COMMENTARY
Input-output: The Role of Undergraduate Curriculum in Successful Graduate Training in the Neurosciences

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This article was motivated by the 2010 SfN session on Undergraduate Curricula and Graduate Expectations. To prepare for my role as panelist, I examined the background of Washington University Neuroscience Ph.D. students. Current students with a declared thesis lab were queried, and records from past graduates were reviewed to determine the characteristics that contribute to graduate success. This pilot research suggests that no specific undergraduate curriculum element or quantitative undergraduate achievement metric predicts success at the graduate level, measured by graduate GPA, years to degree, or number of publications. I extrapolate these results to suggest that students from non-typical backgrounds should not be deterred from applying to Ph.D. programs in Neuroscience. I speculate that less tangible traits may be most important for graduate success. These include critical thinking skills and independent research experience.

Key words: graduate education; undergraduate curriculum; admissions requirements; grades; GRE scores

This editorial arises from observations made as I prepared a presentation for the 2010 SfN session on Undergraduate Curricula and Graduate Expectations, organized by Richard Olivo. To prepare my remarks for this session, I drew on my own experiences as a student in the late 1980's and early 1990's, and upon my experience over 10 years (three years as chair) on the Ph.D. Neurosciences Admissions Committee at Washington University. As with all Admissions Committees, our committee spends countless hours poring over the tea leaves of undergraduate transcripts, GRE scores, essays, and recommendation letters in an effort to offer admission to the "best" applicants, those most likely to be our future star Neuroscience graduate students. What role does undergraduate curriculum play in predicting future graduate success? I think graduate educators would agree that undergraduate preparation is critical, but has the proliferation of undergraduate training programs in the Neurosciences over the last 20 years been tangibly beneficial to those students who choose Ph.D. training the Neurosciences?

From the admittedly imperfect measures of undergraduate preparation and graduate success that I was able to obtain, I concluded that the specifics of undergraduate curriculum are not correlated with success at the graduate level. Furthermore, I could find no evidence that conventional quantitative indicators of our "best" students predict graduate success. I decided to write about these observations here for a couple of reasons. First, I hope to stimulate more rigorous thinking and research on the topic. Second, I think the conclusions remind us that it is antithetical to think that we can arm an undergraduate with all of the concrete facts and knowledge that they will need for a career in research, a career whose goal is to be effective seekers of new knowledge. Certain brands of enlightened ignorance, which one essayist has termed "absolute stupidity" (Schwartz, 2008) are essential in the scientific enterprise. That is, being at the cutting edge of the unknown requires that we embrace our ignorance and act creatively to fill knowledge gaps. We want to guard against peppering undergraduate curricula with factoids from all corners of biology and neuroscience (not to mention chemistry, physics, mathematics, and psychology) at the expense of teaching core, permeating skills that are the heart of graduate study and, I would argue, also the heart of an educated citizenry. Key among these are independent research experience and coursework that incorporates critical reading, thinking, and writing.

Let me be clear that my essay is not meant as an indictment of modern undergraduate Neuroscience programs or majors. These curricula are clearly potentially great ways to introduce students to the awe and wonder of the nervous system and to the excitement of a truly interdisciplinary field. My essay is mainly meant to suggest broad guidelines for priorities in training those students who may be interested in a research career. Furthermore, my thesis implies that students who arrive at an interest in Neuroscience relatively late or who do not major in Neuroscience should not be deterred from pursuing a research career in Neuroscience.

My own undergraduate training was completed in an age prior to formal undergraduate Neuroscience majors or programs. Even had such programs existed, I doubt Neuroscience would have been my major. Psychology was my chosen major, and for my first three and a half years as an undergraduate, I waffled between the poles of the field as a social and experimental science. "Hard" science did not emerge as a strong interest until relatively late in my undergraduate work, as a result of a few stimulating experimental psychology courses. Thus, my transcript had numerous deficiencies for a career in neuroscience research. Given my late start, a full-time research assistant position for two years was a huge help in filling knowledge and experience gaps before I applied to Neuroscience Ph.D. programs. Even with this experience, I remember feeling overwhelmed by the culture and language of Neuroscience when I entered grad school, a feeling shared to varying degrees by my classmates of all levels of experience. I chose cellular neuroscience as my field, pretty far from where I started as an undergraduate. With the help of excellent mentors and colleagues along the way, I did well enough in graduate and postdoctoral training to enter a faculty position and compete for funding. I myself have now mentored three successful dissertation students in cellular neuroscience and have co-authored more than 100 original papers in the field.

