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ARTICLE

Strategies for Fostering Synergy between Neuroscience Programs and Chemistry Departments

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The successful model of the Neuroscience Program at Concordia College is used as a source of illustrative examples in a presentation of strategies to foster synergy between neuroscience programs and chemistry departments. Chemistry is an increasing voice in the dialog of modern neuroscience. To be well-prepared to engage in this dialog, students must have strong chemistry training and be comfortable applying it to situations in neuroscience. The strategies presented here are designed to stimulate thought and discussion in the undergraduate neuroscience education community. Hopefully this will lead to greater interaction between chemistry and neuroscience at the undergraduate level in other institutions.

Key words: Chemistry Departments; Neurochemistry major; Neuroscience programs

Neuroscience is truly an integrative discipline (Snyder, 1984; Lewis, 2006) and chemistry is playing an increasing role within the field. The modern problems in neuroscience for which we, as a community, are sending forth our students to solve are becoming more physically based. Chemists have made significant contributions to neuroscience throughout its history by offering much insight into the molecular basis of neural function. With the development of sophisticated instrumentation and a growing understanding of biological chemistry, chemists are playing an even larger and more significant role in the interdisciplinary dialog required to tackle problems in neuroscience. Chemical understanding of elusive problems in neuroscience is increasing every day. Pushing the frontier of our understanding of the brain, conquering neurological disorders, and addressing issues such as mental illness and addiction will require a significant and active role for the field of chemistry. One needs only to take a moment to survey the landscape of activity in the chemical literature to fully appreciate this. Indeed, the American Chemical Society (ACS) publishing group launched the journal *ACS Chemical Neuroscience* in January of 2010 to "serve as an international forum for the dissemination of important research in all areas of neuroscience" (Lindsley, 2010). Neuroscience topics have captured the interest of chemists in all subfields. Primary research articles abound in analytical, physical, organic, inorganic, and, of course biochemistry journals. We list here several recent review articles. Analytical chemists are keenly interested in determining methods for detecting neurotransmitters (Robinson et al., 2008; Perry et al., 2009) and in separating compounds important to neural function (Lapainis and Sweedler, 2008). Physical chemists employ spectroscopic methods to induce and monitor calcium responses in cells (Warther et al., 2010). Both organic and inorganic synthetic chemists produce a myriad of organic (Treweek et al., 2009; Trauner, 2010) and inorganic (Little et al., 2008; Nolen and Lippard, 2009) molecules of neural significance.

With this trend in the chemical literature, our community should actively work to increase the presence of chemistry and chemists in undergraduate neuroscience programs. The unfortunate present reality has a limited participation by chemists. Indeed, Wiertelak and Ramirez report neuroscience as being nested in psychology or nested in biology in their blueprint for undergraduate neuroscience education in the 21st century (Wiertelak and Ramirez, 2008). The thought of neuroscience nested in chemistry is not seriously considered because it is rare to find undergraduate chemistry faculty fully engaged and committed to neuroscience programs. Chemistry is included in the blueprint but only in a passive role as cognate courses in general, organic and biochemistry. This lack of chemistry involvement is evident by considering the demographics of the Faculty for Undergraduate Neuroscience (FUN) membership list on the FUN website. Of those reporting a home department, only 1.4% of listed members are from chemistry departments. Similarly the participants list from the 2008 FUN/PKAL *Faculty for Undergraduate Neuroscience Workshop* reveal three of 89 are chemistry or physics faculty.

Based on what has been discussed so far, a well-prepared student will necessarily need a strong understanding of chemical principles to participate in the full range of careers in neuro-related fields. While this need can be addressed by advising our students to simply take as much chemistry (and physics and mathematics for that matter) as their schedules will allow, it is perhaps more valuable to think about ways in which chemistry departments and neuroscience programs can work with one another for the benefit of both programs. Chemistry can play a much more active role in neuroscience programs. The goal of this paper is to provide some strategies along with examples of how to engage chemistry departments and individual faculty members in dialogue that can enhance collaboration. This collaboration can be mutually beneficial to both chemistry departments and neuroscience programs. We use our program as an illustration of how this might take place.

