

Sowing the Seeds of Neuroscience Middle School Curriculum Program: Learning about the Nervous System Using Medicinal Plants

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Abstract: Educators are increasingly looking to neuroscience for guidance to improve classroom instruction and to teach their students about the nervous system. Although materials to assist teachers are available, many educators still have misconceptions about the brain. Twenty-three middle school teachers were trained to use the Sowing the Seeds of Neuroscience (neuroseeds.org) curriculum in their sixth, seventh, and eighth grade classrooms. The novel, hands-on, interactive lessons are aligned with Next Generation Science Standards and Common Core standards. The curriculum uses the “5E” model of instruction to study the neuroactive properties of plants and increase students’ neuroscience literacy. The lessons are designed to be culturally responsive by encouraging students to bridge their home and school experiences through an examination of medicinal plants used by their families, communities, and/or ancestors. Student pretest-posttest (N=1,240) results revealed that students significantly improved their neuroscience content knowledge after participating in the Sowing the Seeds of Neuroscience curriculum program. These findings suggest that this curriculum program is a promising resource for middle school educators who want to improve their students’ neuroscience literacy.

INTRODUCTION

Public interest in the field of neuroscience has expanded greatly in the past two decades. During this time, many discoveries from neuroscience laboratories across the world have made magazine covers, newspaper headlines, and television news stories. Educators, looking for the best methods to improve their teaching, have often turned to neuroscience for answers (Blackwell et al., 2007; Pickering and Howard-Jones, 2007). Despite the great public interest in neuroscience, misunderstandings and misconceptions about the brain are common (Dekker et al., 2012; Howard-Jones, 2014). Herculano-Houzel (2002) found that high school students, college students and college graduates incorrectly answered questions about brain size, the role of emotions in decision-making, and memory storage. The erroneous assumption that we use only 10% of the brain (Beyerstein, 1999) was also common in this study population. Educators harbor similar misconceptions about the nervous system. A majority of teachers in one survey were unsure if mental activity originates from brain function, and only 10% of the 158 teachers surveyed disagreed with the statement “We mostly only use 10% of our brains” (Howard-Jones, 2009, 2010).

Cameron and Chudler (2003) discuss the importance of neuroscientific literacy to young students. For example,

knowledge about the brain may help reduce the stigma attached to mental and neurological illnesses. Lifestyle choices (e.g., drug abuse, adherence to prescription medication, risk-taking behavior) may be influenced by students’ understanding of the nervous system and the consequences of damage to the brain. Student knowledge about the brain, especially the brain’s capacity to change, may also have positive influences on academic performance (Blackwell et al., 2007).

Many existing programs teach students about the effects of drugs on the brain. For example, the National Institutes of Health Office of Science Education distributes two supplements for high school students about drug addiction (Landes and Westbrook, 2000) and sleep (Bybee and Bloom, 2003). The National Institute on Drug Abuse also produces exemplary precollege classroom material about drug abuse (e.g., Brain Power! The NIDA Junior Scientist Program; Mind over Matter). Other resources for precollege classrooms have been developed that focus on addiction, the reward pathway, and drug abuse. For example, BRAINU, an NIH-funded neuroscience education program for grade 5-12 students and teachers (Dubinsky, 2010; MacNabb et al., 2006), includes an excellent hands-on laboratory experiment testing the effects of alcohol on the roundworm *C. elegans*.

Valuable online resources for precollege students that address drug abuse have also been created, such as those by the Genetic Science Learning Center (Stark and Pompei, 2010), Center for Technology in Teaching and Learning (Klisch et al., 2012; Miller et al., 2006) and the Pharmacology Education Program (Schwartz-Bloom et al., 2011). In contrast to the wide range of programs that seek to educate students about the brain and drugs, few educational resources discuss the neuroactive properties and medicinal uses of plants and herbs (Straus and Chudler, 2016).

The Sowing the Seeds of Neuroscience curriculum was designed to engage students with hands-on learning, culturally relevant content, and the possibility of real scientific discovery. Previous work has documented that hands-on or “active” learning is a more effective way to teach science (Freeman et al., 2007; Michael, 2006; Taraban et al., 2007) and that such teaching may benefit underrepresented minority students disproportionately (Gordon et al., 2001; Haak et al., 2011). The lessons were designed to be culturally responsive by encouraging students to bridge their home and school experiences through an examination of medicinal plants used by their families, communities, and/or ancestors. The importance of cultural factors and beliefs to science learning are well documented (Aikenhead and Jegede, 1999). Culturally relevant science teaching involves bridging students’ home experiences with their class experiences by bringing elements into their school learning which validate their culture. Such connections may make this curriculum more empowering and exciting to students. Furthermore, this curriculum encourages students to do truly authentic science: to engage in practices similar to those of scientists, including questioning and critical thinking (Chinn and Malhotra, 2002) while, for example, determining which plants to test in which experiment.

Learning experiences prior to high school are essential to encourage students’ interest and literacy in science, and have a significant impact on students’ success in science (Osborne et al., 2003). In fact, early interest is a stronger predictor than test performance for determining which students become scientists (Tai et al., 2006). Teachers who have taught Sowing the Seeds of Neuroscience report that their students are deeply engaged in the curriculum, exploring plant-based medicines in their classrooms on invertebrate models, and talking with their families about traditional uses of plants. Many students have explored these questions further in science fairs, demonstrating a deep interest in the content or methods used in our curriculum.

