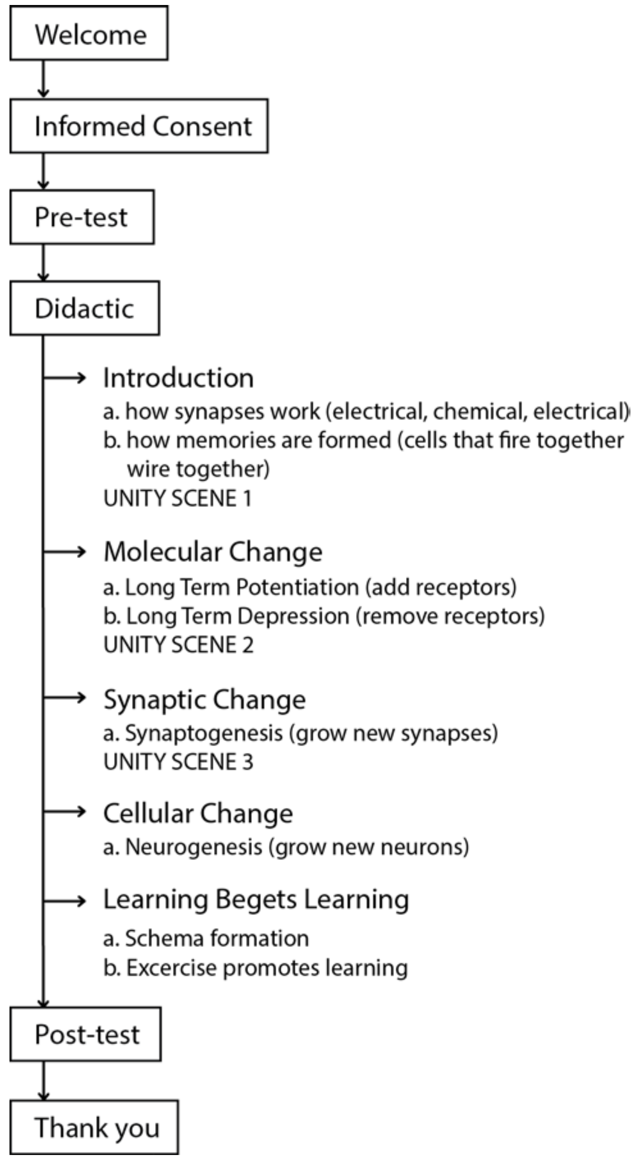
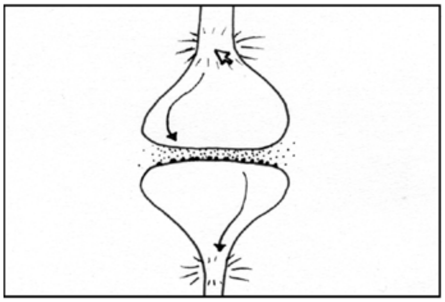


Figure 1. Wireframe of digital interactive.

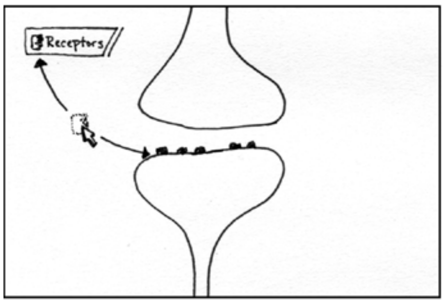


Unity Scene 1: Introduction to Synapses

User can click pre-synaptic neuron to initiate action potential (glow), which will cause neurotransmitter release, and then a post-synaptic electrical signal (glow).

effects:
- moving glow for electrical signal
- particle system for neurotransmitter

function:
- click on object, cause event
- have one event cause another

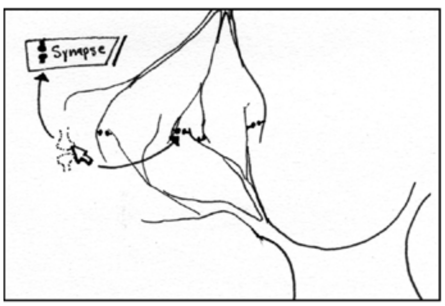


Unity Scene 2: Molecular Change

User can click and drag receptors onto and off of the synapse, this changes the strength of the synapse and affects whether or not a post-synaptic electrical change will occur when the

effects:
- GUI: graphical user interface
- have an image follow the mouse (click and drag)

function:
- click and drag between GUI, geometry, and empty space
- calculate AP based on #receptros, #neurotransmitters/unit time
- receptors snap to points when placed



Unity Scene 3: Synaptic Change

User can click to add and remove synapses. Clicking on any neuron will start an action potential, allowing the user to see the effect of their work on the neuronal network's scope. Use arrow keys to move and a slider to zoom.

effects:
- GUI slider to control camera position

function:
- add and remove synapses
- include refractory period in AP calculation

Figure 2. Storyboard of Unity scenes.

The target audience for the interactive was average adults, and was therefore written in plain, conversational language suitable for a seventh grade level reader (Flesch-Kincaid grade level of 7.6). In accordance with cognitive load theory, information was broken down into small units to avoid exceeding the limits of working memory. The pace was entirely user-defined. Text and diagrams are all presented together to aid comprehension by utilizing both visual and verbal channels. Attention is directed to the most important parts through use of insets, judicious labels, and highlighting; for example, in Unity scene 1 (Appendix A, pg.34) the labels are next to the corresponding portion of the scene and change color in sync with the phases of neuronal signaling.

B. Data Collection

This study utilizes an online pre-/post-test research design. Subjects were recruited from the general adult population: a truly unique feature for implicit theory research. Previous studies have focused primarily on "samples of mostly White, Midwestern grade students or on college students attending elite universities," (Yeager, Trzesniewski, Tirri, Nokelainen, & Dweck, 2011).

The research was conducted in two phases: a pilot followed by full deployment. Nineteen subjects met the inclusion criteria for the pilot. Pilot data were used in a sample size calculation for the full deployment. Of the two research questions, examining a change in implicit theory required more participants to reach appropriate statistical strength and therefore it determined the necessary sample size. On a scale from one to six, the standard deviation for the change in implicit theory score was 0.79, with a mean change of 0.49; therefore, the full study would require 41 participants to reach statistical strength.

Subjects were recruited through Amazon's Mechanical Turk. Mechanical Turk is a crowdsourcing platform, an online job market for small digital tasks. For researchers doing online experiments, it provides access to a large, stable, and diverse group of adults willing to perform tasks, such as participate in research studies. According to their website, Mechanical Turk workers comprise a group of over 500,000 people from over 190 countries (though a 2012 study by Mason and Suri found the majority are in the United States or India, the only two countries with the option of direct deposit payment), who are able to sit in their living rooms and make money doing the tasks that they choose on their own schedule.

The Principal Investigator created a requester account on Mechanical Turk and posted the task with a brief summary of the research study and remuneration, including the qualification that workers be 18 years or older (recruitment materials in Appendix B). Though it was impossible to guarantee that no minors employed deceit to participate, previous work has found 93% of Turk workers to be consistent when they self-report age (Rand, 2012).

Though Mechanical Turk is internationally accessible, use of the site did limit potential subjects to those able to read English. Enrolling opened the informed consent (full text in Appendix C), a link to the experiment, and a box to enter a code that was supplied upon experiment completion.

The pre- and post-tests were conducted within Qualtrics. Using Qualtrics ensured that all data was stored exclusively on secure servers; Amazon never had a copy of it.

The pre-test included broad non-identifying demographic questions, standard test questions to assess baseline knowledge of neuroplasticity, Likert-style scales to assess baseline implicit theories of intelligence, and a "reverse Turing test" question designed to prevent spam bots from contaminating the data. Though CAPTCHA questions would have fulfilled the same role, they do not work well with screen readers and therefore would have limited accessibility.

Within the pre-test, factual understanding of neuroplasticity was assessed with eight multiple-choice questions. Implicit theories were assessed through their level of agreement with three statements, rated along a Likert-style scale from 1-6. The statements, taken from a study by Dweck et al. in 1995, read:

1) You have a certain amount of intelligence and you really can't do much to change it.
2) Your intelligence is something about you that you can't really change that much.
3) You can learn new things, but you can't really change your basic intelligence.

They found the test, though short, to be internally reliable and to exhibit test/re-test reliability. Statements of an increment theory are not included because participants gravitate toward increment ideas even if they actually hold entity beliefs. Finally, disagreement with the entity statements above is equivalent to agreeing with an increment statement (full pre- and post-test in Appendix D).

Once the pre-test was complete, users were redirected to the digital interactive (described in detail below). After reviewing the interactive, they were directed back to Qualtrics for the post-test. The post-test repeated the same standard test questions and Likert-style scales to assess any changes in factual understanding of neuroplasticity or change in implicit theory of intelligence. After finishing the post-test, participants were thanked for participating and given a code. The code was entered into the original Mechanical Turk page (still open on their machines), allowing them to submit the work through Mechanical Turk.

Submitted Mechanical Turk jobs then went to the requestor (researcher) for review. All participants finished within a reasonable time period, passed the reverse Turing test, and supplied a correct code and, therefore, were compensated $2.00 for their time. This is appropriate remuneration for online work done: the reservation wage for Mechanical Turk, below which participants won't accept jobs, is $1.38/hour (Mason & Suri, 2012).

There was minimal risk in study participation. Subjects were entirely anonymous, known only through Mechanical Turk by a non-identifiable worker ID number. Though being tested can be a stressor, it was made clear that the research did not judge the subjects' performance, but rather employed them to judge the efficacy of the interactive as a teaching tool.

IV. RESULTS

A. Demographics

Based on the sample size estimate from the pilot data, the full study was opened to 50 participants. In addition to those 50, 18 started but did not complete the study and were excluded from analysis. Of the 50, three were excluded because, though supposedly different individuals, the data were from the same IP address with the same geographic area at concurrent times. A total of 47 respondents were included in data analysis, none of whom overlapped with the 19 from the pilot.

Those 47 respondents were mainly from the United States (64%) and India (32%) with one from North America (2%) and one from Scotland (2%, Figure 3). They ranged in age from 18 to over 55 years, with the largest demographic being 26-35 years old (47%) followed by 18-25 years (28%), 46-55 years (15%), 36-45 years (9%) and one individual 55 years or older (2%, Figure 4). Just over half the participants were male (55%), the rest female (45%, Figure 5). “Neither category” and “Prefer not to say” were available options, but were not selected by any participants. It was a well-educated group; 2% had only completed some high school. Eleven percent had received their high school diploma. Another 11% had completed some college. The largest group, 38%, had received their college diploma; 19% had some graduate or professional school. The same percentage, 19%, had received their graduate or professional diplomas (Figure 6).

