Supplemental Material

CBE—Life Sciences Education

Ellingson *et al*.

Supplementary Materials

Connecting the dots from Professional Development to Student Learning

Charlene L. Ellingson[1], Katherine Edwards[2], Gillian H. Roehrig[3,] M. Clark Hoelscher[3,6],

Rachelle A. Haroldson[4], Janet M. Dubinsky[5]

[3]STEM Education Center, University of Minnesota, St. Paul, MN 55108

[4]Department of Teacher Education, University of Wisconsin – River Falls, WI 54022

[5]Department of Neuroscience, University of Minnesota, Minneapolis, MN 55455

[2]Minnesota Department of Education, Roseville, MN 55113

[1]Department of Elementary and Literacy Education, Mankato State University, MN 56001

[6]current address: Saint Paul Public Schools • 600 Weir Dr., Woodbury, MN 55125

Table of Contents

Supplementary Table 1. Alignment of PD goals, PD content, student knowledge test questions and NGSS standards to lessons implemented by teachers.

PD Goals	PD Content	Possible Lessons*	Number of Teachers Reporting Using the Lesson			Assessment Questions	NGSS standard, concept, or practice
			Unit N=12	Sprinkling N=8	Control** N=11		
Teachers acquire sufficient neuroscience knowledge to be able to teach it well.	Plasticity	Altered Reality	9	6	2	1-4	HS-LS1-3, HS-LS1-2; Stability and change; Cause and effect; Systems and system models; Structure and function
		C. elegans	0	2	0		
		Mindflex	2	4	0		
		Connect the Neurons	5	4	1		
		Motor Learning & Memory	6	4	0		
		Virtual Neurons	4	2	0		
		Balance: The Ears Have It	1	1	0		
		Your Incredible Memory	3	0	0		
		Experiential Stations***	8	6	1		
		TOTALS	38	29	4		
		Lessons / Teacher	3.2	3.6	0.4		
	Structure / Function	Bead Neuron	9	3	1	5,6,13	HS-LS1-3, HS-LS1-2; Stability and change; Cause and effect; Systems and system models; Structure and function
		Mirroring Emotions	3	4	0		
		Sheep Dissection	6	3	2		
		Connect the Neurons	5	4	1		
		Virtual Neurons	4	2	0		
		Balance: The Ears Have It	1	1	0		
		Your Incredible Memory	3	0	0		
		Makes Me Sweat	0	1	0		
		Close Up of the Nervous System	0	2	0		
		Experiential Stations	8	6	1		
		TOTALS	39	26	5		
		Lessons / Teacher	3.3	3.3	0.5		

Teachers become proficient in teaching inquiry processes to students.	Inquiry	Altered Reality	9	6	2	7-12	Stability and change; Cause and effect; Systems and system models; Asking questions; Developing and using models; Planning and carrying out investigations; Analyzing and interpreting data; Using math and computational thinking; Constructing an explanation; Arguing from evidence; Obtaining, evaluating, and communicating information
		C. elegens	0	2	0		
		Mirroring Emotions	3	4	0		
		Mindflex	2	4	0		
		Motor Learning & Memory	6	4	0		
		Virtual Neurons	4	2	0		
		Your Incredible Memory	3	0	0		
		Makes Me Sweat	0	1	0		
		Neuromarketing	0	1	0		
		Close Up of the Nervous System	0	2	0		
		Balance: The Ears Have It	1	1	0		
		Experiential Stations	8	6	1		
		TOTALS	34	30	3		
		Lessons / Teacher	2.8	3.8	0.3		

* Written teacher and student guides are provided for all lessons at Brainu.org {Macnabb 2006}.
** Control teachers used lessons of their own design that were not tracked. Given that control teachers were in the same building as teachers receiving PD, some leakage was expected.
*** Teachers used an individually chosen subset of the 9 Experiential Stations.