The present paper focuses on a novel middle school neuroscience curriculum that is designed to better engage all students resulting in improved neuroscience literacy and attitudes about science. The objective of this education intervention was to improve neuroscience literacy and attitudes toward science for all students. Furthermore, the curriculum

developers hypothesized that the culturally relevant, hands-on curriculum using medicinal plants to teach neuroscience would increase knowledge gains and interest in science at higher rates for underrepresented minority students.

METHODS

This study was conducted under University of Washington IRB #43828. All students and teachers consented to participate in this study.

Resource Content. The Sowing the Seeds of Neuroscience curriculum was developed for use by middle school students and consists of eight lessons using the “5E” instructional model (Bybee, 1997, 2002; Tanner, 2010; Trowbridge et al., 2004) as a framework. The 5E model consists of five phases to improve student understanding: engagement, exploration, explanation, elaboration, and evaluation. Each of the eight lessons was also aligned with the Next Generation Science Standards (States, 2013) and the Common Core Mathematical and English Language Arts Standards (National Governors Association Center for Best Practices, 2010a, 2010b). A short description of each of the eight lessons is below.

1. Neuroscience 101: Students will gain a basic understanding of neuroanatomy and neurophysiology. After observing the structure of the brain, spinal cord, and nerve cells, students will model neuroanatomy and neurotransmission.

2. Infusions and Decoctions: Students will learn that many plants contain chemicals with medical and neuroactive properties and explore how plants are used around the world to treat illness and alter brain function. In the laboratory portion, students will make infusions or decoctions that contain these plant chemicals. These extracts will be used in subsequent lessons.

3. If Worms Drank Coffee: Students will be introduced to the ideas that the brain controls the body’s movements and that Parkinson’s disease is a neurological disorder that affects movement. Students will think about the type of plant extracts that might affect planaria (flatworm) movement and then conduct an experiment to explore planaria movement with and without the addition of a plant extract.

4. Chromatography: Students will investigate how plant extracts are mixtures of many chemical compounds and how the health benefits of a medicinal plant may be due to a single chemical or a combination of chemical compounds working together. Students will use paper chromatography to separate chemical compounds from plant extracts.

5. Botanical Superheroes: Students will learn that bacteria can cause illness, including neurological diseases such as meningitis. In the hands-on portion of the lesson, students will investigate whether plant extracts are effective at inhibiting bacterial growth.

6. Heads and Tails: Students will be introduced to the con-

cepts of stem cells and regeneration using planaria as a model organism. Students will hear that neuroscience research promotes health and may lead to a better understanding of neurological disease and therapies to treat neurological disorders. In the laboratory portion, students will examine how their plant extracts affect planaria regeneration.

7. **Botanical Heart Throbs:** Students will learn about stimulants and depressants and then apply this knowledge to an experiment on pulsation rate in *Lumbriculus variegatus* (blackworm) (Straus and Chudler, 2015). Students will observe and count the *Lumbriculus* pulsation rate with and without the addition of a plant extract. Students will explore chemical transmission in the nervous system and circulatory system and discover how plant extracts affect the *Lumbriculus* circulatory system.

8. **SpikerBoxes:** Students will use inexpensive bioamplifiers called SpikerBoxes (Marzullo and Gage, 2012) to investigate the electrical responses in the cockroach nervous system. The SpikerBox allows students to hear and see action potentials generated by cockroach leg neurons. Students will investigate how plant extracts affect the discharge rate of action potentials.

Curriculum Development. As part of the design phase and prior to dissemination of the lessons within classrooms, six middle school science teachers were trained to use the curriculum during a one-week workshop. Teachers worked through all lessons and provided feedback to improve the usefulness of the materials for their students. These teachers were given kits containing all the materials necessary to implement the lessons in their classrooms during the following academic year. A total of 362 students piloted the lessons during the spring of 2013. Written and oral comments about the lessons from teachers and students were used to further revise the resource. After these revisions, the lessons were placed online at the project web site: www.neuroseeds.org.

Teaching Training. After the curriculum was revised based on the suggestions of the teachers and students who piloted the lessons, new middle school science teachers were recruited. In the 2016-2017 school year, 23 teachers at 14 different Washington State and Oregon schools were recruited to use the Sowing the Seeds of Neuroscience materials in their middle school classrooms. These teachers attended a professional development workshop in either Seattle or Yakima where they were taught about neuroscience and trained to use the equipment and materials. All workshops followed the same core curriculum and all teachers had the opportunity to work through all eight Sowing the Seeds of Neuroscience lessons. The Yakima workshops took place over three days while the Seattle workshops took place over five shorter days and included additional field trips and extension activities. Successful completion of the workshop allowed

the teachers to borrow kits to teach the Sowing the Seeds of Neuroscience curriculum in their classrooms in both the present and future school years. These kits contained all the materials necessary to teach the curriculum, including petri dishes, dried medicinal plants, and hot plates. Teachers borrowed the kits for up to 12 weeks and taught the lessons over the course of that period. Teachers were instructed to administer the pretest prior to the first lesson and to administer the posttest no more than 12 weeks after the pretest.

Pretest-Posttest Data Collection. The 23 trained teachers administered a pretest to their students before teaching any lessons and an identical posttest after completion of the lessons and no more than 12 weeks after the pretest. The test included fifteen content knowledge questions about neuroscience, medicinal plants, and model organisms, thirteen questions to assess attitudes about science, and five demographic questions (i.e. grade, gender, ethnicity, race, and language spoken at home; see supplemental materials). Student attitudes about science were measured using a subset of questions from the Simpson-Troost Attitude Questionnaire (STAQ) (Owen et al., 2008).