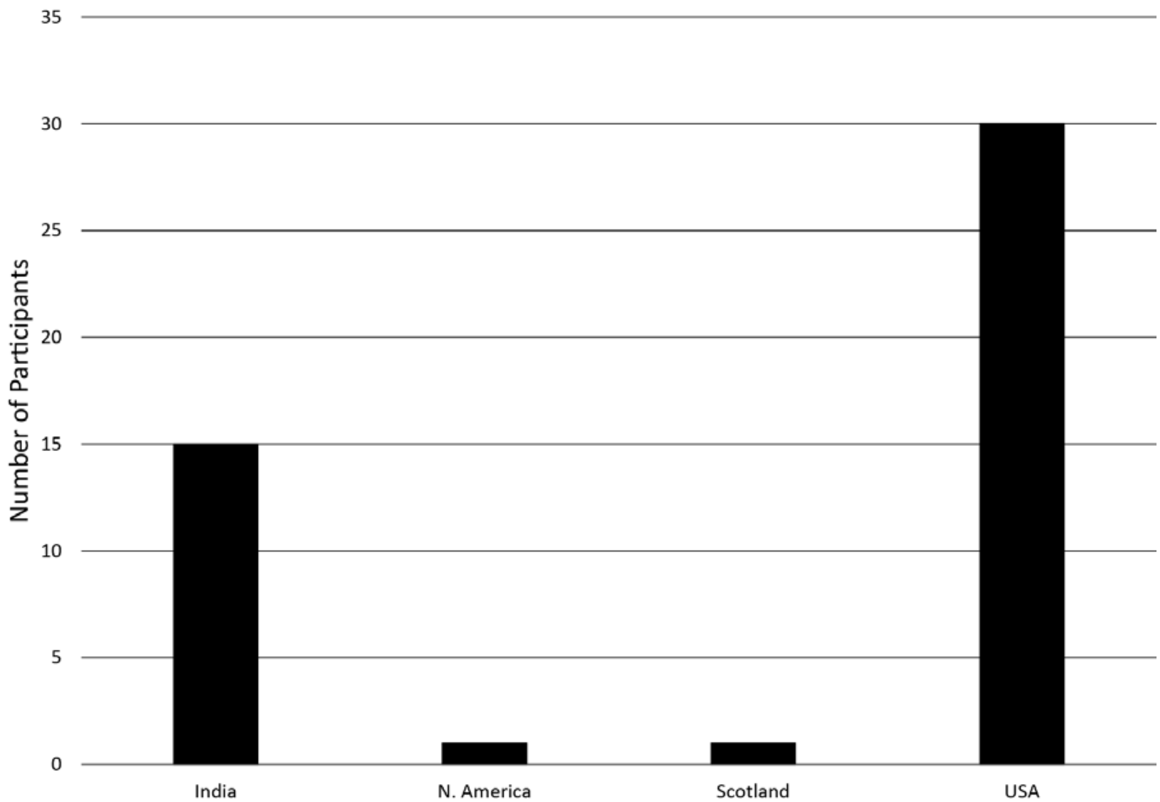


Figure 3. Self-reported country of residence. 64% from the USA, 32% from India, 2% from Scotland, and 2% saying only N. America.

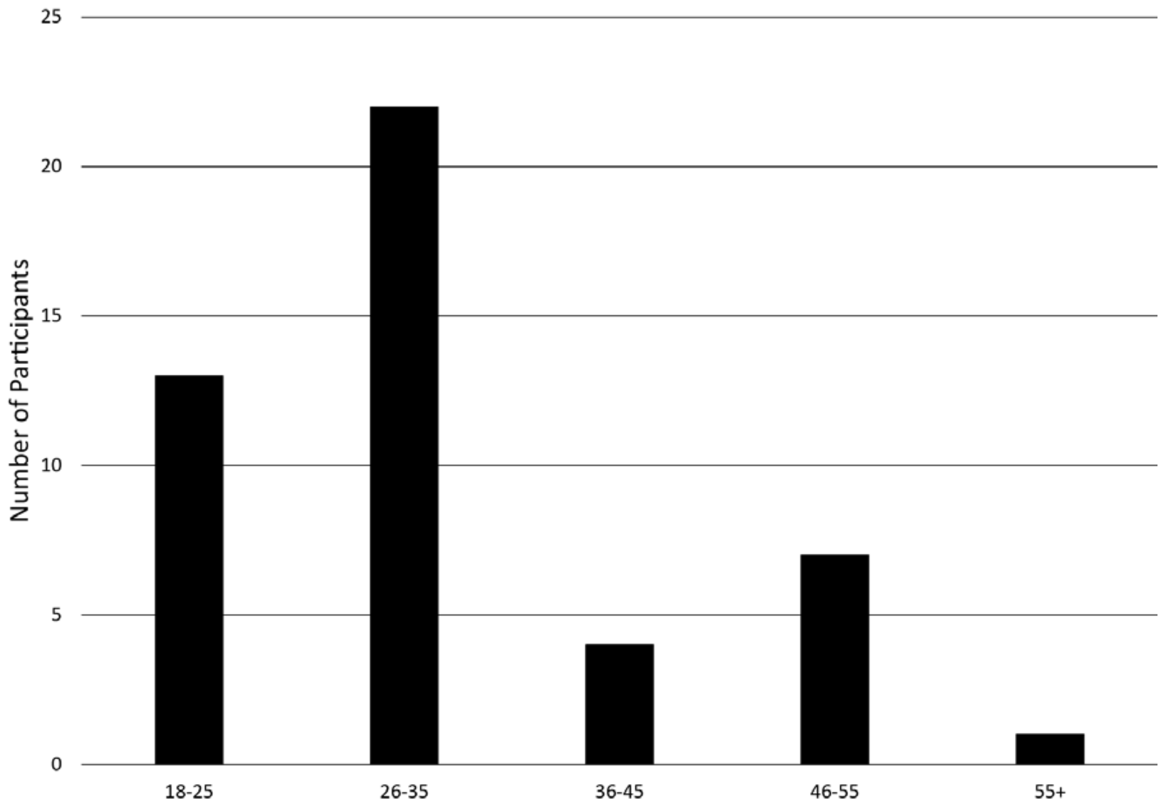


Figure 4. Age distribution. 28% were 18-25 years old, 47% were 26-35 years, 9% were 36-45 years, 15% were 46-55 years, and 2% were 55 years or older.

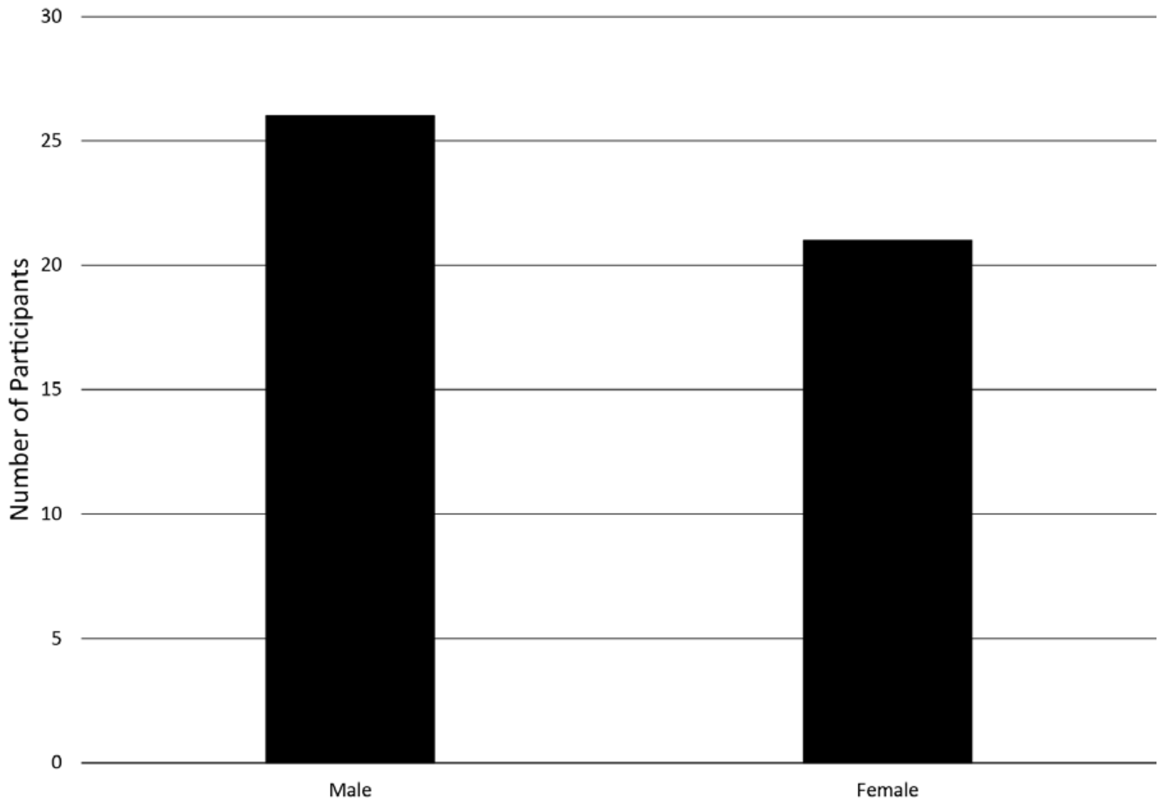


Figure 5. Gender distribution. 55% of participants were male, 45% female. “Neither category” and “prefer not to say” were both available options, but were not selected by any participants.

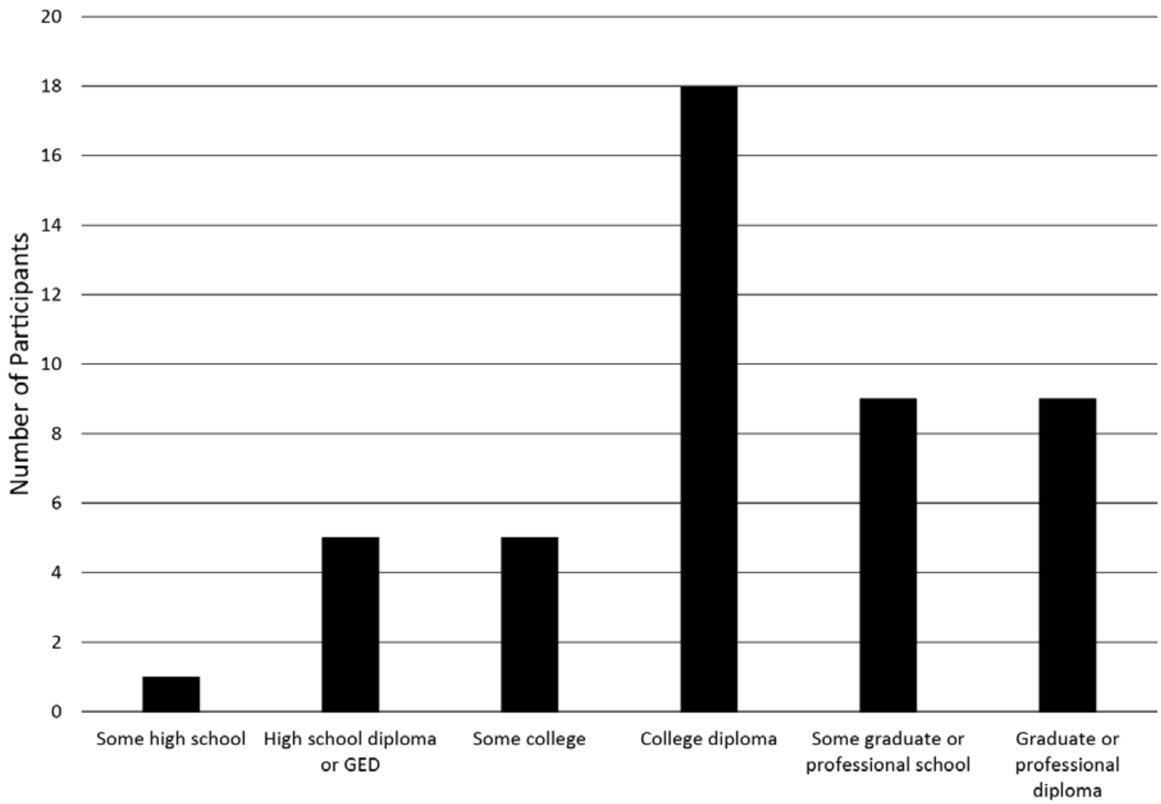


Figure 6. Education level. 2% had completed some high school, 11% their high school diploma or GED, 11% some college, 38% their college diploma, 19% some graduate or professional school, and 19% had received their graduate or professional degree.

