ARTICLE

Undergraduate Neuropharmacology: A Model for Delivering College-Level Neuroscience to High School Students *in situ*

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Our university course for non-majors (Biology 100) on the neurobiology of drug addiction was recently retooled for delivery at high schools around the state of Washington in order to engage younger students in the study of psychoactive drugs. Many of these students are earning both high school and university credits (dual-enrollment). This paper outlines the course design principles we used to ensure that high school students are earning valid college credits. We present an analysis of learning gains experienced by both university and high school students as measured by before and after course knowledge surveys. We also describe how assessment strategies used for on-campus students have been transferred to our high school partner teachers and how generous interchange and observation ensure that the high school students are engaging deeply in their study of neuroscience. Indeed, many have had a transformative experience that inspires them to contemplate the field of neuroscience as they transition into university study.

Key words: neurobiology; neuropharmacology; addiction; neuroscience; undergraduate, dual-enrollment

Dual enrollment programs offer accelerated learning opportunities to high school students to better prepare them for college-level study and alleviate some of the burden of ever-increasing costs of college tuition. These programs facilitate the transition to university-level courses and timely completion of graduation requirements (Bailey et al., 2002). Further, taking higher-level science courses in high school can reduce racial disparity in STEM majors (Tyson et al., 2007). These programs are providing an increasingly diverse suite of course offerings. In Washington State alone, over 550,000 high school students were engaged in some dual-enrollment program in the 2012-13 school year (OSPI web site). However, the efforts to make these opportunities widely accessible may conflict with the goal of maintaining college-level rigor (Karp et al., 2004). To address this challenge, we report two strategies used in a dual enrollment neuropharmacology course developed at the University of Washington: a set of shared assessment tools and a strong foundation in support and observation between the university and high school partners.

We chose neuropharmacology as the topic of the dual enrollment Biology 100 course because it captures student interest in a challenging science topic, and because understanding the biology of drug addiction may offer an alternative to currently ineffective drug prevention programs. We wanted the science of the dual enrollment Biology 100 course to remain rigorous and research-based, so rather than dilute or simplify the content, we worked with university and public education partners to offer the same college-level curriculum to high school students as a dual-credit offering.

Evidence reveals that many drug prevention programs based on psycho-social avoidance strategies (example Drug Awareness Education or DARE) are failing to accomplish strong and lasting successes in helping adolescents to either avoid drug-using choices or minimize the harm of drug-using behaviors (Ennett, Rosenbaum et al., 1994; Ennett, Tobler et al.,1994; and Clayton et al., 1996).

Evidence-based interventions ("prevention science," a term originated by Coie et al., 1993) have shown more promise (example: Hawkins et al., 2002). A comprehensive examination of risk and protective factors is driving drug education to chip away at the risk factors that can be impacted and bolster the protective factors. Programs such as "Communities that Care" (www.communitiesthatcare.net) are having sustained and measureable impacts on drug use and other risky behaviors associated with adolescence (Hawkins et al., 2009). Additionally, research-based drug education is cost-effective. Several sources estimate that for every dollar spent on science-based drug education, approximately $5 - $10 are saved from future drug-treatment costs (Pentz et al., 1998; Hawkins et al., 1999; Kuklinski et al., 2012).

The Substance Abuse and Mental Health Services Administration (SAMHSA) lists numerous risk and protective factors for alcohol and drug use (www.samhsa.gov). Among the risk factors is the "low perception of harm" (Henry et al., 2005). People who feel that drug-using is not harmful are more likely to engage in drug use. Among the protective factors for drug use is academic rigor (Birckmayer et al., 2004). Students who have a commitment to their schooling and perform well are less likely to engage in drug use. Offering a biology course based on rigorous, research-based information about the impacts of drug use and addiction therefore provides a foundation for increasing accurate perceptions of harm due to drug use, which may impact drug using behavior among enrolled adolescents as well as increasing academic rigor and scientific literacy.

Many studies point to the importance of programs directed at early ages (Kandel et al., 1986; Hawkins et al., 1992; Hawkins et al., 1995; Hawkins et al., 1997). The Pharmacology Education Partnership has shown that drug-based science curricula are both welcomed by students and can impart a deeper understanding of basic biology and chemistry through their context-dependent relevance (Schwartz-Bloom and Halpin, 2003; Kwiek et al., 2007; Schwartz-Bloom et al., 2011, Godin et al., 2014). Our university Biology 100 curriculum was therefore remodeled for high school students.