The Neuroscience Program at Concordia College had a relatively rare genesis. Although it cannot be said that our program is nested in chemistry, the Chemistry Department is an equal contributor with the Psychology and Biology Departments within the program. Key faculty in the development of the program (and in the current program) are members of the Department of Chemistry and the current authors: A physical chemist (current chair of the Chemistry Department) and a pharmacologist (current chair of the Neuroscience Program). Although this is rare among the colleges similar to Concordia that we have studied, we feel that reporting on the origin and nature of our program will be valuable to the undergraduate neuroscience community.

The purpose of this work is to share with the undergraduate neuroscience community strategies for building synergy between chemistry departments and neuroscience programs beyond simply having biochemistry as an elective and the occasional hallway conversation with the biochemists. We are hopeful that this paper will stimulate conversation at other institutions and throughout the undergraduate neuroscience community. Within the context of this, we will provide information about the Neuroscience Program at Concordia College; specifically about connections between Chemistry and Neuroscience. Hopefully the commentary on our program will provide concrete examples for readers to consider and adapt to the needs of their programs.

THE NEUROSCIENCE PROGRAM AT CONCORDIA COLLEGE

Concordia College is a mid-sized college with an enrollment of approximately 2700 students. The College offers some professional programs but is primarily a liberal arts college with a strong Core Curriculum based upon the theme of “becoming responsibly engaged in the world.”

The Chemistry Department consists of seven full-time faculty whose specialties cover the major subfields of chemistry: analytical, biochemistry, inorganic, organic, and physical. In a typical year the department graduates approximately 20 majors. Approximately a third of these go to graduate school, about half go to medical school and the remainder enter into various jobs.

Serious effort towards establishing the Neuroscience Program and the attendant minor at Concordia College began in the spring of 2004 when two faculty members from Chemistry and one from Psychology teamed up to develop a proposal for a minor in neuroscience. A member from the Biology faculty joined the team shortly after that. The spirit among the development team was to build a program with significant physical science foundation; particularly chemistry. An extensive web-based investigation of existing programs at institutions similar to Concordia College and a separate email survey of graduate program directors left the team with a strong sense that our program—heavily integrated with chemistry—was unique and valuable. For the web-based investigation, it was found that 33% (20 of 60) of “Tier 2” liberal arts colleges (as per US NEWS rankings) offer a neuroscience program. Roughly half of the neuroscience programs at colleges similar to Concordia have independent neuroscience courses, usually with a neuroscience designation. Of these, most have an introductory course and possibly a seminar course. Taking select courses from the Psychology department, Biology department, and to a lesser extent the Chemistry, Physics, and Philosophy departments completes the rest of the program requirements. Though some neuroscience programs do offer chemistry electives, none included chemistry faculty within the program. In addition, the chemistry courses offered in these neuroscience programs are those that many students would take for biology or chemistry program requirements.

To learn more about the needs of graduate programs, a brief e-mail survey was conducted by a member of our neuroscience team in which 15 chairs of neuroscience graduate programs (chosen at random from the ANDP website) were asked what education and training they hoped their students had attained by the time they started graduate school. Five helpful responses were received. Answers confirmed that a neuroscience program integrating education in the physical sciences would serve students well in graduate school; all respondents indicated that experience in chemistry, particularly biochemistry, as well as other physical sciences courses are desirable for entering graduate students. Respondents also noted that a strong background in biology and undergraduate research experience were important contributors to success in graduate school. One respondent mentioned that experience in cellular electrophysiology at the undergraduate level would be helpful to students as this is one area with which graduate students often have the most difficulty.

The 2005 PKAL/FUN workshop on neuroscience programs provided key insight and wisdom to help mold the program and build momentum towards ratification of the minor by the College. Key administrative support led to separate hires in Psychology and Biology. These new hires have rounded out a strong core of faculty upon which the Neuroscience Program rests. Ratification by the college senate of the minor occurred in February of 2007. The Neuroscience Program has seen steady growth since that time. A single student graduated with the minor in 2007 and seven graduated in May of 2011. There are currently 32 students whom have declared a neuroscience minor across all academic years.