B. Effect on Factual Understanding

The effect of the interactive on the participants' factual understanding of neuroplasticity was assessed with an eight-question didactic test before and after the intervention. The responses were scored and averaged. Out of a highest possible score of eight, the pre-test average was 4.1, 51% correct. The post-test improved to an average of 6.53, 82% correct (Figure 7). The average change was therefore 2.42 with a standard deviation of 1.58. The result of a paired T-test was a P-value of <0.0001, meaning the data is extremely statistically significant with 99.9% likelihood the change was not due to chance. Not only is the change significant, but effect size (Cohen's d) was calculated to be 1.53. The general guidelines for interpretation state a medium size effect to be d = 0.5 and large to be d = 0.8. It means that 93% of the post-test scores are higher than the mean of the pre-test scores.

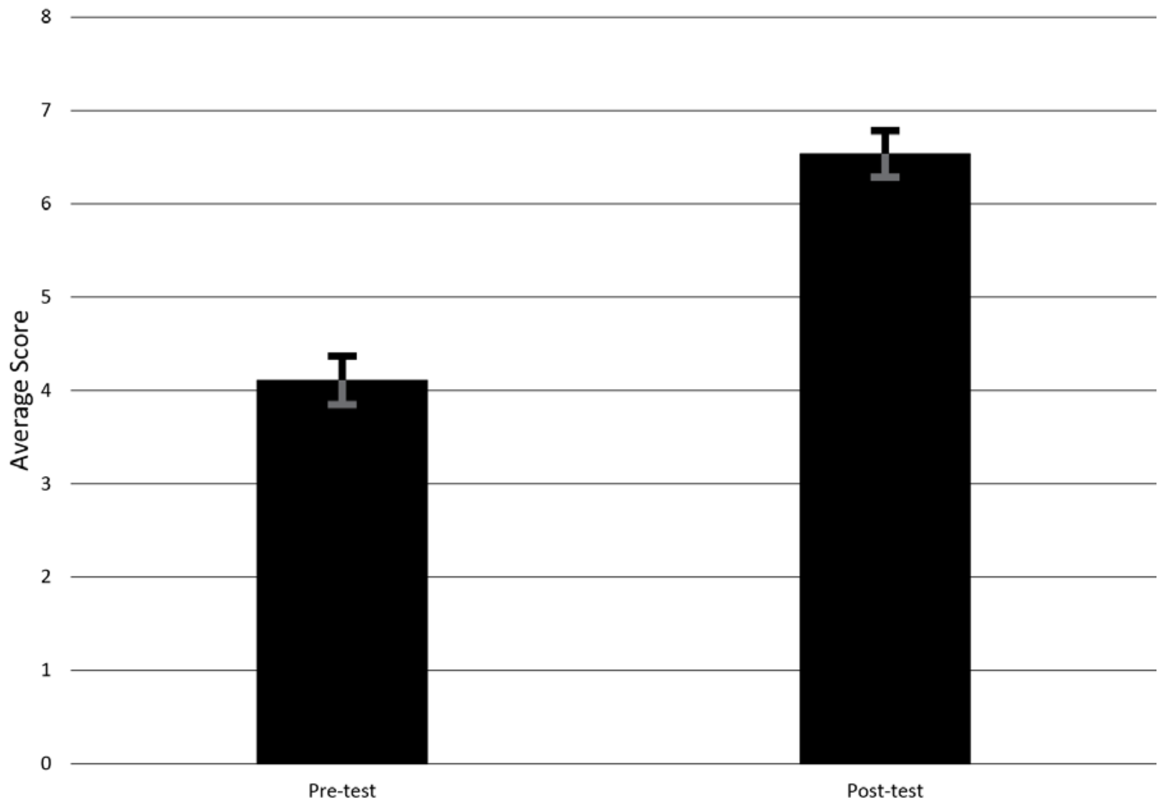


Figure 7. Change in didactic test scores ($p<0.0001$). The pretest average was 4.1/8, 51% correct. The post-test average was 6.53/8, 82% correct. Error bars denote standard error.

C. Effect on Implicit Theories

The effect on participants' implicit theories was assessed with a 6-point Likert-style scale. A strong entity theory will score an average of one, revealing a belief that intelligence is a static attribute. A strong increment theory will score an average of six, revealing a belief that intelligence is a dynamic attribute. The pre-test average was 3.77 and the post-test average was 4.32 (Figure 8). The average change was therefore 0.55 with a standard deviation of 0.86. The result of a paired T-test was a P-value of <0.0001, meaning the change is extremely statistically significant, as with the change in didactic scores. The effect size was calculated to be d = 0.64, generally considered to be of medium strength. This means that 73% of the post-test scores are higher than the mean of the pre-test scores. For comparison within the field, an eight-week intervention teaching middle school students about how the brain changes, assessed using the same implicit theory scoring system, measured an effect size of d = 0.66 (Blackwell et al., 2007).

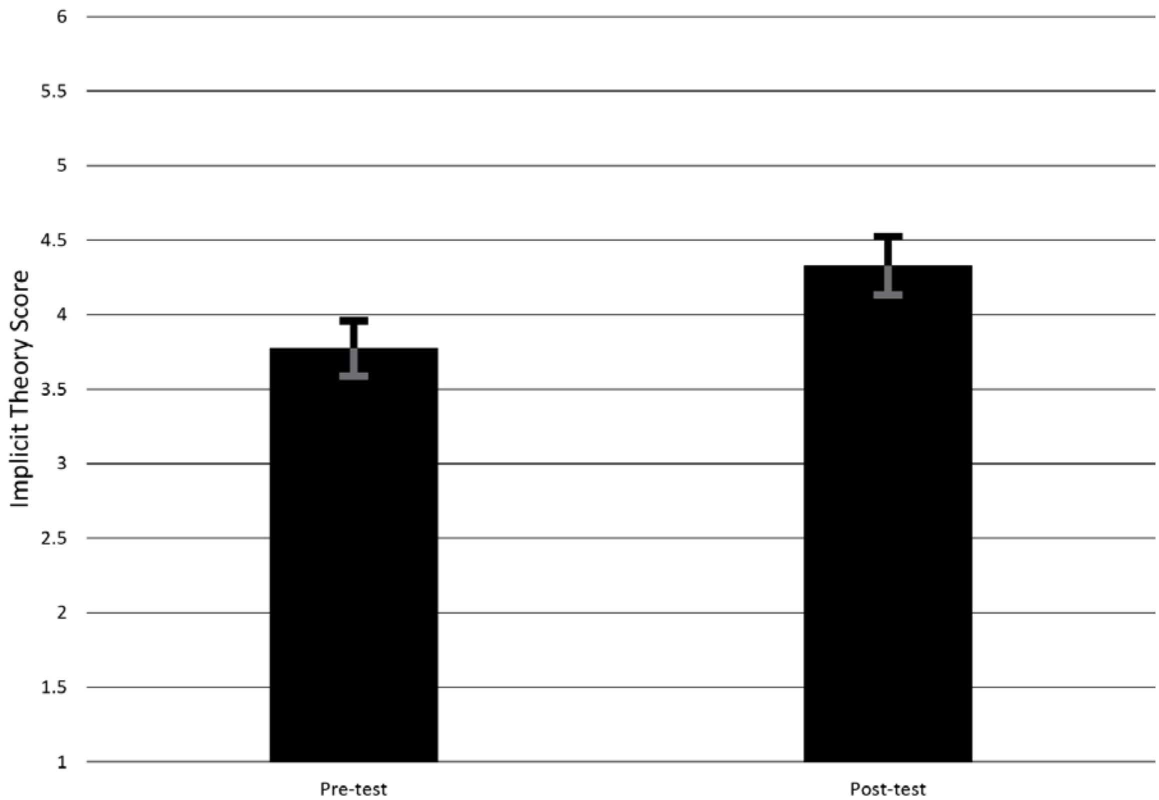


Figure 8. Change in implicit theory scores ($p<0.0001$). Higher scores correspond to a stronger increment theory, lower scores correspond to a stronger entity theory. The pretest average was 3.77 and the post-test average was 4.33. Error bars denote standard error.

V. CONCLUSION AND DISCUSSION

A. Conclusion

As a result of the analysis, there is strong support for both hypotheses. Working through the interactive achieved traditional learning outcomes; participants in the study learned the material. It also achieved formative learning outcomes. The implicit theories of the participants’ were affected, leading to a stronger increment theory of intelligence.

B. Discussion and Future Directions

The implication of this study is that knowledge affects our belief systems. This study has shown that visualizations of neuroplasticity not only increased a user’s understanding of the science, but also strengthened an increment theory of intelligence. As discussed in the introduction, implicit theories have profound implications on behavior. Individuals with an increment theory are less punitive (Dweck et al., 1993) than entity theorists. They are more likely to cope well after failure (Dweck et al., 1995) and are less threatened by the potential for future failure (Mangels, et al., 2006). They are less likely to seek revenge, more likely to negotiate (Yeager, et al., 2011), more likely to seek out challenging situations, and even perform better in serious gaming (Lee et al., 2012).

It is important to note that the interactive module did not teach that intelligence is malleable. Beliefs about the nature of intelligence and understanding the mechanics of neuroplasticity are not synonymous. Yet this study demonstrates that understanding the mechanics strengthens the belief that intelligence is malleable.