Student Subjects. A total of 1809 students completed a pretest and 1727 students completed a posttest. From these, it was possible to compile a matched analytic sample of 1245 students who completed both the pretest and posttest. The demographics of the analytic sample are summarized in Table 1.

Data Processing. Student responses to the 15 content knowledge questions were recorded as correct only if the single correct answer was selected on the Scantron form. One point was assigned for each correct answer recorded. Answers were not weighted. If multiple answers or no answer was selected on the Scantron form, the response was recorded as incorrect and zero points were assigned. The overall student content knowledge score was calculated both

Table 1. Student Demographics (N=1240) (number of students / % of total sample; missing data are not included).

Grade level	6th Grade (597/48.1%)
	7th Grade (379/30.6%)
	8th Grade (255/20.6%)
Gender	Female (615/50.0%)
	Male (616/50.0%)
Race/Ethnicity	American Indian/Alaska Native (56/5.0%)
	Asian (202/18.2%)
	Black or African American (133/12.0%)
	Hispanic or Latino/Latina (345/28.3%)
	Native Hawaiian or other Pacific Islander (6/0.5%)
	Multiracial (293/26.3%)
White (422/38%)	

as a count and as a percent of items correct based on the number of items marked as correct out of 15 content knowledge test items.

Three of the five scales or domains from STAQ were used in this study:

1. *Motivating Science Class* scale (six items) measures the student's positive affect toward their science class, particularly with regard to teacher-determined lessons.

2. *Self-Directed Effort* scale (four items) measures the student's perceptions of their willingness to work hard to do well in science.

3. *Science is Fun for Me* scale (three items) measures the student's positive affect toward science in general.

Students' scores for each of the three domains were calculated by averaging their responses to each of the items in that domain. Due to the limited number of items measuring each scale, each attitude scale score was calculated only if there were no missing responses for the student. Higher scores indicated a more positive attitude.

Statistical Analysis. Statistical analyses were performed using the Stata statistical software package, including paired t-tests and effect size calculations, to compare pretest and posttest scores of the four outcome measures (one content knowledge and three attitude measures) for the full matched sample and then by each participating teacher. Regression models were run to investigate the potential associations between content knowledge scores and student demographic, school, and teacher/classroom attributes. The model chosen was a regression of students' content knowledge posttest scores on their pretest scores, grade level, gender, ethnicity, race, language spoken at home, school type, teacher experience teaching Sowing the Seeds of Neuroscience (in years) and the number of Sowing the Seeds of Neuroscience lessons taught. A quality assurance check of the statistical analyses was performed, which consisted of a second quantitative analyst reviewing the assumptions and the syntax developed to run the analysis and validating the outcomes for a subset of students and classrooms.

The regression models take the following general form:

$$\text{post-test} = \beta_0 + \beta_1 \text{pretest} + \delta_1 \text{GRADE} + \delta_2 \text{GENDER} + \delta_3 \text{ETHNICITY} + \delta_4 \text{RACE} + \delta_5 \text{HOMELANG} + \delta_7 \text{SCHTYPE} + \beta_2 \text{nyrstch} + \beta_3 \text{nlessons} + u$$

where β_0 is the intercept (constant term), β_1 is the regression coefficient for pretest scores, β_2 is the regression coefficient for the number of years that the students' teachers have been teaching the Sowing the Seeds of Neuroscience unit, β_3 is the regression coefficient for the number of Sowing the Seeds of Neuroscience units the students' teachers taught this year, and the δ_i are regression coefficients for dummy variables

that represent the categories for each of the student and school attributes.

The grade category variable was collapsed to be a simple indicator for sixth graders to improve performance of the regression model, particularly with regard to multicollinearity. The school setting categorical variable was dropped from the model to correct for multicollinearity with the teacher attributes that were added to account for how the Sowing the Seeds of Neuroscience instruction was delivered. A post-estimation analysis of variance inflation factors suggests that the level of multicollinearity in these models is not a problem.

RESULTS

Students in grades six through eight correctly answered significantly more science content knowledge questions at posttest compared to pretest. The average correct pretest score for all students was 54.1% compared to an average correct posttest score of 69.3%. This difference represents a statistically significant increase in content knowledge ($t=29.08$, $df=1244$, $p < 0.01$; Figure 1). A Cohen's $d=0.82$ effect size was calculated to determine the magnitude of the observed difference from pretest to posttest. The observed effect size exceeds Cohen's convention for a large effect ($d=0.80$).

Not all teachers taught all lessons during the 12-week period: the number of lessons taught ranged from two to seven

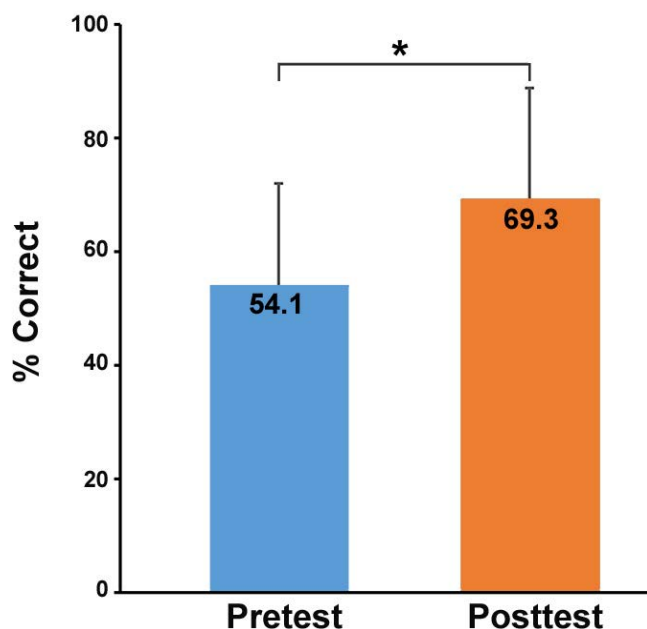


Figure 1. Overall student content knowledge, percent correct, before (pretest) and after (posttest) using the Sowing the Seeds of Neuroscience lessons based on grade level. Significant gains in the number of correct science content knowledge questions were observed on the posttest compared to the pretest when students from all grades were grouped together. (* = $p < 0.01$). Error bars indicate standard deviation.