Four new courses were created during the development of the Neuroscience Program: Introduction to Neuroscience, Neurobiology, Physical Neuroscience, and Neurochemistry. The last two of these four are briefly described here for later reference. Physical Neuroscience, a sophomore-level course offered every other spring semester, exemplifies the emphasis on physical science within that program. Four main topics are covered: action potential (voltage-gated channel dynamics and Hodgkin-Huxley equations), neurotransmitter release (SNARE complex structure and dynamics, calcium sensing, and protein regulation), neurotransmitter reception (ligand-gated channel structure and dynamics), and long-term potentiation (protein regulation of NMDAR dynamics and

AMPAR recruitment). Physical Neuroscience is an elective in the neuroscience major. The prerequisite for Physical Neuroscience is Introduction to Neuroscience.

Neurochemistry is an upper level (junior/senior) course that is offered every year. This course covers the neurochemical events underlying neural signaling, synaptic transmission, signal transduction, and neurodegenerative diseases. Neurochemistry is a unique course for a variety of reasons. It is required for the Neuroscience minor and for the ACS Neurochemistry major (described below). It also serves as an upper level elective for the regular (non-ACS) chemistry major. Furthermore, it serves as a capstone course for the college Core Curriculum. Because Neurochemistry has several points of entry, the prerequisite is consent of instructor who evaluates the background of each student individually. Table 1 outlines the Neuroscience minor at Concordia College.

○ **NEU 109 (with lab) - Introduction to Neuroscience, 4 credits**
○ **NEU 400/BIOL 400 - Neurobiology OR PSYC 319 - Behavioral Neuroscience, 4 credits**
○ **NEU 475/CHEM 475 - Neurochemistry OR PSYC 324 - Drugs and Behavior, 4 credits**
○ **NEU 406 - Senior Seminar, 2 credits**
○ **4 additional course credits at least one course from the following**
NEU 252 - Physical Neuroscience, 4 credits
NEU 328/PSYC 328 - Human Neuropsychology, 4 credits
NEU 380 - Special Topics, 1 to 4 credits
NEU 475/CHEM 475 - Neurochemistry, 4 credits
○ **4 additional course credits; at least one course from the following:**
BIOL 306 - Human Anatomy and Physiology, 4 credits
BIOL 345 - Molecular Biology, 4 credits
BIOL 380 - Animal Behavior, 2 to 4 credits
BIOL 415 - Genetics, 4 credits
CHEM 373 - Biochemistry I, 4 credits
CHEM 374 - Biochemistry II, 4 credits
PSYC 318 - Learning and Behavior, 4 credits
PSYC 319 - Behavioral Neuroscience, 4 credits
PSYC 323 – Perception, 2 credits
PSYC 361 - Cognition Psychology, 4 credits
Required supporting courses:
○ **BIOL 101 - General Biology OR BIOL 121 - Vertebrate Biology, 4 credits**
○ **CHEM 142 - Survey of Organic and Biochemistry OR CHEM 373 - Biochemistry I, 4 credits**
Total: 30 credits

Table 1. Requirements for a minor in neuroscience at Concordia College; bold type signifies required components of the minor.

AVENUES FOR SYNERGY WITH CHEMISTRY DEPARTMENTS

Although it is easy to buy into the idea that the integration of chemistry into an existing neuroscience program is beneficial, there are often many roadblocks to having this occur in practice. One counter-example to this can be found in the chemical education literature where Uffelman et al. have developed an NMR lab for General Chemistry I in consultation with their Neuroscience Department (Uffelman et al., 2003). Given the nature of the program at Concordia College and the make-up of its faculty, we feel we can provide some helpful insight into overcoming some of the obstacles that hinder significant involvement of chemistry departments in neuroscience programs.