Previous interventions with students have, by strengthening increment theories of intelligence, observed improved GPAs and increased desire to learn (Aronson et al., 2002; Dweck et al., 1995). GPA provides a convenient measure for behavior change in students, but future work is needed to develop a comparable measure for adults. Other limitations of the study include the limits of the demographics; though a diverse group, the population was well-educated and almost exclusively from two countries. It is not known what the effect of the interactive module would be on a group of other nationalities or on a group with less education.

The next step in future work would be to study the longevity of the change observed. If retested later, how much information will participants remember? How will their implicit theory of intelligence have changed? There is opportunity to examine the behavioral implications in adults after working through the module as well as to compare the visually-oriented module to a text-driven article version of the same information. A sub-group analysis of this study also implies the potential for cultural differences in implicit theories. Though the group average change for implicit theory scores was 0.55, the American average change was 0.45 whereas the Indian average change was 0.8. More participants would be needed for this to have statistical significance ($p = 0.2186$).

The study also opens the question to the relationship of other scientific knowledge to our belief systems and behavior. There likely is a relationship between knowing muscle physiology and exercise, or between knowing ecology and recycling, but might there also be a relationship between understanding the carbon cycle and beliefs on mortality and permanence, or perhaps between epigenetic modifications and self-efficacy? There is rich territory for future investigation to utilize the power of visualizations to not only instruct but also influence.

CITED LITERATURE

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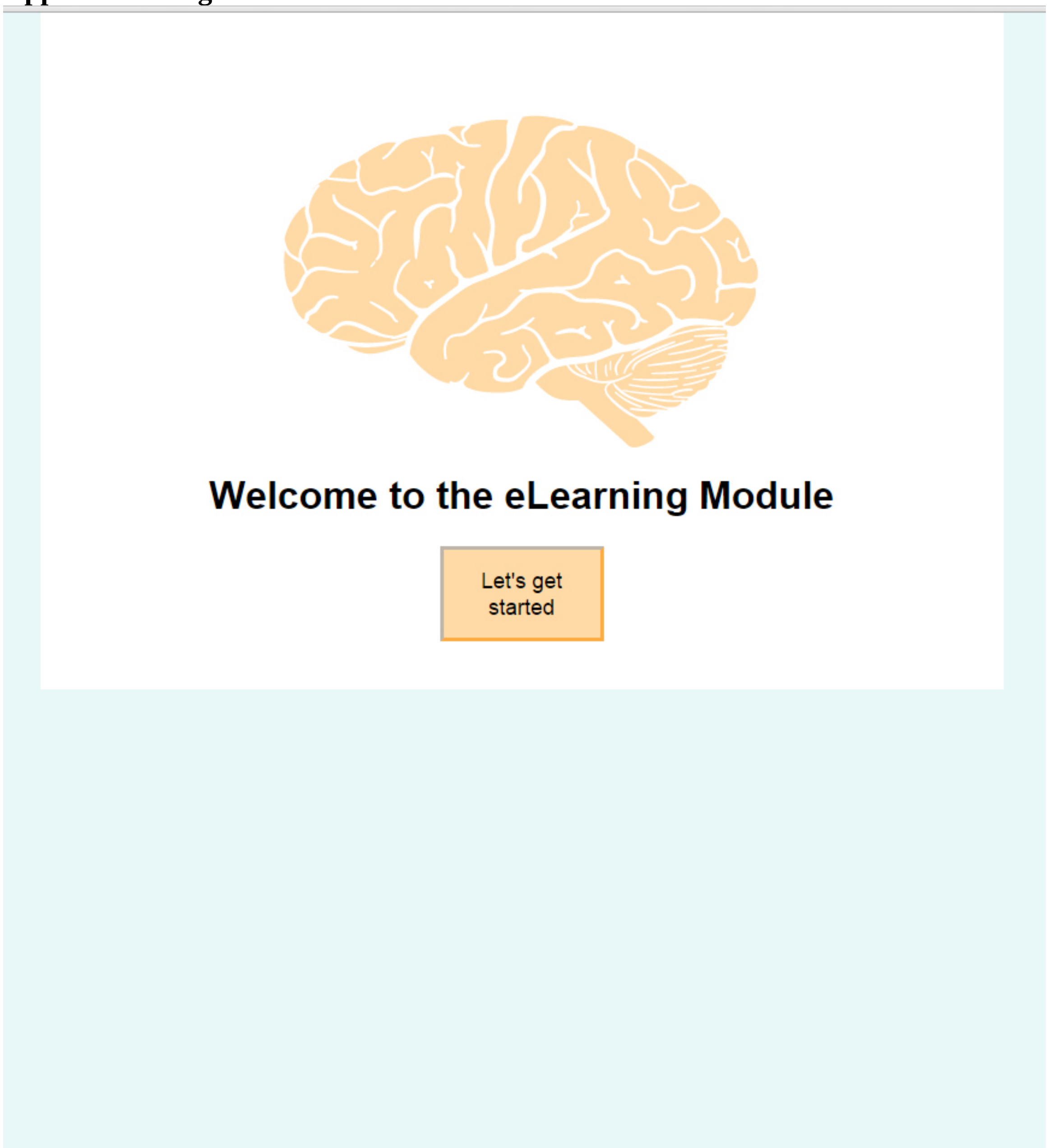
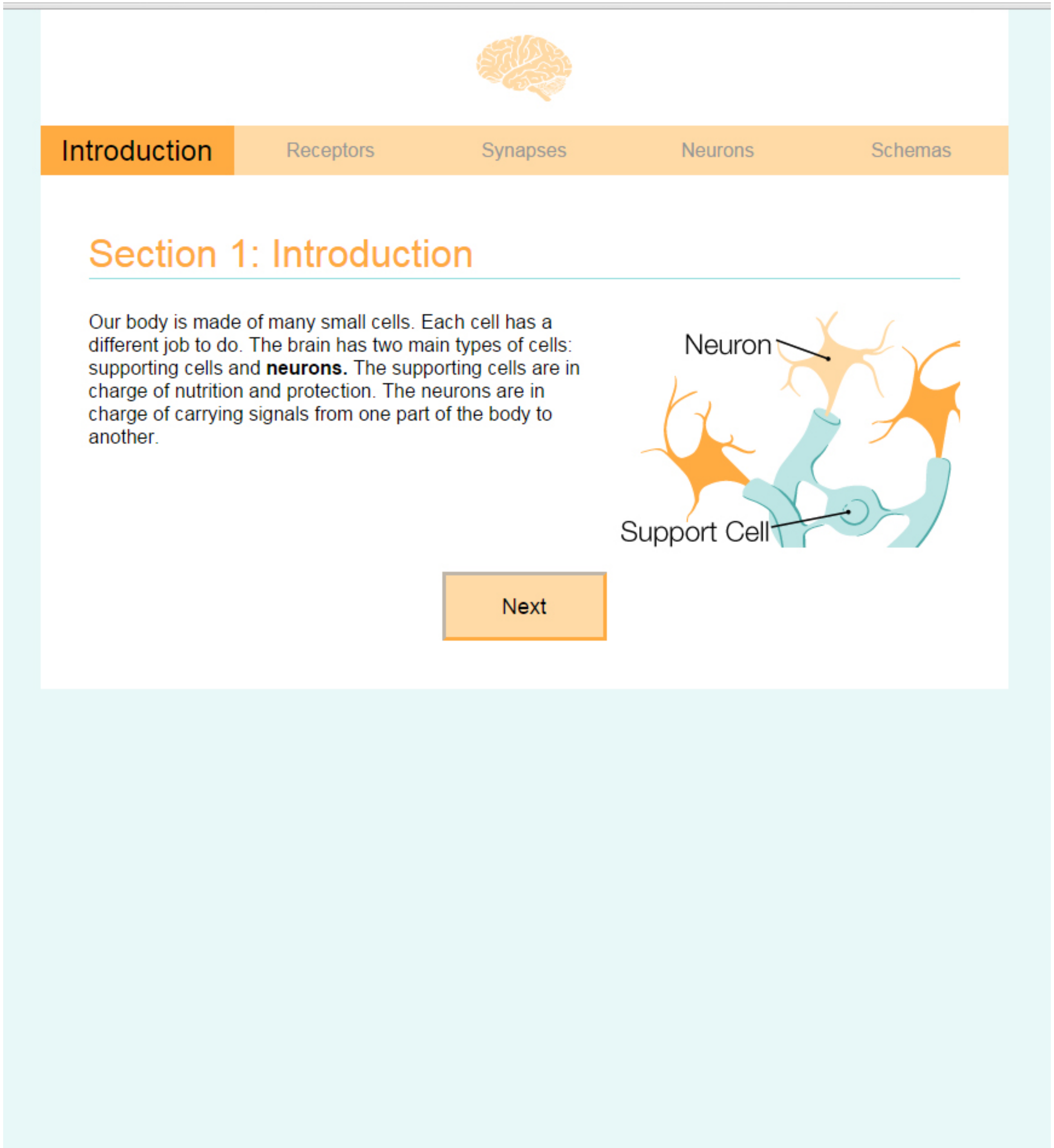
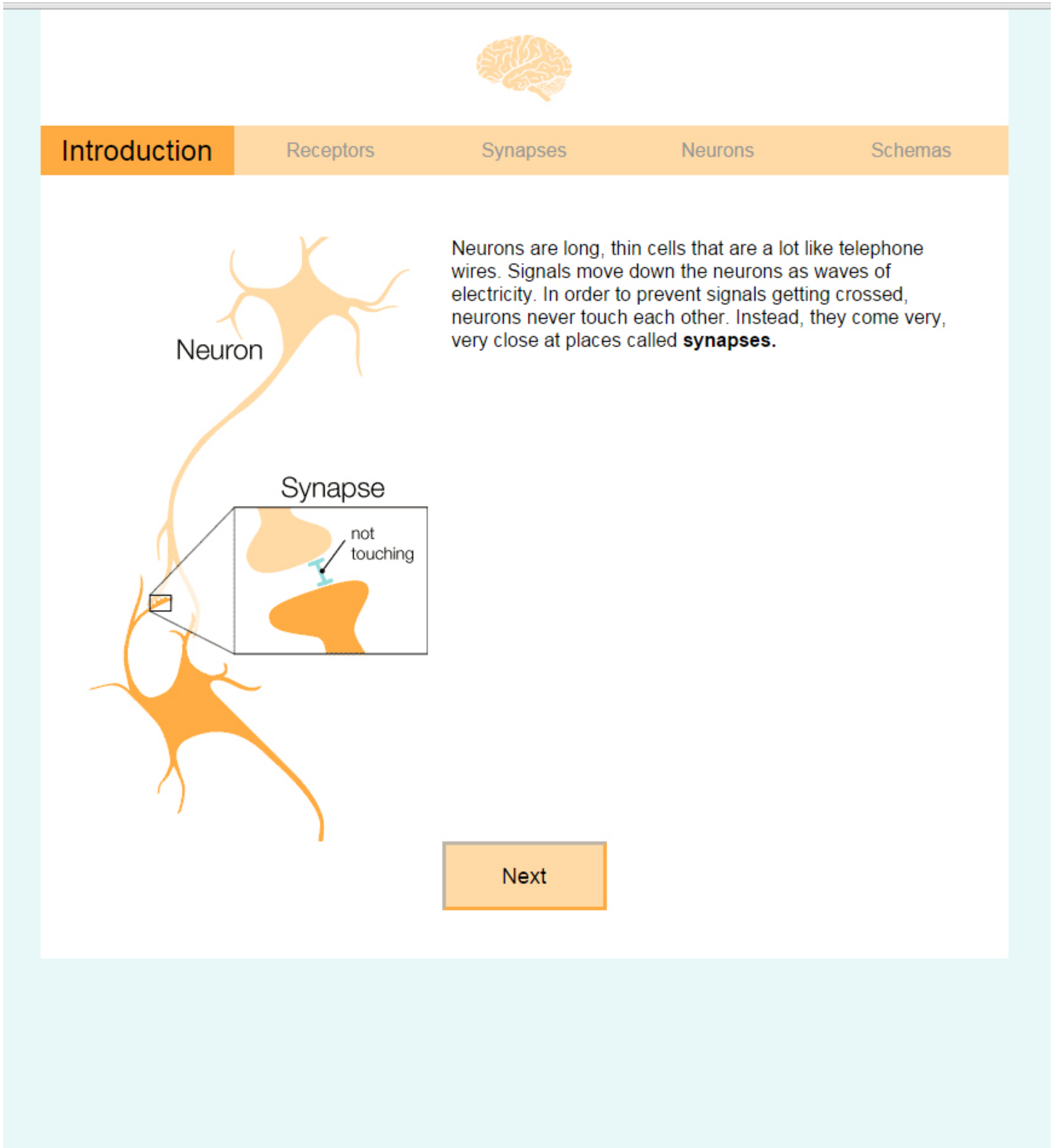
APPENDICES