Despite some measure of success in my own career, I grew curious about whether people like me who make a fairly dramatic shift in fields from undergraduate to graduate training are, on average, deficient in metrics of success in their Ph.D. program. Are undergraduates who train in Neuroscience programs at an advantage and more productive during their graduate training than students who train in more disparate fields such as Psychology? To begin to address this question, I took two approaches. First, I surveyed the population of Washington University Neuroscience Ph.D. students with a declared thesis lab. Second, I obtained the generous help of our graduate studies office in the Division of Biology and Biomedical Sciences (DBBS) at Washington University to compile data for the last decade of Washington University Neuroscience Ph.D. graduates. Although my methods were crude, I found the results thought provoking.

I was aided in analysis by the fact that my institution has a very broad Ph.D. training program. Students are allowed to choose a dissertation laboratory from more than 100 faculty in pre-clinical and clinical departments and thus can (and do) choose from among a broad selection of scientific inquiry levels covering virtually all facets of molecular, cellular, developmental, and systems neuroscience. Neuroscience faculty are housed at two campuses in departments of Biology, Psychology, Engineering, Anatomy & Neurobiology, Developmental Biology, Cell Biology & Physiology, Ophthalmology, Anesthesiology, Neurology, Psychiatry, Pathology, Pediatrics, Radiology, and others.

In Washington University's training program, students apply to DBBS, the umbrella for all graduate and M.D./Ph.D training in the biological sciences at our institution. On the application for admission, students indicate their first choice among 12 training programs. After initial screening by DBBS administration, applications with a first choice of Neuroscience are reviewed by an Admissions Committee composed of 8-10 faculty affiliated with the Neuroscience Program.

Washington University's Ph.D. Program has fairly minimal coursework requirements, essentially limited to the first year. Classes include a Molecular Cell Biology course (common with the Molecular Cell Biology Program), a course in Cellular, Molecular, and Developmental Neuroscience, and a Systems Neuroscience course. First-year students also typically rotate through three laboratories to establish their dissertation lab. As in most programs, students must maintain a B or better grade average in the coursework. Advanced coursework is optional, but several curriculum sub-pathways are available for students with a desire for additional coursework. Students are also encouraged to attend seminars and journal clubs throughout their time as students.

At the end of the first year, students take a qualifying examination. This takes the form of a mock grant proposal, with emphasis on critical review of the literature. It is written on a topic of the student's choice, often the student's intended thesis topic. There is also an oral defense of the written document. Students must pass both the written and oral components of the qualifying exam to advance to Ph.D. candidacy.

Students propose their thesis to a faculty thesis committee (chosen by the student) and hold committee meetings at approximately six-month intervals. The average time to defense of the dissertation is approximately five and a half years. The program has no formal requirement to publish, but most students publish one or more first-author original research papers. Many students successfully apply for NSF and NIH predoctoral fellowships, which come with a slightly supplemented stipend.

Surveyed students for this study had passed their coursework and qualifying exams and had actively begun their thesis work. There were 27 anonymous respondents to the survey. The questions are given here as supplemental material. When asked about their undergraduate training (questions 2 and 3), more students said that they had a weak (N = 17) undergraduate background in cellular/molecular neuroscience than a strong background (N = 10). Respondents were similarly divided in self-report of strength of their systems neuroscience background (N = 15 weak, 12 strong). This seems to be because most of our students come to our Program with a traditional biology, psychology, or physical sciences major or background (survey question 1 and below). Many students reported being happy with their undergraduate training (survey question 9, Figure 1), but a majority would have taken more coursework in something as an undergraduate. That something was relatively evenly split among cellular neuroscience, systems neuroscience, and quantitative/physical sciences coursework (Figure 1).

I asked students about how students' backgrounds influenced their academic success and in their perceived success with their dissertation project. When asked about their success in courses and qualifying exams, a slight majority of students credited their hard work in filling their knowledge gaps rather than their undergraduate coursework (question 5, Figure 2). With regard to dissertation work, 17 of the 27 students reported that their dissertation was not well matched to their undergraduate coursework (question 6, Figure 2). None of these students felt that their dissertation was harmed by the mismatch (question 7, Figure 2). Most felt that the mismatch was irrelevant. A few felt that their mismatched dissertation work was actually helped by cross-pollination from their undergraduate field (Figure 2). Furthermore, the nine students who ranked their training "weak" in both cellular neuroscience and systems neuroscience felt that