Supplementary Table 2. Alignment of BrainU PD with characteristics of quality PD (Darling-Hammond et al., 2017)

Characteristic of Quality PD	Description	Inclusion within BrainU
Duration	Duration considers both the total hours of PD and the length of time over which the PD occurs.	80 hours in summer with follow-up classroom support during the academic year
Content-focused	Content-focus refers to what teachers learn during PD. This consists of (i) subject matter knowledge and (ii) knowledge of how students learn that content.	Focus on neuroscience concepts of plasticity, structure, and function. Teachers participated as learners in lessons from the BrainU curriculum, as well as an authentic inquiry experience using C-Elegans.
Active Learning	Active Learning addresses *how* teachers learn during PD.	Teachers were actively engaged in model inquiry lessons throughout the PD using BrainU curricular materials. Teachers were expected to develop action plans and implement neuroscience lessons in their classrooms following the summer PD.
Grounded in Effective Models of Instruction	Curricular and instructional models and modeling of instruction help teachers to have a vision of practice.	BrainU provided curricular materials to support teacher and student learning of target neuroscience concepts through inquiry-based instruction.
Collaboration	High-quality PD creates space for teachers to share ideas and collaborate in their learning.	Active learning opportunities engaged teachers in social constructivist forms of learning, working in small groups during modelled lessons. Teachers were recruited from two partner districts allowing for collective conversations about implementation.

Supplementary Table 3. Teacher Characteristics

School	Number of Teachers	Years of Experience	Subjects Taught
Suburban District - participants			
High School A	3	6-20	2 biology, 1 chemistry
High School B	3	15– 34	1 biology, 1 physical science
High School C	2	3 – 31	1 biology, 1 physical science
Alternative Learning Centers	4	1 – 31	4 biology
Suburban District - controls			
High School A	1	na	1 biology, physical science
High School B	1	na	1 biology, environmental science
High School C	1	12	1 biology
Alternative Learning Centers	1	1	1 biology
Urban District – participants			
High School A	2	3 - 21	2 biology
High School B	4	3 – 31	4 biology
High School C	3	11 - 15	3 biology
High School D	1	11	1 biology, IB biology
High School E	1	20	1 biology
Alternative Learning Centers	2	8 - 14	2 biology
Urban District – controls			
High School A	1	14	1 biology
High School B	1	na	1 IB biology
High School C	1	na	1 biology, environmental science
High School D	1	8	1 biology, earth science
High School E	1	5	1 biology, genomics & bioinformatics
Alternative Learning Centers	1	17	1 biology

na not available

Supplementary Table 4

Pre- and post-test student scores by teacher training and implementation groups.

	Pretest			Post-Test		
Teacher Group	*M*	*SD*	*N*	*M*	*SD*	*N*
PD participants	5.33	2.26	1205	6.66	2.79	1128
Control	5.46	2.39	444	5.58	2.48	444
Unit	5.59	2.40	603	7.66	2.90	526
Sprinkling	5.07	2.09	602	5.77	2.36	602

Comparing students of all PD participants to students of controls, pre-tests were not significantly different, but at post-test, students of PD participants performed significantly better than students of controls ($p<0.0001$, 2 tailed t test; $d=0.41$ effect size, Cohen's d). Comparing students among teachers who had PD and taught units or sprinkled, both sets of pre-tests and post-tests were significantly different (pre-test, $p=0.0001$, $d=0.23$; post-test, $p<0.0001$, $d=0.72$, 2 tailed t tests).

Student Assessment

Choose the single best answer for each of the following questions.

1) In which order do signals travel from one neuron to another?

   a. cell body → synapse → dendrite → axon
   b. cell body → axon → synapse → dendrite
   c. dendrite → cell body → synapse → axon
   d. dendrite → synapse → cell body → axon

2) Once an action potential arrives at the nerve terminal, what happens before neurotransmitter is released?

   a. Calcium channels open and calcium moves into the neuron.
   b. Calcium channels open and magnesium moves into the neuron.
   c. Synaptic vesicles are recycled from the plasma membrane.
   d. Synaptic vesicles are pinched off from the plasma membrane.