Delivering university neuroscience to high school students does not guarantee that these students will master the material to the same degree as our on-campus university scholars. In this paper, we present assessment strategies that enabled college-rigor to be maintained by our high school partners in their classrooms. We wanted to ensure high rigor while also providing some flexibility for our high school partners. Our low-stakes assessments and pre-, post-course surveys were therefore implemented verbatim in off-site classrooms. For higher stakes assessments (summative tests), we created a rich test bank from which our teachers select questions to evaluate student progress. In this paper, we describe assessments of learning outcomes and methodologies for teacher support and observation that have allowed us, with grant support from the National Institute on Drug Abuse, to provide college-level neuroscience learning opportunities to high school students for over three years.

MATERIALS AND METHODS

Course Content and Structure

Biology 100, The Neurobiology of Addiction, is taught in six units. In the first three, students meet general concepts related to 1) neurobiology, 2) pharmacology, and 3) genetics. In the last three units, students investigate 1) stimulants, 2) depressants, and 3) psychedelic drugs. The lessons within the neurobiology unit are shown in Table 1. Most of the concepts taught during the introductory units are revisited during the "drug" units. For example, when we discuss ethanol during the depressants unit, we spend considerable time talking about genetic variants that correlate with ethanol aversion or ethanol addiction.

To earn credits in Biology 100, students must engage in lecture-style learning with intermittent clicker questions, laboratory activities, examinations, and group-projects. The laboratory activities are listed in Table 1. Students explore their own perceptions and try out different field sobriety tests. They also examine model organisms in a dissection and a double-blind drug trial. Students also participate in group projects designed to inspire independent research and to encourage questions for which there frequently is no "right" answer. One example is a project that requires the students to explore the legal status of a drug, how that status has changed historically, and how and why that status might change in the future. For instance, one group imagined caffeine going underground in the future due to its addictive properties and the availability of high-concentration caffeine.

Course Materials

Course materials were developed over 10 quarters at the University of Washington (UW). All student-versions of course materials were established on a learning management system (LMS), which was provided to all teachers. The LMS included 28 lessons, organized into six units. Table 2 shows the assessments that are transferred

Lesson	**Topics**
Introduction	Mood-altering drugs and adolescents. Is addiction a disease? How do drugs impact brain function?
Nervous systems	Central and peripheral nervous systems. Autonomic and somatic nervous systems. Sympathetic and parasympathetic nervous systems.
Brains	Brain mapping. Brain imaging. Brain dissection. Brain organization. Brain pathways.
Membranes	Membrane composition. Gradients. Transporters. Neurons and neuroglia. Resting and action potentials.
Synapses	Presynaptic and postsynaptic cells. Neurotransmitters. Ionotropic receptors. Stimulatory and inhibitory signals. Synapses and learning.
Addiction circuitry	Addiction stages. Biochemistry of addiction. Hallmarks of addiction. Addiction treatment. Relapse.
Laboratory Activity	**Description of laboratory lesson**
Brains	Human brain demonstration and sheep brain dissection.
Enzymes	Catalase activity as a model for drug-metabolizing enzymes.
DNA isolation	Strawberry DNA isolation.
Complex genetics	Workshop to practice Punnett squares and branch diagrams for polygenic traits.
Worms on drugs	Double-blind treatment of *Lumbriculus variegatus* with household drugs, examining changes in pulse rate.
Measuring intoxication	Field sobriety tests examined and compared to laboratory tests for intoxication (using distraction as a model for intoxication).
Limits of perception	Analysis of human chemo-, photo-, and mechano-reception and their subjectivity.

Table 1. The concepts taught in the neurobiology unit of Biology 100 and the laboratory activities for all units. There are six lessons in the neurobiology unit, and for each lesson, we show a list of concepts taught. We also show the seven laboratory activities that accompany the course.

Assessment	Purpose	No.	Percent of Course Points
Lab Worksheet	Analysis of laboratory findings	7	10
Problem Sets	Promote end-of-unit formative assessment	6	2
Discussion Forums	Promote peer conversation and debate	~10	5
Group Projects	Promote synthesis of ideas and collaboration	4	10

Table 2. University assessments that are transferred verbatim to high school students.

from the university course to our high school partners. These assessments are used verbatim to ensure continuity of instructional rigor. The LMS also gives teachers and their students access to seven laboratory activities, six interviews with professionals, and six study guides.

Teachers also have access to additional materials intended only for them and to a social media group site (through Edmodo.com). Here we share late-breaking research, conference findings and opportunities, and teacher-designed course embellishments. These embellishments include activities designed by teachers to help make the college material more accessible to their students. Answer keys to homework assignments are also housed here. Most importantly, six test banks, coded for different degrees of intellectual challenge are provided with answer keys.