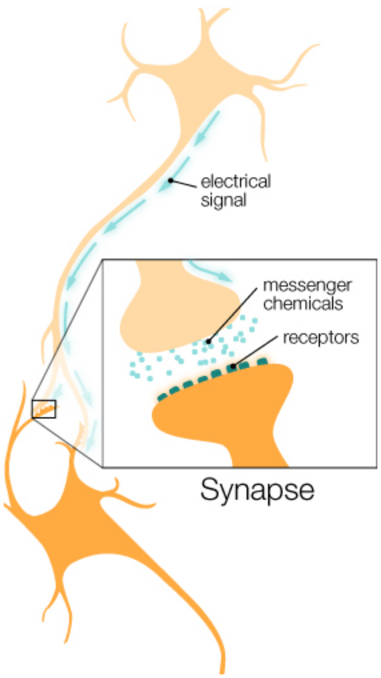
Appendix A: Digital Interactive




Introduction
Receptors
Synapses
Neurons
Schemas
Section 1: Introduction
Our body is made of many small cells. Each cell has a different job to do. The brain has two main types of cells: supporting cells and neurons. The supporting cells are in charge of nutrition and protection. The neurons are in charge of carrying signals from one part of the body to another.
Neuron
Support Cell
Next

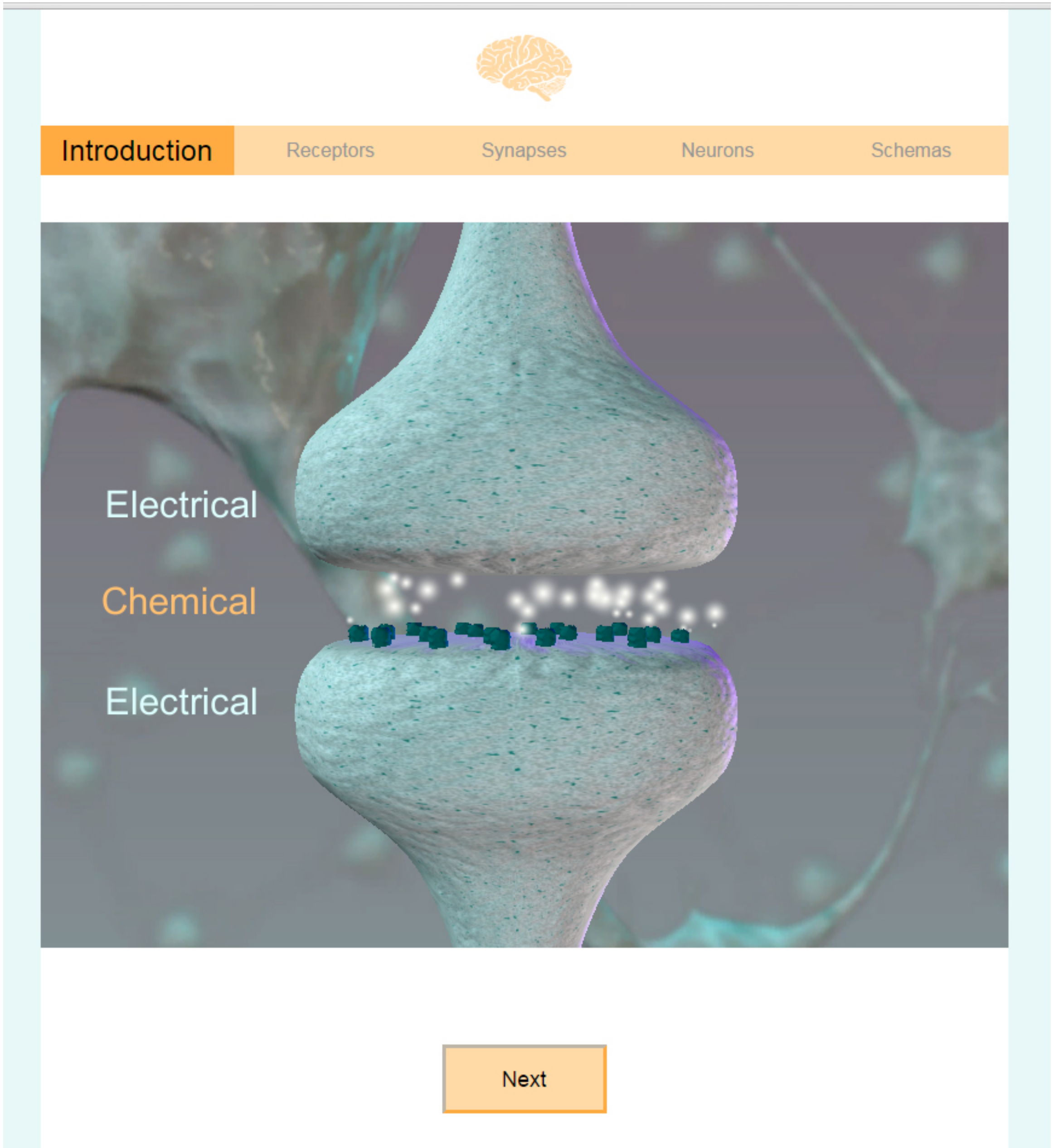

Introduction
Receptors
Synapses
Neurons
Schemas
Neuron
Synapse
not
touching
Neurons are long, thin cells that are a lot like telephone wires. Signals move down the neurons as waves of electricity. In order to prevent signals getting crossed, neurons never touch each other. Instead, they come very, very close at places called **synapses.**
Next

Introduction | Receptors | Synapses | Neurons | Schemas



When the electrical signal reaches the synapse, it causes small chemicals to be released onto the next neuron. Those messenger chemicals bind to molecules called **receptors.** The receptors start an electrical signal in the next cell. In this manner -- electrical signal down the cell, chemical messenger across the synapse, electrical signal down the next cell --neurons are able to pass information in the brain.

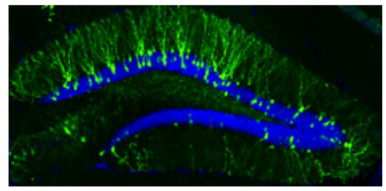
Next


Introduction
Receptors
Synapses
Neurons
Schemas
Electrical
Chemical
Electrical
Next

Introduction | Receptors | Synapses | Neurons | Schemas

Section 2: Receptors

Synapses are also very important in learning and memory formation. Scientists use the phrase, "cells that fire together wire together." It means that cells that talk through synapses often have a strong connection. That's what memories are. Remembering something is just reactivating that connection.

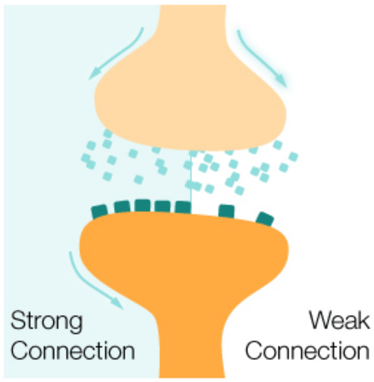


This image of a mouse brain shows all the cells involved in one memory labelled green.

Reprinted by permission from Macmillan Publishers Ltd: [Nature] (Liu, X., Ramirez, S., Pang, P. T., Puryear, C. B., Govindarajan, A., Deisseroth, K., et al. (2012). Optogenetic stimulation of a hippocampal engram activates fear memory recall. *Nature*, *484*(7394), 381-385. doi:10.1038/nature11028 [doi]), copyright (2012)