3) What changes when a synapse gets stronger?

   a. More receptors
   b. More neurotransmitter recycling
   c. Fewer receptors
   d. Less transmitter release

4) Within a species, spiders always spin webs with the same pattern. When given street drugs, the web pattern changes. Which hypothesis best explains why?

   a. Drugs change the amount of myelin on axons
   b. Drugs change how synapses work
   c. Drugs change the rate mitochondria generate energy
   d. Drugs change the wiring of the spider nervous system

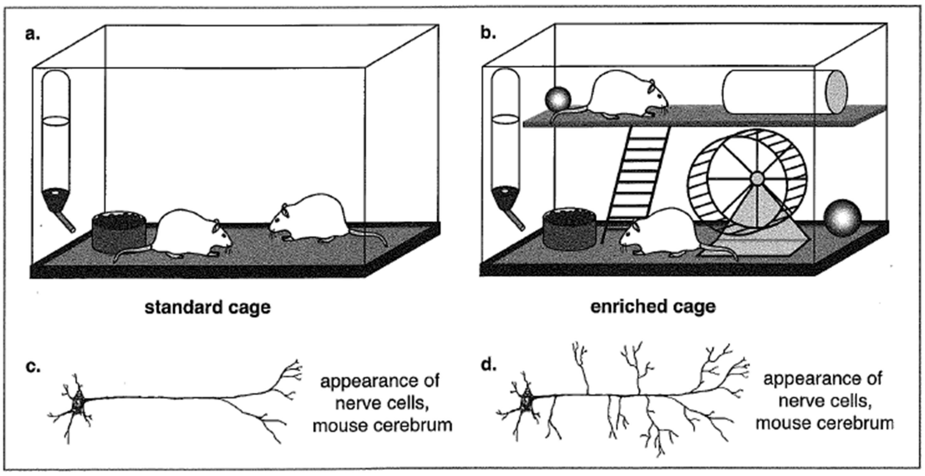
5) What brain structure is associated with emotional memories?

   a. Amygdala
   b. Cerebellum
   c. Corpus callosum
   d. Thalamus

6) What is the difference between the sympathetic and parasympathetic divisions of the autonomic nervous system?

   a. The parasympathetic NS controls the small intestine, the sympathetic NS controls the large intestine.
   b. The parasympathetic NS controls the large intestine, the sympathetic NS controls the small intestine.
   c. Their actions have similar effects upon internal body systems or states.
   d. Their actions have opposite effects upon internal body systems or states.

Dr. Kalike works as a neuroscientist at the U of M. In his lab, he has been conducting experiments with mice to study learning and memory. In his recent experiment, he placed mice in different environments; some were raised in a standard cage (Figure a) and some in an enriched cage which contains toys (Figure b). Two months later, Dr. Kalike found differences in the appearance of nerve cells from the cerebrum between the different groups of mice. Figure c shows a typical nerve cell from mice raised in standard cages. Figure d shows a typical nerve cell of the mice who lived in enriched cages.



(image Copyright BSCS)

7) What did Dr. Kalike learn from this experiment?

a) Mice raised in a standard environment show less dendrite growth than mice raised in an enriched environment.

b) Mice have fewer neurons living in a standard environment.

c) Environment does not have a significant effect on learning.

d) Mice raised in an standard environment can’t play with toys.

8) Which of the following procedures was essential for Dr. Kalike to follow in his experimental study?

a) Give different amounts of food to the different cages.

b) Divide mice into experimental groups and put mutant mice in enriched cages and normal mice in standard cages.

c) Divide mice into experimental groups and raise half in enriched cages and raise the other half in standard cages.

d) Move mice around between cages so that every mouse had some time in the enriched cages.

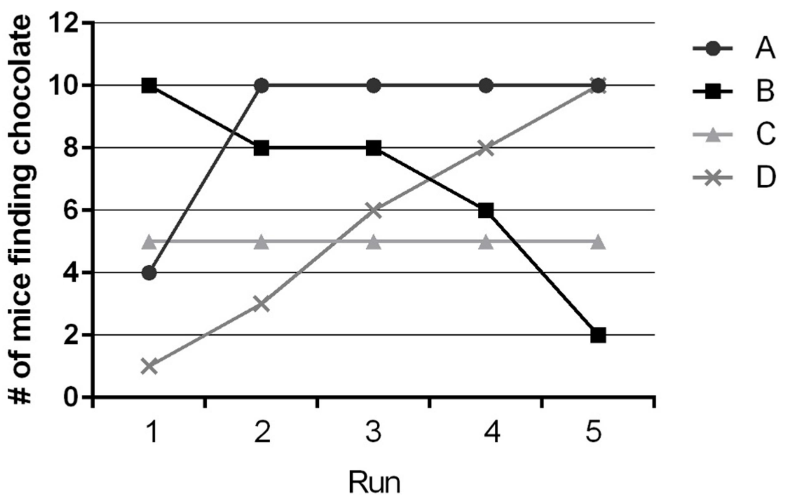
9) The results shown above suggest which of the following might also be true?