Channels of Communication

Establishing communication channels between chemistry and neuroscience faculty is a critical first step in developing a plan for concrete initiatives. Concordia College has the fortuitous situation where active members of the Neuroscience Program are members of the chemistry faculty. This allowed for the program to develop from its infancy with the spirit of integrating chemistry strongly embraced. Many institutions do not have this natural conduit of communication. However, relatively simple actions can greatly improve communication between programs. An obvious strategy is to suggest inter-department meetings to gauge interest. From there, strategic members of the Chemistry Department could be identified to form a working group. These meetings are an excellent opportunity to share how neuroscience is such a fruitful ground for placing many basic chemical concepts into modern applications. These conversations could be followed with summer round-table discussions or workshops with an eye for producing concrete products that connect the programs. These products can range from problems for homework assignments, to guest lecture arrangements, to an integrated lecture or lecture series on neurochemistry. By way of example, in the Physical Chemistry course at Concordia (enrollment of approximately 20), students receive a self-study workbook entitled "Physical Chemistry Applied to Neuroscience" (Ulness, 2006). Sections of this workbook are assigned as part of the weekly problem sets. This has the effect of showing chemistry students, many of whom are interested in the life sciences, that physical chemistry underlies many of the processes in neuroscience. Additionally, it potentially sparks an interest in neuroscience among more physical science minded students.

One might anticipate that the biochemists or organic chemists would be the key contact within chemistry departments for interaction with neuroscience programs. For example, the organic chemists might be inspired by a recent review discussing Schiff-base chemistry; particularly the enamine mechanism for sterioselectivity and the Maillard reaction for forming advanced glycation end products (Treweek et al., 2009). This review could provide a working example in a lecture or problem set which connects what the students are learning in organic chemistry with the applied area of treatment for drug abuse. Nonetheless, the other specialists also should be considered such as faculty teaching in well established content fields who are actively looking for modern application of their material. These applications help impress upon the students the value of learning that particular material. For example, a difficult technical challenge in modern analytical chemistry is *in-situ* measurement of biological molecules (Robinson et al., 2008). Neuroscience naturally fits into this as analytical chemists are very interested in developing techniques to measure, for example, neurotransmitter release into synapses (Robinson et al., 2008). These methodologies involve techniques that are taught as standard content in analytical chemistry. Also, the area of bio-inorganic chemistry continues to accelerate. Developing catalysts for drug design or constructing metal-ligand complexes to act as biosensors (Nolen and Lippard, 2009) are just two areas where an inorganic chemist could envision connecting with neuroscience in his/her course. Finally, many of the basic physical models for kinetics and thermodynamics that have been taught for 30 – 40 years in Physical Chemistry are being employed by neuroscientists to describe the basic physics underlying many neurological processes. These range from the movement of ions through channels, to gating kinetics, to calcium diffusion dynamics (Hille, 2001). These are some of the topics of conversation one might have with the various chemistry faculty. Again, applications that are modern, employ the topics of the course, and resonate with today's students will be very attractive to chemistry faculty.

Neurochemistry Tracks

Of course, chemistry departments need to serve their field first and foremost. Consequently, initiatives that conflict with or drain students and/or resources from the chemistry curriculum will not gain much traction among the chemistry faculty. So focus should be on initiatives that will be mutually beneficial to both the chemistry and neuroscience curricula. It is counter-intuitive but we see one of the potentially easiest and most significant initiatives to develop is an American Chemical Society (ACS) chemistry major in Neurochemistry. If a strong neuroscience program exists, as is probably the case for most readers, and the Chemistry Department is ACS approved, it is relatively simple to construct an ACS track in Neurochemistry. Indeed, the most significant synergistic initiative at Concordia was the creation of a Neurochemistry track within the ACS chemistry major (Ulness and Mach, 2010). See Table 2 for details. This was made possible because the ACS recently changed its guidelines for approved departments to construct ACS chemistry degrees. Under these new guidelines, students take foundation courses where they must receive the equivalent of one semester of material from each of the subfields of chemistry. Students must also take at least four in-depth courses, which build upon the foundation courses. The new guidelines were adopted by the ACS to provide greater flexibility in the ACS major and to allow individual departments to use their creativity in developing a curriculum. In that regard, there exists the freedom to develop "tracks" within the ACS major (ACS Committee on Professional Training, 2008) that best meets the needs of their students and plays to the strength of the department. These tracks may also incorporate courses from other departments. For example, a track in chemical ecology might include several advanced biology or environmental science courses among its requirements. The Chemistry