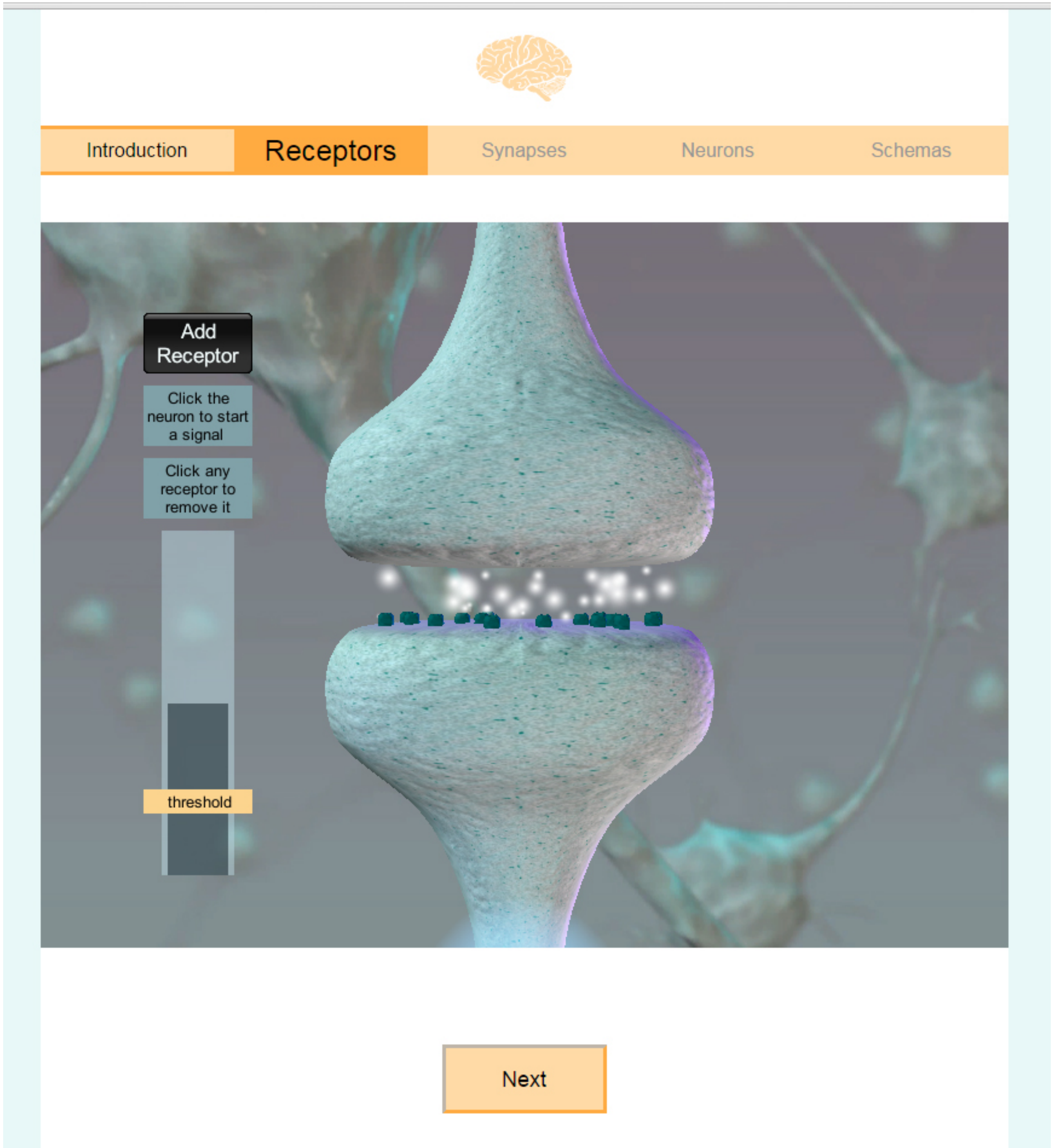
Next

Introduction | **Receptors** | Synapses | Neurons | Schemas



In order for cells to create a strong connection, they must be able to add receptors to their surface. Adding receptors means it takes fewer chemical messengers to continue the signal. On the other hand, the brain can also remove receptors from the surface. Without as many receptors, it takes a lot of chemical messengers to continue the signal.

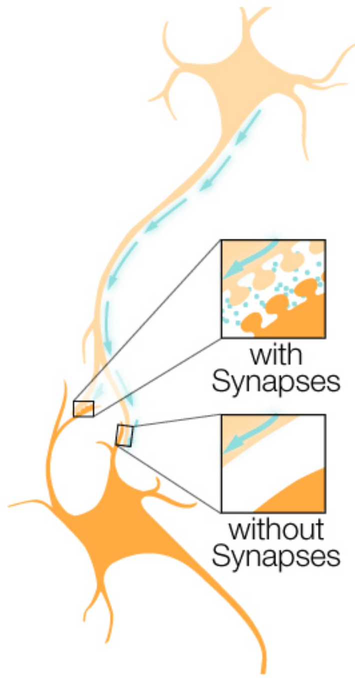
Next


Introduction
Receptors
Synapses
Neurons
Schemas
Add Receptor
Click the neuron to start a signal
Click any receptor to remove it
threshold
Next

Introduction | Receptors | **Synapses** | Neurons | Schemas

Section 3: Synapses

In the last scene, we learned that the body is always adding and subtracting receptors as we learn every day. It also is capable of adding and subtracting entire synapses. The more synapses two neurons share, they more they can talk to each other. By adding and removing synapses, neurons form networks of the cells they talk to the most. Though any one neuron isn't very powerful, these broad networks are very powerful. The networks are responsible for things like consciousness, personality, and intelligence.



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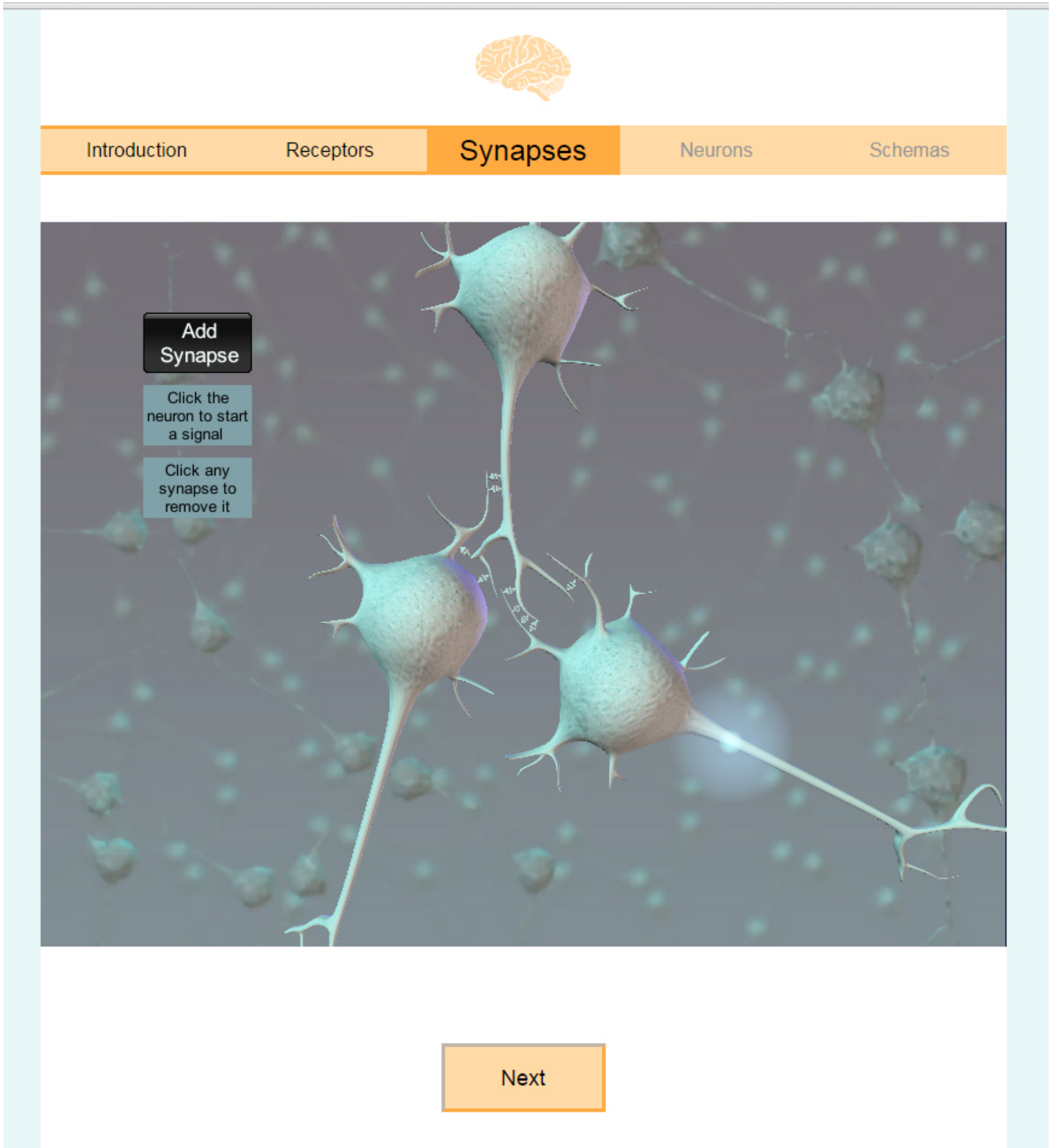

Introduction
Receptors
Synapses
Neurons
Schemas
Add Synapse
Click the neuron to start a signal
Click any synapse to remove it
Next

Introduction | Receptors | Synapses | **Neurons** | Schemas

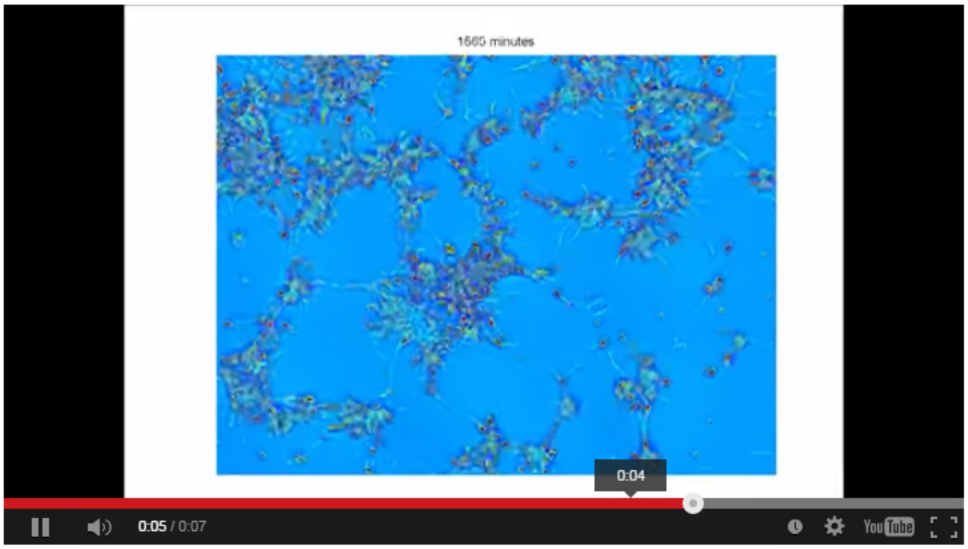
Section 4: Neurons

Not only can the body change neuron networks by adding and removing synapses, but it can also add new **neurons.** You may have heard that neurons don't divide into new cells. That's true. But the body does make new baby neurons every day from pre-neuron cells that can divide. The new neurons will only live if they get included in a neuron network. So they reach out, making new synapses and putting in new receptors to talk to other cells. That should sound familiar – making new synapses and putting in new receptors is also how we learn. That means the same processes involved in learning are also involved in the survival of new neurons every day. As we learn, the neurons survive and our neuron networks continue to grow and be refined.

Next

Introduction | Receptors | Synapses | **Neurons** | Schemas

Now that you understand the process of adding new receptors, new synapses, and new neurons, let's see it happen in real life. It is hard to put a microscope and video camera inside your brain, but we can put them around a petri dish. This video is taken by a research team under Dr. Popescu in Illinois, USA. The team put neurons inside a petri dish and filmed them for 24 hours as they reached out and formed networks. Watch the long, thin processes forming a web of connections.