a) Mice raised in a standard environment may be able to teach their own litters how to perform better on a maze.

b) Mice raised in an enriched environment may perform better on learning tasks than those raised without toys.

c) Environment does not have a significant effect on learning.

d) Mice raised without toys may be able to learn faster than those raised with toys.



Graph 1. Mouse Maze Results

10) Dr. Kalike next tests 10 standard cage and 10 enriched cage mice in a maze. A mouse finds a piece of chocolate on successfully reaching the end of the maze. Each mouse runs the maze 5 times. Which of the lines in Graph 1 best predict the behaviors of the standard cage and enriched cage mice?

a) Line D is the standard cage mice and Line C is the enriched cage mice.

b) Line B is the standard cage mice and Line A is the enriched cage mice.

c) Line B is the standard cage mice and Line D is the enriched cage mice.

d) Line D is the standard cage mice and Line A is the enriched cage mice.

11) If after 2 months in the standard cage, mice are moved to the enriched cage, what would you expect will happen?

a) Neurons in their brains will grow more synapses.

b) Neurons in their brains will not change at all.

c) Neurons in their brains will grow more axons.

d) Neurons in their brains will grow more myelin.

12) In this experiment, Dr. Kalike investigated the effects of the environment on neural growth. He wants to continue studying factors that might affect learning. Which of the following factors may have a negative influence on neural growth?

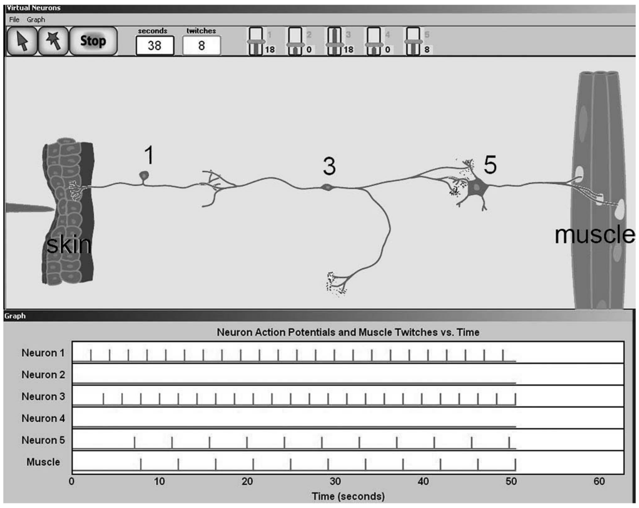
a) Lots of social interactions

b) Proper Nutrition

c) Living under constant stress conditions

d) Mental engagement

Circuit 1



13) Circuit 1 shows neurons connected to make the muscle contract. What kind of neuron is neuron #1?