ACS-Traditional	**ACS-Neurochemistry**
Intro Chemistry (8 credits)	
○ CHEM 127-128 – General Chemistry I and II, 4 credits each OR CHEM 137-138 – Honors General Chemistry I and II, 4 credits each	○ CHEM 127-128 – General Chemistry I and II, 4 credits each OR CHEM 137-138 – Honors General Chemistry I and II, 4 credits each
Foundation Courses (20 credits)	
○ CHEM 330 – Analytical Chemistry I, 4 credits ○ CHEM 341 – Organic Chemistry I, 4 credits ○ CHEM 351 – Physical Chemistry I, 4 credits ○ CHEM 373 – Biochemistry I, 4 credits ○ CHEM 462 – Advanced Inorganic Chemistry, 4 credits	○ CHEM 330 – Analytical Chemistry I, 4 credits ○ CHEM 341 – Organic Chemistry I, 4 credits ○ CHEM 351 – Physical Chemistry I, 4 credits ○ CHEM 373 – Biochemistry I, 4 credits ○ CHEM 462 – Advanced Inorganic Chemistry, 4 credits
In-depth courses - required	
○ CHEM 342 – Organic Chemistry II, 4 credits ○ CHEM 352 – Physical Chemistry II, 4 credits ○ CHEM 431 – Analytical Chemistry II, 4 credits	○ CHEM 342 – Organic Chemistry II, 4 credits ○ CHEM 374 – Biochemistry II, 4 credits ○ CHEM 475 – Neurochemistry, 4 credits ○ CHEM 490 – Introduction to Research, 4 credits
In-depth courses – elective (4 credits)	
○ CHEM 344 – Spectroscopy, 4 credits ○ CHEM 374 – Biochemistry II, 4 credits ○ CHEM 445 – Organic Chemistry III, 4 credits ○ CHEM 475 – Neurochemistry, 4 credits ○ CHEM 490 – Introduction to Research, 4 credits	○ CHEM 344 – Spectroscopy, 4 credits ○ CHEM 352 – Physical Chemistry II, 4 credits ○ CHEM 431 – Analytical Chemistry II, 4 credits ○ CHEM 445 – Organic Chemistry III, 4 credits
Supporting courses	
○ MATH 121-122 – Calculus I and II, 4 credits each ○ PHYSICS 111-112 – General College Physics I and II, 4 credits each OR PHYSICS 128-211 – Physics for Scientists and Engineers I and II, 4 credits each	○ MATH 121-122 – Calculus I and II, 4 credits each ○ PHYSICS 111-112 – General College Physics I and II, 4 credits each OR PHYSICS 128-211 – Physics for Scientists and Engineers I and II, 4 credits each
Additional required courses	
○ CHEM 403, 404 – Senior Seminar I and II, 1 credit each	○ NEUR 109 – Introduction to Neuroscience, 4 credits ○ NEUR 252 – Physical Neuroscience, 4 credits ○ CHEM 403, 404 – Senior Seminar I and II, 1 credit each
Total credits: 62 credits	**Total credits: 74 credits**

Table 2. ACS tracks in chemistry at Concordia College.

Department at Concordia College embraced this spirit in developing a track in Neurochemistry (Ulness and Mach, 2010). (At Concordia College, the track is officially referred to as a concentration to allow consistency for the registrar.)

Both the Neuroscience Program and the Chemistry Department have benefited significantly from the development of this track. Neuroscience has benefited by effectively getting a "professional major," albeit specific to neurochemistry. Although these students are not counted among neuroscience minors, they occupy upper level neuroscience courses and contribute in very significant ways to the intellectual atmosphere of the Neuroscience Program. Chemistry has seen a nearly immediate increase in declared ACS majors of roughly two students per grade level. (Although this seems like a small number it is very significant in that it amounts to a 50% increase over the historical average.) The reason for the increase in students is that it has created a rigorous major that is an exciting area for the chemistry majors who are life-science minded. Chemistry departments are often very concerned about the number of ACS majors because it is these students who populate upper level courses. Increasing the number of ACS majors can relieve administrative pressure to cancel low enrollment courses. Also, ACS students are most likely to be interested in research and they often contribute in a very positive way to the atmosphere of the Chemistry Department. For these reasons, chemistry departments may be very attracted to the idea of teaming up with neuroscience programs to construct ACS tracks in Neurochemistry. Working together with chemistry departments on an ACS track might well garner administrative support for new courses that will serve both programs.