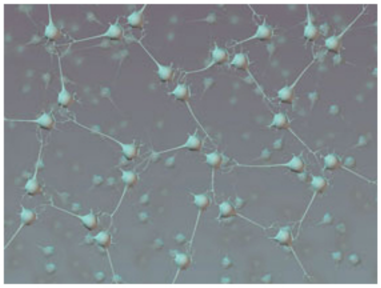
Reprinted by permission from Dr. Popescu (Mir, M., Kim, T., Majumder, A., Xiang, M., Wang, R., Liu, S. C., et al. (2014). Label-free characterization of emerging human neuronal networks. Scientific Reports, 4, 10.1038/srep04434. doi:10.1038/srep04434 [doi])

Next

Introduction | Receptors | Synapses | Neurons | **Schemas**

Section 5: Schemas

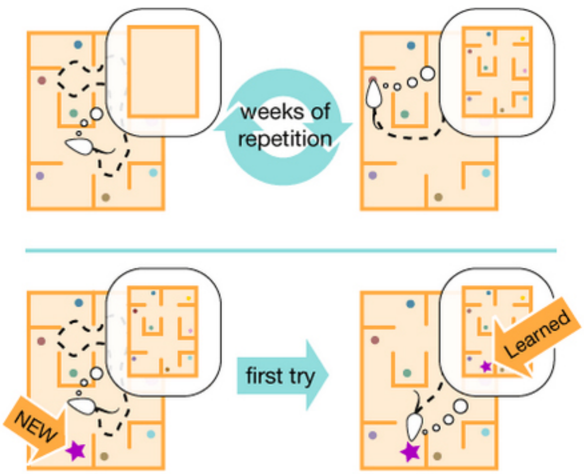
You've learned that the brain is always adding and subtracting new receptors, new synapses, and new cells. We've also talked about how these cells form networks with the cells they talk to most. The networks are responsible for big things like consciousness, intelligence, and personality. But let's get more specific about how the networks are involved with learning.



Next

Introduction | Receptors | Synapses | Neurons | **Schemas**

The big word here is **schema.** A schema is one network that represents a certain set of knowledge. An easy example is research done by training rats in an obstacle course. The course had different treats hidden at specific places. It took weeks of training for the rats to learn which treats were where. During that time, their brains were adding receptors, synapses, and neurons to from a schema representing the maze. Then the researchers added a new treat and a new place. The rats learned the new information on the first try. Because they had already worked to make a schema, it was easy to learn new similar information.



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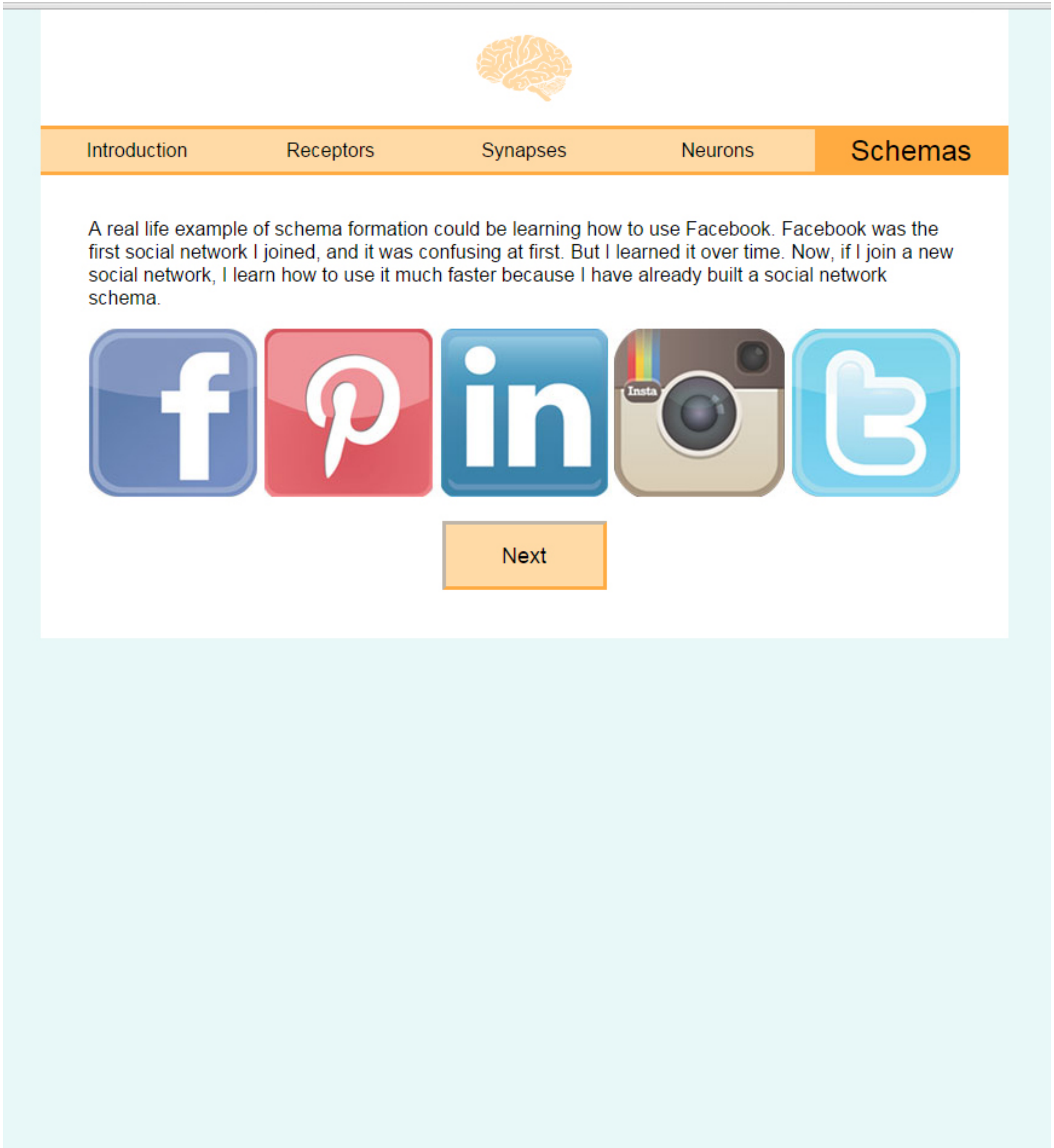
Introduction
Receptors
Synapses
Neurons
Schemas
A real life example of schema formation could be learning how to use Facebook. Facebook was the first social network I joined, and it was confusing at first. But I learned it over time. Now, if I join a new social network, I learn how to use it much faster because I have already built a social network schema.
Insta
Next

Introduction | Receptors | Synapses | Neurons | **Schemas**

Schema formation means that the brain is like a muscle. It gets stronger when you use it. The brain also gets stronger when you use your actual muscles by exercising. Every day your brain adds and subtracts receptors, synapses, and cells. Exercise supercharges these processes to give your brain even more receptors, synapses, and new neurons to work with. By working our bodies and working our brain we grow and refine our neuron networks.

Finish

Appendix B: Recruitment Script for Mechanical Turk

Below are the fields of data to create a job listing on Mechanical Turk:

Title: Research survey to test eLearning module about the brain
Description: A research study including a 12 questions pre-test, a 15 minute eLearning module about the brain, followed by retaking the 12 question test. Must be 18 years or older.
Keywords: research, survey, brain
Reward per assignment: $2.00
Number of assignments: 20 (for pilot), 450 (maximum for full deployment)
Time allotted per assignment: 4 hours (though it is expected to only take 45 minutes)
HIT expires in: 21 days (the study will be open for either 21 days or until all the desired number of participants have participated, whichever comes sooner).
Auto-approve and pay workers in: 24 hours
Worker qualifications: 90% approval rate

Appendix C: Informed Consent Document

University of Illinois at Chicago
Research Information and Consent for Participation in Social Behavioral Research
Formative Learning: the Effects of Understanding Neuroplasticity on Implicit Theories of Intelligence

You are being asked to participate in a research study. Researchers are required to provide a consent form such as this one to tell you about the research, to explain that taking part is voluntary, to describe the risks and benefits of participation, and to help you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Principal Investigator:
Meredith Osborn, MS candidate
Biomedical Visualization at the University of Illinois at Chicago
1919 W Taylor St., Chicago, IL 60612
mosbor6@uic.edu

Why am I being asked?

You are being asked to be a subject in a research study to test the effectiveness of a short learning module about the brain.

You have been asked to participate in the research because you're an adult over 18 years old.

Your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future dealings with the University of Illinois at Chicago. **If you decide to participate, you are free to withdraw at any time without affecting that relationship.**

Approximately 470 subjects may be involved in this research at UIC.

What is the purpose of this research?

This research will test the effectiveness of a learning module teaching about the brain.

What procedures are involved?

This research will be performed as an online survey. It will take no more than 45 minutes to complete.

You will answer 4 demographic questions, take a 12-question pre-test, read through the module, and retake the test.

What are the potential risks and discomforts?

To the best of our knowledge, the things you will be doing have no more risk of harm than you would experience in everyday life

Are there benefits to taking part in the research?

You may directly benefit, but no benefits are guaranteed. Benefits would include learning about the brain and a shift in beliefs about intelligence.

What other options are there?

You have the option to not participate in this study.

What about privacy and confidentiality?

Work through Mechanical Turk is anonymous to the requestor. No identifying information will be collected from you.

Should you choose to contact the researcher, you will no longer be anonymous. In this situation, information about you will only be disclosed to others with your written permission, or if necessary to protect your rights or welfare (for example, if you are injured and need emergency care or when the UIC Office for the Protection of Research Subjects monitors the research or consent process) or if required by law.

A possible risk of the research is that your participation in the research or information about you might become known to individuals outside the research. Though no information collected is identifying, it will be stored on secure servers and password-protected computers.

When the results of the research are published or discussed in conferences, no information will be included that would reveal your identity.

What are the costs for participating in this research?

There are no costs to you for participating in this research.

Will I be reimbursed for any of my expenses or paid for my participation in this research?

You will receive $2.00 through Mechanical Turk for completion of the experiment. Your work will be reviewed and paid for within 24 hours of completion.

Can I withdraw or be removed from the study?

If you decide to participate, you are free to withdraw your consent and discontinue participation at any time.

Who should I contact if I have questions?

Contact the researchers Meredith Osborn at email address: mosbor6@uic.edu or John Daugherty at (312) 996-4975.

- if you have any questions about this study or your part in it
- if you have questions, concerns or complaints about the research.

What are my rights as a research subject?

If you feel you have not been treated according to the descriptions in this form, or if you have any questions about your rights as a research subject, including questions, concerns, complaints, or to offer input, you may call the Office for the Protection of Research Subjects (OPRS) at 312-996-1711 or 1-866-789-6215 (toll-free) or e-mail OPRS at uicirb@uic.edu.

Clicking to begin the survey will serve as your consent:

I have read (or someone has read to me) the above information. I have been given an opportunity to ask questions (via email or phone) and my questions have been answered to my satisfaction. I agree to participate in this research. I have the opportunity to make a copy of this form for my records.