High School Teacher Partners

Cahill (2007) advocates that school-based drug awareness programs provide substantial teacher training to be most effective. Few pre-teaching professionals have studied neuropharmacology as they prepared for their teaching careers. In addition, the field of addiction neuroscience evolves quickly. In 2013 alone, 526 research and review articles are listed in a search through the US National Library of Medicine National Institutes of Health (PubMed) using “neuroscience, drug, and addiction” as search terms. Secondary school teachers have insufficient time to cull through the advances in this field. This deluge of new data strongly supports the need for ongoing training such that high school teachers might deliver university-level neuroscience in their classrooms.

Our teachers are recruited to participate in the UW in the High School program, a program that offers a variety of dual enrollment courses to high schools. To be selected, they must hold a master’s degree and be certified to teach biology. They are also screened for their interest in our content and willingness to follow our guidelines. Once selected, each teacher commits to a four-day training program prior to teaching the lessons. In addition, teachers have the opportunity to participate in mini-conferences during the school year. Lastly, the “Edmodo” group enables updates and corrections for teachers from university instructors as well as from each other. Teachers must participate in refresher training at least every other year. The multi-pronged approach to teacher training is described in a separate article (Buckland et al., in preparation).

Group	Percent		Group	Percent
Caucasian	53		Male	30
Asian American	11		Female	67
Hispanic	7.6		Unspecified	2.1
African American	3.8			
Pacific Islander	2.1			
Native American	1.1		10th grade	16
Biracial	15		11th grade	27
Other	4		12th grade	52
Unspecified	2.1		Unspecified	2

Table 3. Student demographics for 853 high school enrollees in the undergraduate neuroscience course about the brain and drug addiction. Students were enrolled between September 2011 and June 2014.

Each classroom is visited at least once each year by university course personnel. These visits facilitate resource-sharing (such as a collection of preserved human brains) and enhance communication about the quality and level of instruction and student engagement. To fulfill college-level rigor, instruction is not only evaluated for depth of content, but also for promoting skills such as hypothesis generation, critical interpretation of data, and inquiry into how scientific knowledge is obtained. Furthermore, instructors are encouraged to give students opportunities to practice applying their knowledge and skills in the classroom, rather than to exclusively listen to lecture, as meta-analyzed in Freeman et al. (2014). After each classroom visit, teachers not only receive feedback but are also encouraged to provide feedback to the University and share new resources with other teachers.

Students

Nine hundred sixty-nine university undergraduates have taken Biology 100 over 10 academic quarters. These students earned natural sciences distribution credits for majors outside of life sciences. In this paper, these students serve as a comparison group against which we evaluate our high school student counterparts.

Eight hundred and fifty-three students from 13 high schools were enrolled in the dual enrollment Biology 100 course between 2011 and 2014. Many of them simultaneously earned UW credit. ALL high school students, whether or not they are earning college credits, are invited to participate in the pre- and post-course surveys. These students studied the material in their high school classes (41 classroom sections) under the leadership of 14 high school teachers.

Students enrolled in this course in the high school are self-selected. Most students have a strong interest in the content and a willingness to rise to the challenge of university study prior to earning their high school diplomas.

The students are diverse as shown in Table 3. Approximately 7% of our students are in private high schools; the remainder are students in public schools in 11 different school districts.

Assessment

Students are evaluated primarily on the basis of exams, group projects, and laboratory homework. These are the same criteria used to evaluate undergraduates on campus (See Table 2 for the assessments that are transferred verbatim from the university to high schools). To promote equivalent expectations, the group projects and laboratory assignments are the same as those used on campus. Other high school assessments are at the teachers' discretion and constitute less than 20% of course points.

Teachers make their own exams using the coded test bank provided to high school teachers by university faculty. The test bank is coded for question challenge, based on the Webb (1997) depth of knowledge categories used in Washington State (See Hess 2013 for application of Webb Depth of Knowledge categories to scale for Common Core Curriculum). Teachers are instructed to make exams with a required percentage of points coming from higher challenge categories in order to match university exam rigor.

The Webb Depth of Knowledge (DOK) categories are:

- Level 1: Recall & Reproduction
- Level 2: Working with Skills and Concepts
- Level 3: Short-term Strategic Thinking
- Level 4: Extended Strategic Thinking

Because level 4 requires extensive time on task and synthesis, it is therefore represented by projects rather than exams. The test bank entries are coded as Level 1 – 3 and teachers are instructed that less than 50% of their exam point total should consist of level 1 questions.

Surveys

Ungraded surveys are administered to high school and university students to track their course-related growth. These surveys include very specific questions about attitudes about drug use. All participants take the same survey twice; once prior to, and again at the completion of the course.