Administrative Support and the Liberal Arts

Administrative support is critical for implementing initiatives in general, and this is certainly true for those initiatives envisioned between chemistry and neuroscience programs. A vibrant neuroscience program generally infers that at least some administrative support is present. We focus here on the more subtle issue of matching the synergistic initiatives with the college mission or strategic plan. In particular, we consider developing initiatives in the context of a liberal arts environment. Neuroscience is beautifully matched with the liberal arts as the field itself is one of the remaining frontiers of science where several previously independent disciplines have been integrated into one. Therefore, neuroscience must be approached from multiple perspectives to understand how the brain and nervous system function to mediate behavior. At many institutions, chemistry departments find themselves faced with a responsibility to contribute to the Core Curriculum. This is often done in a trivial way by offering non-majors courses in general chemistry. However, this need to serve the Core Curriculum can be used as an opportunity to benefit both Chemistry and Neuroscience.

An example of how an important component of chemistry-neuroscience interaction can also serve the liberal arts goals of the college is the Neurochemistry course at Concordia. This course was recently approved as a core capstone experience. At Concordia, some of the criteria for a capstone course are to address issues of global concern and be writing intensive. From a global perspective, the World Health Organization states that mental and neurological disorders are highly prevalent, and the burden placed on the global community is large and increasing. Students in Neurochemistry appreciate how solving these problems is dependent on multiple perspectives and that effective communication of that knowledge is imperative. To provide a writing intensive experience, students in Neurochemistry are to summarize assigned primary literature articles in 1-2 page papers, targeting non-science peers. Students appreciate the difficulty in relating the technical information to a broad audience and gain experience in the communication that will be important and necessary to lessen the burden placed on communities due to mental and neurological disorders. Finally, students in the Neurochemistry course are actively engaged in the reading, research, writing and presenting of scientific work which is fundamental to the work of a scientist and a liberally educated person. In addition, much of the assessment of the student work is through peer assessment which models the scientific community's own evaluation and critique of new findings. An exciting aspect to the course is the creation and maintenance of a Neurochemistry wiki in which the students contribute content in a way that will ultimately produce a course "textbook". This has been a valuable way for students to access and evaluate multiple sources of information as they find answers to questions; critically critique content, and utilize the information in an ethical way. Hence, one can utilize the very nature of neuroscience itself to connect with the college core curriculum.

Faculty Development

Inherently, any initiative will require some level of faculty development on the part of the neuroscience as well as the chemistry faculty. Overcoming a lack of expertise in the science itself is perhaps the most time-consuming issue in faculty development. Two models, both of which involve using the literature, have been adopted at Concordia which help with this issue. The first of these is employed in Physical Neuroscience during the development of problem sets. Here a paper is deconstructed into a problem or group of problems. This can be thought of as "inverting an application" where the essential chemical/physical calculations are pulled from a paper. As an illustrative example, say the goal is to have students work mathematically with the Nernst equation and to understand the results physically. After some straightforward Nernst equation problems, a set of problems could be based on a paper on the chemical events within the suprachiasmatic nucleus that contribute to circadian rhythm. One might summarize the paper within the text of the problem and call upon the students to perform Nernst calculations based on the oscillating chloride concentrations. A second part of the problem can ask the students to reflect on how their results are consistent with the information presented about circadian rhythm. The Appendix offers another illustrative example and shows a specific problem asked in the homework for Physical Neuroscience. While this inverted application procedure allows the instructor to pull a specific chemistry-based computation or argument out of a paper, the viewpoint of the student is different. For them, it is an opportunity to see chemistry in a neuroscience context and to develop the sense that chemical principles underlie much of modern neuroscience. From the perspective of the chemistry faculty, an advantage of placing applications into problem sets deals with course content. Unlike neuroscience, the long history of chemistry education along with ACS expectations has established a relatively standard content demand on all of the general and foundational courses in chemistry. Because of this, there is much less flexibility in course content, which makes it challenging to bring neuroscience examples into chemistry courses. The problem sets are an effective solution to this issue.