with a mean and mode number of lessons taught of 4.5 and 4, respectively. The most commonly included lessons were Neuroseeds 101 (taught by 22 teachers), Infusions and Decoctions (taught by 21 teachers), and If Worms Drank Coffee (taught by 20 teachers).

Regression models were run to investigate the potential associations between content knowledge scores and student

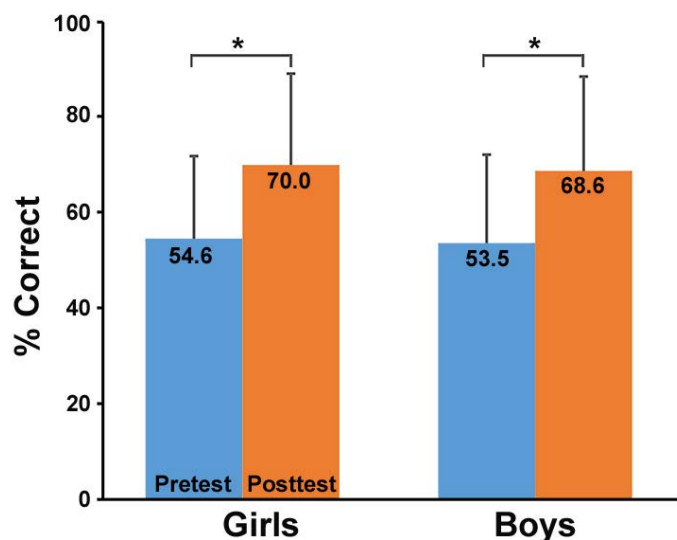


Figure 2. Student content knowledge before (pretest) and after (posttest) using the Sowing the Seeds of Neuroscience lessons based on gender. Both boys and girls correctly answered more questions on the posttest than on the pretest (* = $p < 0.01$) but there were no significant differences between the total percent correct answers between boys and girls on either the pretest or the posttest. Error bars indicate standard deviation.

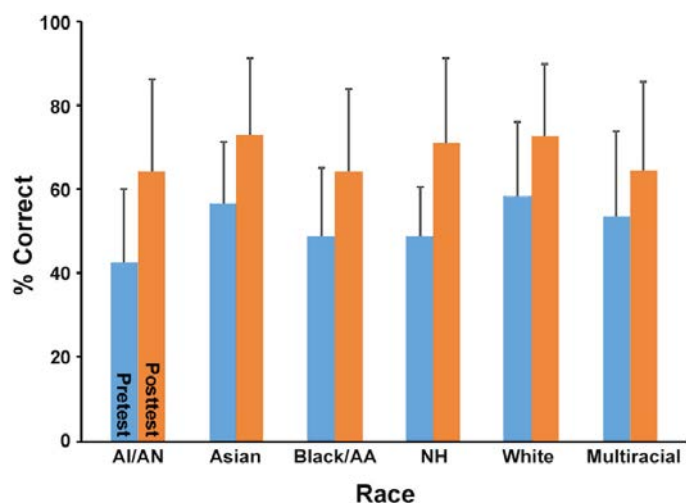


Figure 3. Student content knowledge before (pretest) and after (posttest) using the Sowing the Seeds of Neuroscience lessons based on self-reported race. AI/AN = American Indian/Alaska Native; AA = African American; NH = Native Hawaiian/Pacific Islander. Each bar indicates the percent correct before and after the Neuroseeds lessons were used by students of different self-reported races. Error bars indicate standard deviation.

demographic, school, and teacher/classroom attributes (Table 2 and Table 3). A regression model of students' content knowledge posttest scores on their pretest scores, grade level, gender, ethnicity, race, language spoken at home, school type, teacher experience teaching Sowing the Seeds of Neuroscience (in years), and the number of lessons taught was significant ($F[16, 1061]=37.7, p<0.001$), with an adjusted coefficient of determination (R^2) of 0.353. This indicates that approximately 35.3% of the variation in the dependent variable — posttest content knowledge — is predictable from the independent variables in the model. Most of the explanatory power of the model can be attributed to controlling for pretest scores ($\beta=0.55, SE=0.03$). In addition, several student attributes were found to be significant predictors of content knowledge at posttest, including sixth grade ($\delta=9.10, SE=1.05$), Black or African American ($\delta=-3.98, SE=1.66$), Multiracial ($\delta=-5.11, SE=1.24$), and speaking multiple languages at home ($\delta=-4.56, SE=1.33$). Both of the teacher/classroom attributes included in the model (number of years teaching the lessons [$\beta=1.69, SE=0.57$] and number of lessons taught [$\beta=1.86, SE=0.41$]) were found to be significant predictors of content knowledge at posttest. Three lessons were found to be significant predictors of posttest content knowledge: 1) If Worms Drank Coffee ($\delta=-9.24, se=1.98$), 2) Heads and Tails ($\delta=4.11, se=1.86$) and 3) Chromatography ($\delta=4.61, se=1.24$).