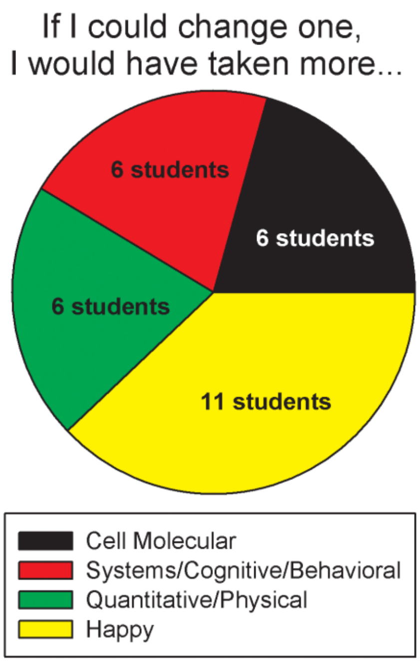

Figure 1. Results of survey question 9. Satisfaction of Washington University graduate students with content of undergraduate curriculum.

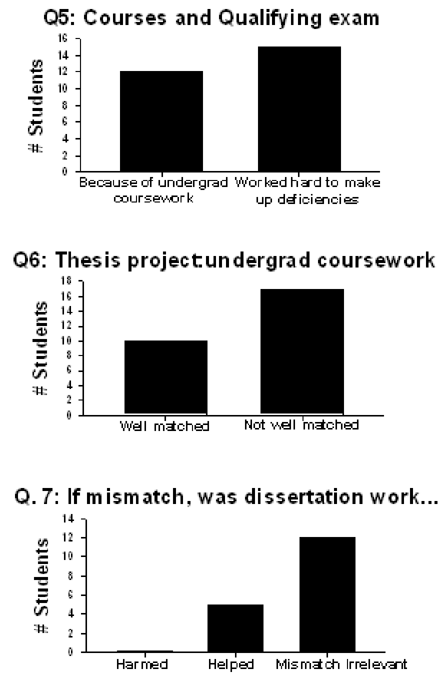

Figure 2: Effects of undergraduate curriculum on academic performance and dissertation work, assessed by survey questions 5-7, as follows (complete survey is supplemental).
5. I passed my 1st year graduate courses and qualifying exam(s) (please force yourself to choose the one that best represents your overall experience)
□ Because of my undergraduate coursework preparation
□ Despite my undergraduate coursework preparation; I passed because I worked hard to make up deficiencies in my background
6. I feel that the topic of my undergraduate coursework
□ is well matched to my dissertation project
□ is not well matched to my dissertation project
7. If your undergraduate coursework was not well matched to your dissertation work, do you feel that
□ My dissertation work has suffered as a result.
□ I see the mismatch as irrelevant.
□ My dissertation work has been improved by the cross-pollination.

undergraduate curriculum was only modestly important for eventual success in their dissertation work (4.1 ± 0.3 rating on question 8). This average rating was statistically not different than that of students who reported strong training in at least one component of neuroscience (3.8 ± 0.4 on question 8, $p = 0.5$). The four students who rated themselves "strong" on undergraduate training in both cellular and systems neuroscience also gave a similar ranking (4.3 ± 0.8 on question 8). Therefore, although students felt that there were gaps in their background relative to the topic of their dissertation project, they didn't feel that these gaps were particularly important to success on their project.

Although the perceptions of students currently in graduate training are an important snapshot perspective, what do more objective data over a longer horizon show? For this, I turned to records kept by our Division of Biology and Biomedical Sciences, the umbrella administration covering Washington University's Ph.D. and M.D./Ph.D. training programs in biology-aligned disciplines. From these records, I divided our 63 Neuroscience graduates over the last 10 years into three undergraduate groups: traditional science majors (including engineering and computer science, N = 39), neuroscience/neurobiology majors (N = 11), and psychology/psychobiology majors (N = 13). I used three outcome measures of success: graduate school GPA, years to completion of the Ph.D., and number of student-authored publications. For none of these measures was there a suggestion that undergraduate major participated in graduate outcome or success (Figure 3).

Does this lack of apparent impact reflect a tendency of our graduates to perform dissertation work that is closely aligned with their undergraduate field? The survey of our current students suggested that students do not necessarily choose dissertation labs closely aligned to their undergraduate field. However, to address this possibility among graduates of our program, I looked at undergraduate major of each graduate of our program and at the dissertation lab in which the student performed his or her research. Based on the primary level of inquiry of the dissertation lab, I assigned a binary designation to each student as "matched" (N = 33) or "unmatched" (N = 30). Again, I found no indication that matching one's graduate work to undergraduate curriculum had a detectable influence on success measures in graduate education (Figure 4). Incidentally, I also found no correlation between any component of GRE scores or undergraduate GPA and these measures of graduate success.