Papers also are used in Neurochemistry where the students become the "experts" on the topic of the paper. In an upper level, interdisciplinary course such as Neurochemistry, the co-learner model is very valuable (Dinan and Frydrychowski, 1995; Hodge, 1999). The primary literature provides the content for this course. Three class periods are devoted to each article, with the last day being a class discussion on the article. Each week on the first day of class, topics that need to be reviewed are identified and assigned to each member of the class to research, present and even teach during the next class period. In this way, many topics are covered and reviewed, but the faculty is not necessarily doing the teaching. For behavioral assays, the psychologists in the class are asked to review the paper; for molecular techniques, the biologists are asked; and so on. In this way, each student brings their own expertise to the class and building these "review days" into the course eases the burden on the faculty with respect to the course content. Students also benefit from the experience of presenting material in an interdisciplinary setting.

Another option for overcoming a lack of expertise is to use a guest lecturer. Small steps to incorporating more chemistry might simply be to invite a faculty member to share or present on a particular neuroscience topic. This can still be a valuable way to show the integrative discipline nature of the field and how different perspectives allow an even more complete understanding of the material.

Student Perspective

Much of what has been discussed involves formulating connections with chemists or integrating more chemistry into neuroscience curricula. From the standpoint of the students, the two biggest student issues at Concordia College are apprehension about taking chemistry and a compartmentalization of fields such that chemistry, math, neuroscience, etc. are viewed as completely separate courses. It is likely not presumptuous to assume these are universal sentiments seen at all institutions. So the challenging goal is to relieve fear of chemistry and math and bolster confidence in their abilities to employ concepts from these fields in their neuroscience studies. Further, the more the curriculum can integrate chemistry (and mathematics) into neuroscience, the easier it is for students to see that chemistry is a necessary component for addressing modern problems in neuroscience. This point was driven home by an unexpected result that occurred in the Physical Neuroscience course. The course was expected to be primarily populated by those neuroscience minors who were also chemistry or physics majors. On the contrary, the course typically has half or more of its population filled by psychology majors. Hence, the original thought for the course was to serve those students who are more physical science minded, but the course now focuses on those students who are entering the program from the behavioral side. These students have a much more limited experience with solving problems of a physical nature. This course broadens their ability to do so. Course evaluation information supports the conjecture that Physical Neuroscience students with stronger behavioral but weaker chemical/mathematical backgrounds benefit from this type of course. The response from this cohort of students has been very positive; again indicated through course evaluations. From a pedagogical point of view the course is problem set driven much like courses in chemistry but it also contains a component where students give a lecture on a topic of their own interest. This occurs in the last few days of the course and the students are expected to incorporate the basic physical principles they have learned about during the course.

Both Neuroscience and Chemistry have their own intellectual atmosphere which is shaped by the interest and passion of the students within each program. However, we have experienced a melding of these atmospheres that is unique in and of itself. This is most noticeable during interdisciplinary seminars when Chemistry and Neuroscience populations come together. We have experienced this to be extremely positive and stimulating.

Academic Advising

Finally, another important synergy exists within the advisement process at Concordia College. The neuroscience minor is well understood by all the chemistry faculty advisors. Often students are encouraged to consider the neuroscience minor as a complement to their chemistry major. This is particularly true for pre-pharmacy students. Additionally, the neuroscience minor is explicitly included in the "Chemistry interest meeting" during freshman orientation. Conversely, the chemistry major is featured explicitly during the "Neuroscience interest meeting" as well. The goal is to create the mindset, very early on, that chemistry is as important a contributing field to the integrative discipline of neuroscience as are biology and psychology. We mention the advisement process at Concordia College to illustrate how simple communication can be very effective in elevating the interplay between chemistry and neuroscience in the minds of the students. The earlier and more pervasive this is, the more effective it will be in breaking down the natural compartmentalization fields on the part of the students.