The number of correct science content answers did not vary significantly based on student gender. On the pretest, boys answered an average of 53.5% of the questions correctly and girls answered an average of 54.6% of the questions correctly ($t=1.11, df=1229, p=0.27$). Although students of both genders correctly answered more questions on the posttest than on the pretest, as reported above, there were no significant differences in either the posttest scores or the changes between pretest and posttest (Figure 2). Students from all races and home language backgrounds showed significant improvements in content knowledge when posttest scores were compared to pretest scores (Figure 3).

A statistically significant effect was observed in which the difference between average pretest score and average posttest score varied by grade level ($F[3, 1236]=4.27, p<0.01$). Specifically, there was a larger difference between pretest and posttest scores among sixth graders than among seventh and eighth grade students. Sixth graders correctly answered 52.9% of the knowledge questions at pretest and 73.0% at posttest; comparable figures for seventh graders were 56.7% at pretest and 66.4% at posttest, and for eighth graders, 53.8% at pretest and 66% at posttest (Figure 4).

Comparison of student pretest and posttest scales on the Simpson Troost Attitude Questionnaire showed little change (Table 4). Although the Motivating Science Class subscale scores were higher on average at posttest compared to scores at pretest, this change was trivial and not significant statis-

Table 2. Regression Models of Posttest Content Knowledge and Attitude Scores on Student, Teacher/Classroom and School Attributes, Focusing on the Number of Neuroseeds Lessons that Were Taught. In this model, the grade category variable was collapsed to be a simple indicator for sixth graders to improve performance of the regression model, particularly with regard to multicollinearity. The school setting categorical variable was dropped from the model to correct for multicollinearity with the teacher attributes that were added to account for how the Neuroseeds instruction was delivered. Standard errors in parentheses; * $p < 0.05$

	1	2	3	4
Pretest Scores				
Content Knowledge at Pretest	0.550* (0.028)			Science is Fun for Me at Posttest
Motivating Science Class at Pretest		0.711* (0.024)		Self-Directed Effort at Posttest
Self-Directed Effort at Pretest			0.746* (0.025)	Science is Fun for Me at Posttest
Science is Fun for Me at Pretest				0.738* (0.023)
Grade (reference category is Seventh, Eighth, or Other)				
Sixth Grader	9.101* (1.046)	0.038 (0.037)	0.109* (0.036)	-0.075 (0.047)
Gender (reference category is Male)				
Female	0.723 (0.946)	0.022 (0.033)	0.023 (0.032)	-0.011 (0.041)
Ethnicity (reference category is Not Hispanic or Latino/Latina)				
Hispanic or Latino/Latina	0.914 (1.58)	0.074 (0.056)	0.063 (0.053)	0.019 (0.07)
Race (reference category is White)				
American Indian/Alaska Native	-3.727 (2.458)	0.216* (0.088)	-0.005 (0.086)	0.109 (0.107)
Asian	0.492 (1.565)	0.152* (0.054)	0.044 (0.051)	0.074 (0.066)
Black or African American	-3.978* (1.662)	0.205* (0.059)	0.1 (0.055)	0.075 (0.073)
Native Hawaiian or Other Pacific Islander	-2.683 (6.375)	0.379 (0.226)	0 (0.194)	0.174 (0.278)
Multiracial	-5.114* (1.235)	0.099* (0.043)	-0.026 (0.042)	-0.022 (0.054)
Language Spoken at Home (reference category is English)				
Spanish	-3.402 (2.193)	-0.043 (0.078)	-0.146 (0.075)	-0.089 (0.097)
Another Language	-2.398 (1.704)	-0.051 (0.06)	-0.055 (0.056)	-0.045 (0.073)
Multiple Languages	-4.560* (1.326)	-0.053 (0.048)	-0.120* (0.045)	-0.123* (0.059)
School Type (reference category is Public)				
Parochial	5.64 (2.987)	-0.045 (0.102)	0.127 (0.096)	0.073 (0.125)
Private	-2.161 (1.555)	0.170* (0.054)	-0.059 (0.053)	0.036 (0.07)
Teacher Attributes				
Number of Years Teaching Neuroseeds	1.691* (0.565)	0.003 (0.02)	-0.028 (0.019)	-0.018 (0.025)
Number of Neuroseeds Lessons Taught	1.855* (0.412)	0.046* (0.015)	-0.031* (0.014)	-0.014 (0.018)
Constant	25.507* (3.496)	0.829* (0.14)	1.231* (0.144)	1.115* (0.158)
Observations	1078	919	889	904
Adjusted R²	0.353	0.561	0.543	0.548

Table 3. Regression Models of Changes in Content Knowledge and Attitude Scores on Student, Teacher/Classroom and School Attributes, Focusing on which Neuroseeds Lessons were Taught. The principal difference between the model used here compared that that shown in Table 2 is that the variable for the number of Neuroseeds lessons taught has been dropped from the model in Table 2 and replaced with a set of dummy variables that indicate whether or not students' teachers included each of the individual Neuroseeds lessons. Standard errors in parentheses; * $p < 0.05$