Appendix D: Questionnaires

Pre-test:

(Demographic Information)

Let's start with the basics:

1) What country do you live in? [text box for answer]

2) How old are you? ❒18-25 years ❒26-35 years ❒36-45 years ❒46-55 years ❒55+ years

3) What is your gender? ❒ Male ❒ Female ❒ Neither category ❒ Prefer not to say

4) How much school have you finished? ❒ some high school ❒ high school diploma or GED ❒ some college ❒ college diploma ❒ some graduate or professional school ❒ graduate or professional diploma

(Didactic Test Questions)

Before working through the module, we'd like to know how much you already know about the brain. There are right and wrong answers, but don't worry too much about it or spend time searching the web for the answer. This is just to see what you know off the top of your head. (Hint: neurons are brain cells.)

5) Do neurons ever touch each other? ❒ Yes ❒ No

6) What is a synapse? ❒ The center of a neuron where it makes decisions ❒ The place where two neurons communicate with each other ❒ A chemical messenger used by neurons ❒ A supporting cell that protects neurons

7) What sentence best describes memories? ❒ Memories are kept in a specific part of the brain ❒ Memories are only in our mind, there aren't any physical changes involved ❒ Memories are stored in the spinal cord and brain stem as reticulated pathways ❒ Memories are a network of connectivity between the neurons active during the original experience

8) The molecule on the surface of a neuron that receives signals is called: ❒ a receptor ❒ a receiver ❒ an electrode ❒ a neurolabel

9) The molecules from question #8 – does each neuron have a set amount or can the brain add and remove them as needed? ❒ Each cell has a defined amount ❒ The brain can add and remove them

10) Does the number of synapses in the brain change? ❒ Yes ❒ No

11) What statement best describes neuron growth? ❒ New neurons only grow during infancy. ❒ New neurons only growth during critical periods of development throughout life. ❒ New neurons grow every day no matter your age. ❒ New neurons only grow during adulthood.

12) Because of schema formation, it is true to say: ❒ The brain is like a muscle that gets stronger with practice. ❒ The brain is like a CEO controlling the other organs.

❒ The brain is like a dictionary because it weighs 3 lbs and is full of information.

❒ The brain is like a wind-up toy with a specific task it is good at.

(Implicit Theory Questionnaire)

These questions are will help us understand your beliefs about intelligence. There are no right or wrong answers. We are interested in your ideas. Just tell us how much you agree or disagree with the three statements.

13) You have a certain amount of intelligence and you can't do much to change it.

❒ Strongly Agree ❒ Agree ❒ Mostly Agree ❒ Mostly Disagree ❒ Disagree ❒ Strongly Disagree

14) Your intelligence is something about you that you can't really change that much.

❒ Strongly Agree ❒ Agree ❒ Mostly Agree ❒ Mostly Disagree ❒ Disagree ❒ Strongly Disagree

15) You can learn new things, but you can't really change your basic intelligence.

❒ Strongly Agree ❒ Agree ❒ Mostly Agree ❒ Mostly Disagree ❒ Disagree ❒ Strongly Disagree

(Reverse Turing Test)

This question has nothing to do with the research, we just want to make sure you aren't a spambot. (Note: if you get this wrong, or complete the experiment faster than humanly possible, we'll assume you are a robot and will reject your work.)

16) What is 2+2? [empty text box]

Thanks! You're all finished with the pre-test, next you'll work through the learning module.

Post-test:

Wonderful! You've finished the module. We're going to ask you some of the same questions to see how effective the module was. Again, these questions are to test how good the teaching module was, not to evaluate you.

(The didactic questions will be repeated)

We're also curious if there was any change in your beliefs about intelligence. Like before, there are no right or wrong answers here. We are just interested in your ideas. Tell us how much you agree or disagree with the three statements.

(The implicit theory questionnaire will be repeated)

Thank you for your time! You're responses will help us evaluate the effectiveness of the learning module both to teach about the brain and to influence beliefs about intelligence.

Below is the code you need to enter into Mechanical Turk to be paid for your time.

Appendix E: Letters of Permission to Reprint Material

Permission to embed link to neuron growth video:

Popescu, Gabriel [redacted] Jan 25

to me

HI Meredith,

Please use the movie as you see fit (as long as the source paper is referenced. You can also refer to our website for more info: http://light.ece.illinois.edu/) Keep me posted about the outcome.

Thanks,
gabi

GABRIEL POPESCU
Associate Professor

Department of Electrical and Computer Engineering & Bioengineering
University of Illinois at Urbana-Champaign
Beckman Institute for Advanced Science and Technology
405 North Mathews Avenue, Room 4055,Urbana, IL 61801
Phone: [redacted] Fax: [redacted]

Email: [redacted]
QLI Lab: http://light.ece.uiuc.edu

Permission to include image of mouse memory:

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Feb 12, 2015

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VITA

MEREDITH OSBORN
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Chicago, IL 60612

EDUCATION

2013 - 2015	**MS in Biomedical Visualization** University of Illinois at Chicago. Chicago, IL
2009 - 2013	**BS in Biology, Illustration** Indiana Wesleyan University, summa cum laude. Marion, IN

WORK EXPERIENCE

2014 - Present **Graphic Designer**	UIC School of Public Health. Chicago, IL Designed logo, branding, website, and brochures for the Great Lakes Center for Occupational and Environmental Health that expressed the Center's unique identity while maintaining cohesion with the University brand.
2014 - Present **Research Assistant Health Informatics**	UIC College of Applied Health Science, Chicago, IL Spent 80+ hours in the hospital observing resident and nurse handoffs. Wrote and edited grant proposals about communication between health care professionals and their impact on patient outcomes. Managed a team of four undergraduate student assistants.
2010 - Present **Data Management Intern**	Phylogeny Inc., Columbus, OH Served on committee designing an in-house, web-based LIMS (laboratory information management system) to catalog samples for the Ohio Biorepository. Assembled a training manual and used it to train successive interns. Worked on developing a histology block to serve as a more accurate and versatile alternative to a tissue microarray analysis.
Spring 2013 **Medical Artist**	Division of Health and Human Performance, Indiana Wesleyan University, Marion, IN Created "Tom" a 6' mannequin painted with dermatomes and myotomes to assist students in translating their knowledge from 2D textbook diagrams to injured athletes.

Spring 2013 **Illustration Intern**	Kidzmatter Inc., Marion, IN Illustrated articles for K! Magazine, distributed nationally. Designed print materials and corresponding pin for Awana's Truthscripts adult memorization program, sold internationally.
2011 - 2013 **Research Assistant Electrophysiology**	Hodson Summer Research Institute, Marion, IN Designed and built novel incubator allowing for gas atmosphere control while performing self-referencing. Examined retinal pH dynamics using extracellular self-referencing electrodes and intracellular recording. Collaborated with local research team and Dr. Paul Malchow's lab at the University of Illinois at Chicago.
2011 - 2013 **Logistics Manager**	Intercultural Student Services Office, Indiana Wesleyan University, Marion, IN Provided the organizational network necessary for the team to operate seamlessly. Increased my own intercultural competence and developed the competence of our 14 student diversity coordinators.
2008 - 2009 **Art Intern**	The Kelly Gallery, Dublin, OH Interacted with clients, artists, and owner regarding the sale, display, and content of the work.

PRESENTATIONS

February 2014	"Science Careers for Artists" Project Innovation. Hadley Junior High School. Glen Ellyn, IL.
April 2013	"Graduate Reflections" chosen by peers to speak at John Wesley Honors College Senior Luncheon. Marion, IN
March 2013	"Retinal pH Dynamics in the Outer Plexiform Layer" oral and poster presentation at Celebration of Scholarship. Marion, IN
February 2013	"Lessons from the Neurobiology of Love" Indiana Wesleyan University Chapel. Marion, IN
October 2012	"Adapted Self-Referencing Technique Allowing for Bicarbonate Buffering" oral and poster presentation. Hodson Colloquium. Marion, IN
July 2012	"Techniques for Studying Retinal Cell Communication" Hodson Summer Research Institute. Marion, IN
March 2012	"The Formative Interplay Between Love and the Brain" poster presentation at Celebration of Scholarship. Marion, IN
March 2012	"Ion-Selective Self-Referencing Micro-electrode Technique and Applications" poster presentation at Celebration of Scholarship. Marion, IN

PUBLICATIONS

Osborn M, Graduate Reflections. *Aldersgate Review*. 2013, Summer: 28-29

acknowledged for contributions to Kreitzer MA, Jacoby J, Naylor E, Baker A, Grable T, Tran E, Booth SE, Qian H, Malchow RB. Distinctive Patterns of Alterations in Proton Efflux from Goldfish Retinal Horizontal Cells Monitored with Self-Referencing H(+) -selective electrodes. *European Journal of Neuroscience.* 2012; 36: 3040-3050.

cowrote PHiL14, An Ontological Pep-Talk. *Books and Culture: A Christian Review*. 2012.

ART EXHIBITIONS

November 2014	SAMA Show: Inside the Mind of Medical Artists, National Museum of Health and Medicine Chicago. Chicago, IL
September 2014	Public Health Through Pictures gallery, Northwestern Public Health Review Public Health Matters Seminar. Chicago, IL.
July 2013	Polycystic Kidneys featuring the Visible Human Male, National Museum of Health and Medicine Chicago. Chicago, IL.
November 2013	SAMA Show, National Museum of Health and Medicine Chicago. Chicago, IL.
April 2013	Senior Art Show, Indiana Wesleyan University. Marion, IN. April 2013.
January 2013	Made in Marion Art Show, downtown Marion, IN. January 2013.

AWARDS

2013 **John Wesley Scholar** for completion of Honors College liberal arts curriculum

2013 inducted to **Alphi Chi National College Honor Society,** society for the top ten percent of college juniors, seniors, and graduate students

2010 **CRC Press Chemistry Achievement Award** awarded to the chemistry student with the highest academic performance

MEMBERSHIPS

Student Member, Association of Medical Illustrators
Member, Vice President of Student Association of Medical Artists (SAMA)

SKILLS

Animation + Interactive	Autodesk 3D Studio Max, Pixologic Zbrush, Unity 4, Materialise Mimics, Visual Molecular Dynamics, Adobe AfterEffects, Adobe Audition
Digital 2D	Adobe Illustrator, Photoshop, InDesign
Development	HTML5, CSS3, Javascript, Adobe Dreamweaver

GLOBAL AND COMMUNITY SERVICE

Present Chicago, IL	Sunday School Superintendent, First Immanuel Lutheran Church. Lead team of eight teachers and volunteers. Write curriculum. Work with underrepresented children.
August 2008 China	Beijing, Xian, Shenyang, and Xixian for two weeks Participate in international friendship and service camp with students from the Communist Youth League.
June 2006 Mexico	San Luis Potosi for one week Partner with Casa De Ninos to provide housing for orphans.
Jan - Dec 2000 Panama, Nicaragua	Panama City, Panama and Leon, Nicaragua for six months each Assist with medical clinics and hurricane relief from Hurricane Mitch.