CONCLUSION

Concordia College has certainly experienced the benefits of the synergy between the Neuroscience Program and the Chemistry Department. This synergy has been mutually beneficial to the curriculum, students, and faculty of both programs. It afforded new courses to be developed which have served a multitude of purposes. The ACS track in Neurochemistry was conveniently established because of the Neuroscience Program and this, in-turn, effectively provided the Neuroscience Program with a major itself.

Obviously, serendipity of personal interest among the faculty fostered the degree of synergy at Concordia. Nonetheless, we hope the examples set forth here will help stimulate discussions at other institutions and throughout the undergraduate neuroscience community about how chemistry departments can play a larger and more important role in neuroscience programs. Surely this will benefit undergraduate neuroscience education in this country and consequently the neuroscience community as a whole.

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APPENDIX: "Inverting an Application"

The following is an example of an exercise in the "application section" of a problem set assigned for Physical Neuroscience. This particular application might interest a biochemist who is looking for an application illustrating the structure-function principle for proteins. The idea is to condense a literature article (Davletov et al., 2005) into a problem that is manageable for the students and which applies a particular concept.

Example problem as it appears in a problem set: We have learned just a little bit about the botulism toxin protein. Botulism toxin is interesting for a variety of reasons. One interesting aspect is its extreme toxicity. Injection of just one microgram can kill a human adult. Botulism toxin is also interesting for its potential therapeutic use in medicine. Botulism toxin is a 150 kDa protein that comes in seven varieties A--G. Type A was discovered in 1897 and is the type that is generally thought of when one mentions botulism toxin. It is produced by the *Clostridium* bacteria found in ill-prepared foods. It is botulism toxin A that was approved by the FDA in 1989 and has come to be called BOTOX. You are perhaps aware of the use of BOTOX in the cosmetic industry. Most botulism toxin types are released as bacteria in the gut die. The full toxin protein enters the blood stream and targets a receptor on the cell membranes. Then by endocytosis it enters the cell where a sulfur-sulfur bond breaks forming a 50 kDa light chain piece (of 447 amino acids) and a 100 kDa heavy chain piece (of 848). It is the light chain piece that targets the vesicle fusion proteins. Toxins A and E target SNAP--25 whereas toxins B,D,F and G target VAMP. Finally, toxin C targets both SNAP--25 and syntaxin. The toxins cause their respective target proteins to cleave and hence render them ineffective in causing vesicle fusion. The effect of the botulism toxin is not permanent (provided the host survives) as new SNAP--25 etc. replace the old damaged ones. The net effect is a temporary blockage of neurotransmitter release. At the neuromuscular junction this results in temporary paralysis and at the neuron-neuron junctions it prohibits excitation (or inhibition) of the downstream neuron. If you would like to learn more about botulism toxin there is an up-to-date and relatively readable article available: B. Davletov, M. Bajohrs, and T. Binz *TRENDS in Neurosciences* **28**, 446 (2005). You can see me for a copy or find it yourself via Science Direct on any campus computer. Based on the above information answer the following.

a) Which of the following neurological disorders do you think botulism toxin might help treat? Briefly consider the action of botulism, how to get the botulism to the problem site, and what problems might arise.
   - Tremors
   - Memory loss
   - Excessive sweating
   - Facial ticks
   - Seizures
   - Bipolar disorder

b) Botulism toxin A has the longest duration of effect whereas toxin E has the shortest duration even though they cleave the same protein, SNAP-25. Two additional facts are (**i**) toxin A cleaves nine amino acids off the end of SNAP-25 whereas toxin E cleaves 26 amino acids off and (**ii**) toxin A resides at the plasma membrane whereas toxin E resides in the cytosol. Come up with a plausible reason why the effects of toxin A last longer than toxin E. Hint: each of the above two facts suggests a different reason and the reality of the situation is that it is probably a combination of both reasons. For both reasons, however, think about what the cell does to proteins, i.e., does it make proteins once and for all or does it continuously produce new proteins to replace the old ones.

c) Does it seem strange that even though every botulism toxin behaves in almost the exact same way they cleave different proteins? Explain.

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