	1	2	3	4
	Content Knowledge at Posttest	Motivating Science Class at Posttest	Self-Directed Effort at Posttest	Science is Fun for Me at Posttest
Pretest Scores				
Content Knowledge	0.544* (0.028)			
Motivating Science Class		0.706* (0.024)		
Self-Directed Effort			0.745* (0.025)	
Science is Fun for Me				0.740* (0.023)
Grade (reference category is Seventh, Eighth, or Other)				
Sixth Grader	7.118* (1.446)	0.027 (0.052)	0.06 (0.052)	-0.056 (0.066)
Gender (reference category is Male)				
Female	0.852 (0.936)	0.021 (0.034)	0.029 (0.032)	-0.016 (0.041)
Ethnicity (reference category is Not Hispanic or Latino/Latina)				
Hispanic or Latino/Latina	1.682 (1.556)	0.064 (0.056)	0.059 (0.053)	0.007 (0.071)
Race (reference category is White)				
American Indian/Alaska Native	-4.823* (2.422)	0.205* (0.088)	-0.029 (0.086)	0.11 (0.108)
Asian	-0.09 (1.571)	0.129* (0.055)	0.037 (0.053)	0.072 (0.068)
Black or African American	-3.825* (1.682)	0.176* (0.061)	0.093 (0.057)	0.072 (0.076)
Native Hawaiian or Other Pacific Islander	-3.04 (6.241)	0.363 (0.225)	-0.018 (0.194)	0.186 (0.278)
Multiracial	-4.591* (1.234)	0.087 (0.044)	-0.023 (0.043)	-0.022 (0.056)
Language Spoken at Home (reference category is English)				
Spanish	-2.192 (2.181)	-0.05 (0.079)	-0.135 (0.076)	-0.077 (0.099)
Another Language	-1.852 (1.685)	-0.054 (0.06)	-0.055 (0.056)	-0.035 (0.074)
Multiple Languages	-4.376* (1.303)	-0.056 (0.048)	-0.114* (0.045)	-0.118* (0.06)
School Type (reference category is Public)				
Parochial	8.781* (3.144)	-0.039 (0.109)	0.109 (0.103)	0.107 (0.135)
Private	-3.177 (1.747)	0.172* (0.062)	-0.018 (0.062)	-0.004 (0.081)
Teacher Attributes				
Number of Years Teaching Neuroseeds	-1.289 (0.813)	-0.02 (0.029)	-0.031 (0.028)	-0.053 (0.036)
Neuroseeds Session Included in Lesson Plan (reference category is Not Taught)				
Neuroscience 101	-2.183 (3.466)	0.027 (0.119)	0.108 (0.116)	-0.203 (0.153)
Infusions & Decoc-tions	-4.037 (2.838)	-0.166 (0.102)	-0.148 (0.098)	-0.12 (0.13)
If Worms Drank Coffee	-9.241* (1.977)	-0.1 (0.07)	-0.124 (0.067)	-0.096 (0.086)
Heads and Tails	4.106* (1.861)	0.141* (0.065)	-0.016 (0.063)	0.121 (0.082)
Botanical Superheroes	2.677 (1.666)	0.1 (0.059)	0.057 (0.058)	-0.105 (0.075)
Botanical Heart Throbs	-1.704 (1.879)	0.071 (0.068)	0.023 (0.065)	-0.038 (0.086)
Chromatography	4.609* (1.235)	-0.061 (0.044)	-0.08 (0.042)	-0.082 (0.054)
Spiker Box	-3.042 (1.711)	-0.036 (0.06)	-0.130* (0.058)	-0.071 (0.076)
Constant	53.152*	1.246*	1.279*	1.593*
Observations	1078	919	889	904
Adjusted R²	0.381	0.566	0.545	0.548

Table 4. Attitude Scales Item Analysis. The same items were used on both the pretest and posttest. Only responses from students with matched pretest and posttest are included.