Statistical Analysis

Statistical analysis for student knowledge gains was performed using Graphpad Prism 5 software. To measure student-learning gains, 608 students from six UW classes and 264 students from nine high school classes were included in the analysis. First, class means were computed for the pre-test or post-test using individual students' scores. The class means were then used as individual measurements to compare pre- to post-scores using paired t-tests, for UW or high school classes, respectively. Values are reported as the average of separate class means ± standard error of the class means (SEM) (Figure 1A & B).

Furthermore, to compare learning gains for students in the two settings (college campus and high school classrooms), a *normalized* gain score was computed for each class following the formula:

$$\frac{\text{Post-test score} - \text{Pre-test score}}{100 - \text{Pre-test score}} \text{ X } 100$$

(formula based on Theobald and Freeman, 2014). Normalized gain scores were compared between UW and high school students using a student's t-test (Figure 2C). P-values were adjusted using Bonferroni correction to address multiple comparisons.

RESULTS

Student Knowledge Gains

To assess the ability of our high school students to learn

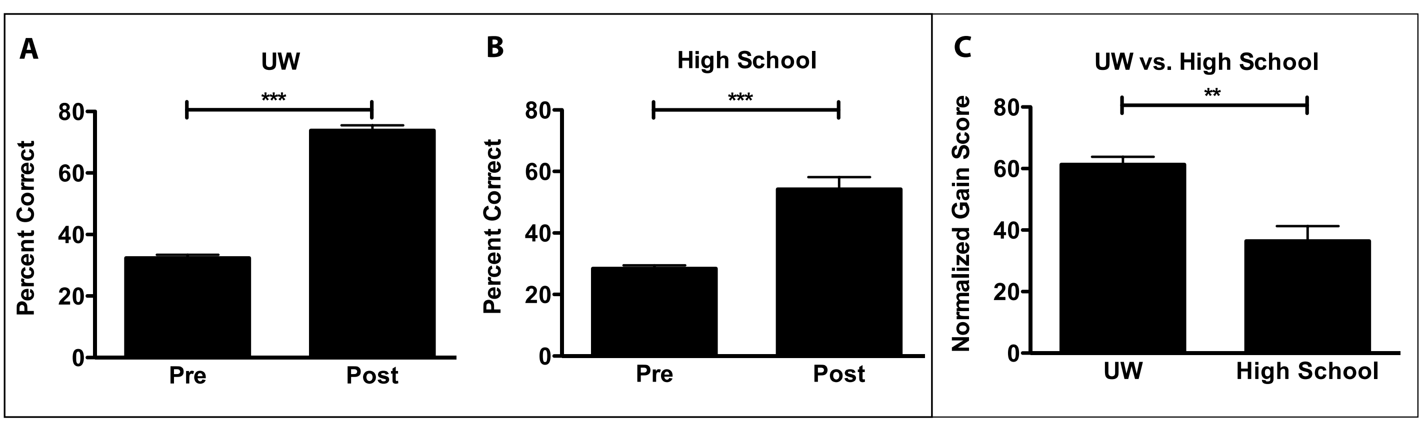

Figure 1. University (UW) students (panel A) and high school students (panel B) enrolled in The Neuroscience of Addiction demonstrated significant learning gains during the course. A survey of knowledge was administered at the start of the course (pre) and upon the course's completion (post). In panels A and B, the percent correct scores for classes was averaged and then the means were computed for all classes of each group (on vs. off campus). (n = 6 UW classes with 608 students & n = 9 high school classes with 264 students). In panel C, the normalized gains for UW students vs. high school students were compared. University students demonstrate more learning gains as analyzed by the pre- vs. post-test comparisons. *** $p<0.0003$ paired t-test with Bonferroni correction; ** $p<0.01$ student's t-test with Bonferroni correction.

college-level material, we evaluated their understanding with a pre- and post-course survey set. Knowledge questions were graded for our high school (HS) cohorts who take the class in their home schools with local teachers and for UW students (single instructor in 10 classes). UW students showed 128% knowledge improvement (from 32.38 ± 1.07 on pre-test to 73.84 ± 1.65 on post-test) while high school students demonstrated 91% knowledge improvement (from 28.43 ± 1.09 on pre-test to 54.23 ± 3.94 on post-test) [Table 4 and Figure 1A (UW) & 1B HS]. Both UW and high school students demonstrated statistically significant learning gains ($p<0.003$ paired t-tests comparing pre and post).