I also examined the undergraduate records of students who left our Program during graduate studies, either voluntarily or involuntarily (N = 8). I found nothing in their records that would have predicted that they would/could not complete the Ph.D. Among these students were two

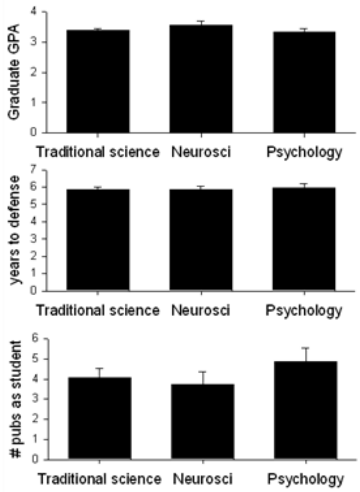

Figure 3. Effect of undergraduate major on measures of success as a graduate student. Graduate GPA (top), years to defense (middle), and total publications as a student (bottom) are plotted for the three undergraduate majors shown. See text for additional details.

neuroscience majors, one biology/psychology major, three biology majors, one chemistry major, and one pre-medicine major. Average undergraduate GPA and GRE scores were no different than the sample of 63 Ph.D. graduates.

Taken at face value, the data would seem to suggest that the subject matter of undergraduate curriculum is not an important predictor of future graduate success. I would argue that this is because the essence of success at the graduate level is learning to deal with the unknown, a skill that can be fostered by many undergraduate majors. A base knowledge level is of course critical for identifying and developing compelling research questions. Furthermore, most would agree that strong quantitative skills are extremely important for graduate work and difficult to acquire on one's own initiative later. However, an active scientific field's fact-based knowledge content and technologies are constantly changing as new information and approaches are accumulated. Therefore, a purely content-driven curriculum could end up doing a disservice to graduate school-bound students. Proactive self-starters with strong passion, work ethic, and confidence navigating uncharted waters are those most likely to do well at the graduate level and beyond. To promote these skills, coursework in any field that encourages critical reading of primary literature and opportunities for independent thought and research are of top priority.

My opinions and interpretations arise from data, but can we really take the data at face value? Probably not. Astute critical readers may already have identified deficiencies in both the independent and the dependent variables used to develop my arguments. For instance, undergraduate major, used in Figures 3 and 4 to categorize students, is probably not a satisfactory proxy for undergraduate curriculum. There are plenty of psychology majors who take strong biology curricula, and this select population of students may be the ones most likely to matriculate into a graduate Ph.D. program. The outcome measures I was able to obtain are also imperfect. The

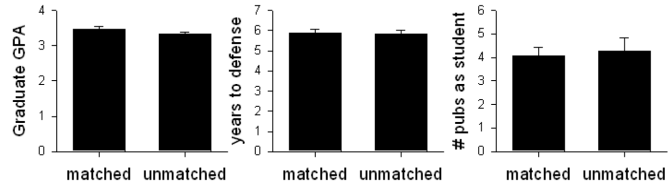

Figure 4. Effect of undergraduate major that was well matched or unmatched to dissertation lab's primary level of inquiry on the same outcome measures shown in Figure 3. See text for additional details.

number of papers published as a grad student is a tangible outcome and has real-world validity, but my metric of total publications did not account for first-authorship or for the impact of the work. Graduate GPA is likely to be a compressed metric with poor dynamic resolving power, since students must maintain a B or better average to meet our Program requirements. These and other deficiencies are why this essay rises to the level of an editorial but not to a peer-reviewed study.

Despite the deficiencies, I think that the complementary pictures offered by the self-report of current students and the more objective query of Program graduates are compelling. The implications resonate with my personal experiences as a student, with my experiences training students in my own lab, and with my experiences on a Ph.D. Admissions Committee. Undergraduates who come to adopt neuroscience and a passion for research relatively late should take heart. If they are persistent in efforts to convince a Ph.D. Program to accept them, there seems to be no indication that they are at a fatal disadvantage that hard work and perseverance can't correct. Among their top priorities should be to convince the Admissions Committee that in addition to possessing a requisite intelligence level, they know and understand the joys and frustrations of full-time bench research and have the passion and fortitude to see the mission through (Chenevix-Trench, 2006). For faculty designing undergraduate neuroscience curricula, the reminder is that no content-based curriculum can be or should be all inclusive. My personal belief is that because the essence of Ph.D. training is to create independent thinkers who can push the boundaries of current knowledge (Schwartz, 2008), students destined for a research path will be best served if their undergraduate preparation arms them with critical thinking skills and independent research experience to facilitate pro-active auto-pedagogy at the graduate level and beyond.

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