		Strongly Disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)	No Response
I would enjoy being a scientist.	Pre	6.9% (n=86)	10.1% (n=126)	35.0% (n=436)	27.9% (n=347)	15.0% (n=187)	5.1% (n=63)
	Post	6.7% (n=84)	11.3% (n=141)	33.8% (n=421)	29.2% (n=363)	15.2% (n=191)	3.6% (n=45)
We learn about important things in science class.	Pre	1.6% (n=20)	2.5% (n=31)	9.4% (n=117)	40.1% (n=499)	42.3% (n=527)	4.1% (n=51)
	Post	1.2% (n=15)	2.7% (n=33)	9.6% (n=120)	40.6% (n=505)	43.7% (n=544)	2.2% (n=28)
Our science classroom contains a lot of interesting equipment.	Pre	1.6% (n=20)	5.5% (n=68)	18.6% (n=232)	40.8% (n=508)	29.2% (n=363)	4.3% (n=54)
	Post	1.5% (n=19)	3.8% (n=47)	17.6% (n=219)	42.6% (n=530)	32.4% (n=404)	2.1% (n=26)
We cover interesting topics in science class.	Pre	2.8% (n=35)	5.3% (n=66)	15.5% (n=193)	42.7% (n=531)	30.4% (n=378)	3.4% (n=42)
	Post	2.4% (n=30)	4.3% (n=53)	16.5% (n=206)	44.0% (n=548)	29.8% (n=371)	3.0% (n=37)
I enjoy science courses.	Pre	3.1% (n=38)	6.5% (n=81)	20.8% (n=259)	38.5% (n=479)	26.2% (n=326)	5.0% (n=62)
	Post	3.3% (n=41)	6.3% (n=79)	21.0% (n=262)	40.2% (n=500)	26.3% (n=328)	2.8% (n=35)
I always try to do my best in school.	Pre	0.3% (n=4)	2.2% (n=27)	6.7% (n=84)	30.8% (n=384)	55.7% (n=693)	4.3% (n=53)
	Post	0.6% (n=8)	2.0% (n=25)	8.9% (n=111)	33.4% (n=416)	52.1% (n=649)	2.9% (n=36)
We do a lot of fun activities in science class.	Pre	3.2% (n=40)	7.0% (n=87)	20.2% (n=251)	40.0% (n=498)	25.5% (n=317)	4.2% (n=52)
	Post	3.0% (n=37)	6.4% (n=80)	19.4% (n=242)	41.4% (n=515)	27.6% (n=344)	2.2% (n=27)
I consider our science class attractive and comfortable.	Pre	3.2% (n=40)	7.0% (n=87)	20.2% (n=251)	40.0% (n=498)	25.5% (n=317)	4.2% (n=52)
	Post	3.5% (n=44)	4.7% (n=58)	20.7% (n=258)	45.5% (n=566)	23.1% (n=288)	2.5% (n=31)
My science teacher makes good plans for us.	Pre	2.0% (n=25)	2.8% (n=35)	12.7% (n=158)	37.6% (n=468)	40.8% (n=508)	4.1% (n=51)
	Post	2.2% (n=28)	2.6% (n=32)	12.2% (n=152)	39.2% (n=488)	41.5% (n=517)	2.2% (n=28)
I try hard to do well in science.	Pre	0.7% (n=9)	0.6% (n=6)	8.9% (n=111)	32.5% (n=405)	53.0% (n=660)	4.2% (n=52)
	Post	1.2% (n=15)	1.8% (n=23)	9.3% (n=116)	35.6% (n=443)	49.5% (n=616)	2.6% (n=32)
When I fail, that makes me try that much harder.	Pre	1.5% (n=19)	3.1% (n=39)	16.0% (n=199)	37.1% (n=462)	37.0% (n=461)	5.2% (n=65)
	Post	1.4% (n=17)	3.5% (n=44)	19.2% (n=239)	36.0% (n=448)	36.2% (n=451)	3.7% (n=46)
I really like science.	Pre	4.2% (n=52)	7.0% (n=87)	23.1% (n=288)	33.3% (n=415)	26.5% (n=330)	5.9% (n=73)
	Post	4.6% (n=57)	6.3% (n=78)	23.7% (n=295)	36.5% (n=455)	25.1% (n=312)	3.9% (n=48)
I always try hard, no matter how difficult the work.	Pre	0.9% (n=11)	2.8% (n=35)	13.7% (n=171)	34.0% (n=423)	41.1% (n=512)	7.5% (n=93)
	Post	1.0% (n=12)	2.0% (n=25)	13.6% (n=169)	34.6% (n=431)	41.7% (n=519)	7.1% (n=89)

Attitude item analysis (N=1,245)

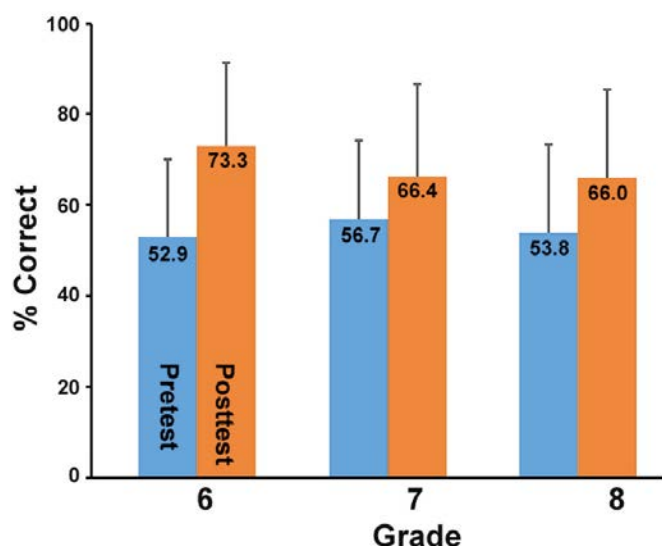


Figure 4. Student content knowledge before (pretest) and after (posttest) using the Sowing the Seeds of Neuroscience lessons based on student grade level. The gain in content knowledge score between pretest and posttest scores among sixth graders was significantly greater than the gain for seventh and eighth grade students. The numbers within each bar indicates the percent correct before and after the Neuroseeds lessons were by students in different grades. Error bars indicate standard deviation.

tically. Similarly, there was no significant change in the Self-Directed Effort Scale or the Science is Fun for me scale.

DISCUSSION

Sowing the Seeds of Neuroscience is a new science curriculum that contributed to an increase in middle school students' content knowledge about neuroscience. Middle school students in classrooms that offered the program showed significant acquisition of knowledge about the basic anatomy and physiology of the nervous system, the neuroactive properties of medicinal plants and herbs, and the use of animals in research. Hattie (2009) conducted a meta-analysis of over 800 education intervention studies with the aim of developing an explanation of key influences on student learning. This meta-analysis is a useful tool for evaluating the relative efficacy of different education interventions. The average effect size (Cohen's *d*) of science programs included in the meta-analysis was 0.40. Hattie (2009) suggests that interventions with a measured effect size greater than 0.40 are worthy of development as these innovations are likely to enhance student achievement in the real world. The large effect size seen in the pretest-posttest results (Cohen's *d*=0.82) suggests that the Sowing the Seeds of Neuroscience program is promising in terms of having a positive impact on student science achievement.

Although sixth graders experienced about the same number of lessons as did students in other grades, sixth grad-

ers had both lower pretest scores and higher posttest scores compared to seventh and eighth grade students. The lower pretest scores suggest that sixth graders had less previous exposure to neuroscience, and the higher posttest scores suggests that they took advantage of the lessons to learn more about the neuroscience topics addressed in this curriculum. The greater knowledge gain for sixth graders suggests that it may be advantageous to introduce this program to students earlier rather than later in middle school.