a) An inhibitory interneuron

b) An excitatory interneuron

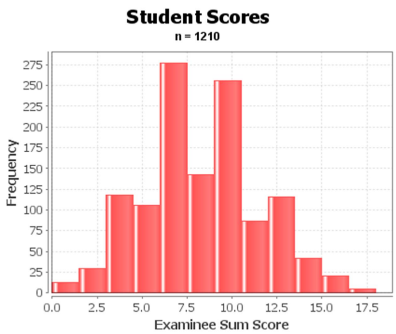
c) A motor neuron

d) A sensory neuron

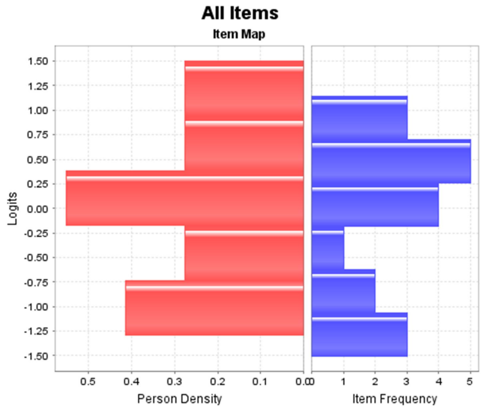
Analysis of Student Assessment

A reliability study of the instrument on the complete set of students' post-test scores from participant teachers indicated that the instrument has a reliability as measured by coefficient alpha of .65 (*SEM* = 1.89). Student responses were normally distributed (Supplementary Figures 1, 3). Confirmatory factor analysis indicated the instrument had a unidimensional structure. Rasch analysis was performed on an initial subset (N=1210) of post-tests to examine test reliability (SPSS, version 19). Scale reliability for the students was 0.65. Mapping of the test items and student responses on a logit scale demonstrated test coverage was good and the distributions of student performance and item difficulty were reasonably matched (Supplementary Figure 2). Item difficulty ranged from 0.22, to 0.76. Item discrimination ranged from 0.02 to 0.43. Items with discrimination of less than 0.2 are generally thought to interfere with the measure. Items 14 through 18 had discrimination values below this level and were subsequently dropped from all further analyses. Cronbach's α for the 13 question version was 0.670.

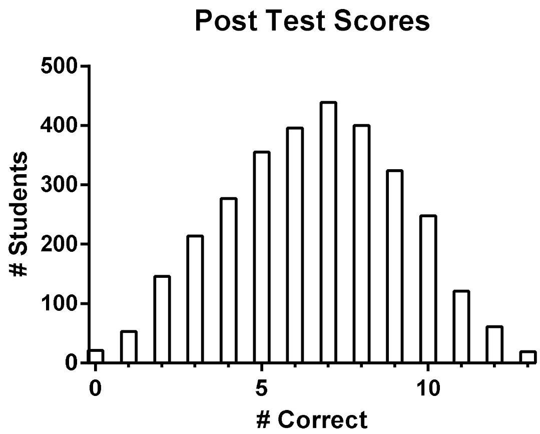
An independent item analysis of a different subset of post-test scores (N=501) confirmed that items 14-18 had point biserials of less than 0.2, reinforcing the decision to eliminate these questions. The average point biserial of the remaining 13 questions was 0.329 ± 0.058 (mean ± sd) from a range of 0.224 to 0.433. The distribution of responses for all post-tests based upon 13 questions was normal (Supplementary Figure 3).



Supplementary Figure 1. Student assessment quality analysis. Post-test results for the initial 18 questions were normally distributed, N=1210.



Supplementary Figure 2. Rasch analysis of student post-test responses on the original 18 questions. Left (red) bars indicate distribution of student performance. Right (blue) bars indicate distribution of questions by item difficulty. N=1210.



Supplementary Figure 3. Post-test results for the 13 question tests were normally distributed, N=3074.

Supplementary Table 5. Statistical Analysis of Change score data from Figure 1. Comparisons are between student change scores in the three classroom conditions; Unit = U, Sprinkling = S, Control = C.

	One-way ANOVA				Bonferroni Post test		
Data from Figure 1	**F**	***df***	***p***	η^2	***Comparison***	***p***	***d***
A Total	57.20	2, 1569	<0.0001	0.068	U>C	<0.0001	0.64
					U>S	<0.0001	0.36
					S>C	<0.0001	0.28
B Plasticity	70.45	2, 1569	<0.0001	0.082	U>C	<0.0001	0.65
					U>S	<0.0001	0.56
					S=C	ns	0.10
C Structure-Function	9.032	2, 1569	<0.001	0.011	U>C	<0.001	0.24
					U>S	<0.01	0.19
					S=C	ns	0.06
D Inquiry	18.44	2, 1569	<0.0001	0.023	U>C	<0.0001	0.33
					U=S	ns	0.00
					S>C	<0.0001	0.30