	UW	High School
Number of students	608	264
Number of classes	6	9
Pre-test class mean ± SEM	32.38 ± 1.07	28.43 ± 1.09
Post-test class mean ± SEM	73.84 ± 1.65***	54.23 ± 3.94***
Normalized gain score ± SEM	61.29 ± 2.54	36.46 ± 4.86**

Table 4. Pre- and post-course survey participants and their percent correct scores. Normalized gains were computed for class score averages.

To compare learning gains between UW and high school students, scores from each class were averaged and the difference between the pre and post scores was calculated and normalized as described in materials and methods. The normalized gains in knowledge scores were 61.29 ± 2.54% for UW and 36.46 ± 4.86% for high school student classes (Figure 1C). The normalized gains made by university students are significantly higher based on this survey ($p<0.01$, student's t-test).

Stimulating Interest in Neuroscience

After completion of the course, a subset of university undergraduates decide to pursue biology or neuroscience. Most students have already chosen a different major and are taking the course to meet general education requirements for graduation. Our high school student cohorts, on the other hand, are both highly motivated and have yet to select their university specialties. These students overwhelm their teachers with questions and enthusiasm for our content. Below are several teachers' comments about some of their transformed students, and a statement from one such student.

"One of my students is pursuing a course in neuroscience. It was this course that made her decide to head in that direction in college!!"

"*[One student] is very interested in a career in science/medicine and is quite the character. He's a very intelligent student but mostly I love his extreme work ethic and integrity!****"*** *(Note that this student was a 10th grader.)*

"I utilized literally every available moment to ask questions to my teacher; before school, during passing, during lunch, and after school. While taking this course, I really got interested in how drugs interact with the brain. I started considering a career path I had never known about before, and then got completely engrossed in it."

DISCUSSION

Our dissemination plan includes methods that help high school partners teach this rigorous course, both in terms of student assessment strategies and teacher training and observation.

Our undergraduate course is impacting hundreds of pre-college students and helping them to understand the science that underlies drug use, drug impact, and drug addiction. This early exposure to neuropharmacology is not unprecedented but is contained within a single university course, for which students earn credits on their university transcripts. High school students who take the course show substantial and significant learning gains as evidenced by the nearly 100% improvement on knowledge questions in a pre- and post- survey.

To our knowledge, this is the first study comparing learning between on-campus and off-campus student populations. Our results demonstrate that university students outperformed their high school counterparts in normalized learning gains (Figure 1C). Several reasons may explain the observed difference between the two student populations. First, the university students may be better prepared, both in terms of age and in that they had to meet university admissions criteria to be in the class. High school classes, however, included not only students enrolled for university credit but also their peers, who were taking the course only for high school credit. Second, university students benefited from taking the course with an instructor who has numerous years dedicated to studying the content. Lastly, university students may have an advantage over the high school students on the post-survey, which is administered after a 10-week course vs. 4-9 month course. As a result, high school students have to retain the information longer to perform on par with university students. Future studies should account for differences in students' preparedness, study skills, and demographics when comparing high school to university populations with the use of regression models (Theobald and Freeman, 2014). Parsing out which of these factors predict learning gains would strengthen the efforts to promote on-campus rigor by targeting support to students and schools who need it most.

High school students may have experienced greater variation in the content, skills, and level of assessment emphasized by individual teachers than UW students. For example, teachers chose a subset of exam questions from a bank provided to them by our course coordinator throughout the course. Although this choice may lead to variability in expectations for students, this approach gives teachers the flexibility to focus assessment on content and skills emphasized in their own classrooms. It is also conceivable that such variation in assessment may influence students' final grade in the course. However, we also measured student learning gains using identical pre-post test questions across all classes in a survey. Therefore, our data (Figure 1) describing learning gains are most likely independent of the potential variation in test bank utilization.

Students are not the only ones showing learning gains. Our high school teachers, even those who do not go on to teach this course, have been trained in neuropharmacology in a "crash course" through attendance at our summer institute. In addition to their knowledge gains (Buckland et al., in preparation), they have made significant connections both with university faculty and with each other in ways that promote excellence in student learning and access to cutting-edge research.

Additionally, in many of our partner schools, students are disseminating course content to peers outside the class through classroom visits, newsletters, and hallway posters.

In summary, the neuropharmacology coursework offered to pre-college students is rigorous, enabling students to earn college credits. It is also stimulating, providing students with previously unimagined ideas about scholarly pursuit. Lastly, it is impactful and transformative, reaching the students enrolled, their teachers, and their school-based peers with research-based information about the science of drug use and drug addiction. Many of our students became motivated to continue to pursue neuroscience coursework as college students. Although our program currently lacks the procedures to track students' educational and career choices long-term, such tracking may be a useful way to assess the impact of this course on students' future choices.

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