The number of years that teachers used Sowing the Seeds of Neuroscience lessons with their students and the number of these lessons taught to students were predictive of student content knowledge at the posttest. This finding suggests that teachers with more experience teaching the lessons were in a better position to contribute to their students' learning and subsequent performance on the posttest, likely by becoming more adept at preparing the experiments, more knowledgeable about the neuroscience topics addressed in the curriculum, and more familiar with the medicinal herbs that the students were studying. Similarly, we posit that students who worked with more lessons were exposed to repeated discussions of neuroscience and medicinal plants that likely contributed to their greater content knowledge gain.

The number of lessons that teachers taught were also predictive of student knowledge gains between pretest and posttest. Students who benefited from only two lessons experienced an average gain of 10.8 points compared to students who benefited from seven lessons, who had an average gain of 18.5 points. Moreover, there were significant positive correlations between teaching Heads and Tails and Chromatography lessons and students' posttest content knowledge scores. Further investigation will help identify the core set of lessons that would constitute a sufficient dose to achieve curriculum learning objectives.

The regression model indicates that only 35.3% of the variation in the dependent variable (posttest content knowledge) was predictable from the independent variables in the model. Most of the explanatory power of the model can be attributed to controlling for pretest scores ($\beta=0.55$, $SE=0.03$). Given that this is a singular level model at the student level, rather than a multilevel model, the remaining variance among the results may be due to 1) individual differences across teachers and across students, and 2) socioeconomic status of student families. Specifically, the model did not include variables to account for where the school was located (urban, suburban, or rural) or whether it was public, private, or parochial. More importantly, variables that are indicators of socioeconomic status (e.g., percentage of students who qualify for free or reduced-price lunch) and variables that assess the overall school environment (e.g., the percentage of English language learners, percentage of students of color) were not included.

Although no significant differences in student's attitudes

about science were observed, this may be because students' attitudes were already quite high on the pretest. In both the Motivating Science Class scale and the Self-Directed Effort scale, mean scores on the pretest were >4.0 ("agree") while on the Science is Fun for me scale, mean pretest scores were >3.5 (between "unsure" and "agree"). With a series of between two and seven lessons taught over a maximum of twelve weeks, it is possible that this is not a large enough "dose" of hands-on science to change already high science attitudes.

There are several consistencies between the pattern of observed pretest-posttest scores across racial, ethnic and home language categories and data on high school graduation rates in Washington State, an important indicator of the status of the K-12 education system. The finding that students who identified as American Indian/Alaska Native, Black/African American, or multiracial scored lower on the posttest compared to students who identified as Hispanic or Latino/a, Asian, or White is consistent with Washington State's graduation rate disaggregated by race and ethnicity which shows in 2016-2017 (Came et al., 2018), 60.3% of American Indian students, 71.5% of Black students, and 79.7% of multiracial students graduated from high school in four years compared to a 79.3% graduation rate for all students. Comparatively, 72.7% of Hispanic students, 87.5% of Asian students, and 81.9% of White students graduated from high school in 2016-2017 in four years. Furthermore, the fact that speaking multiple languages at home was found to be predictive of a lower posttest score is consistent with the fact that 57.8% of students who spoke limited English graduated from high school in four years.

A curriculum of longer duration or one that includes other culturally relevant dimensions, for example ties to social justice (Laughter and Adams, 2012) may also benefit underrepresented students. Also, the hands-on nature of this curriculum may have made the science more engaging and effective for all students. Additionally, as part of this curriculum, students research the medicinal plants used by their families, communities, or ancestors. Teachers discuss traditional Native American, African, South Asian, and Chinese medicines derived from a variety of plants and herbs and indicate that many of these plants have been incorporated into Western medicine (e.g. atropine, aspirin, curare). When students investigate medicinal plants from their own cultures, they may make discoveries that contribute to the scientific literature. In such cases, these data would be confirmed in the Sowing the Seeds of Neuroscience laboratory and students could collaborate with scientists to co-author a paper detailing their findings in a manner similar to Aikenhead and Jegede (1999). Further evaluation is required to understand the relationship between these program components and student learning objective attainment.

All evaluation study designs have limitations and this

study is no exception. A quasi-experimental design including two independent groups of students (a treatment group and a comparison group) would improve our ability to draw conclusions about program effectiveness for improving neuroscience literacy in diverse populations of middle school students. Validation of the pretest-posttest is an additional important improvement needed to ensure that the test is accurately measuring targeted neuroscience knowledge gains. Furthermore, a multilevel modeling approach for the statistical analysis would account for the fact that students are best viewed as being nested within classrooms, which are themselves nested in teachers and schools, and thereby strengthen our ability to draw conclusions. In the present analysis, all students in the matched sample were grouped into one large pool, and attributes associated with teachers and schools were included in the singular level model as student-level covariates.

Two other limitations relate to students' exposure to the curriculum. On one hand, we do not know whether any of the students, particularly those in seventh or eighth grade, had previously received the Sowing the Seeds of Neuroscience curriculum. For students who had previously experienced this content, the impact of the lessons may already be factored into their pretests, and any potential gains this year may be diminished. On the other hand, not all students received the same exposure to the curriculum during this year's implementation of the project. None of the teachers taught all eight of the Sowing the Seeds of Neuroscience lessons, and six of the teachers taught fewer than four lessons. While this is a limitation in terms of evaluating the overall impact of the curriculum, it opens the possibility for a future investigation of how variations in program exposure impact student outcomes, particularly in terms of whether some lessons are more impactful than others.

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The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

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