ARTICLE
Undergraduate Neuroscience Education: Blueprints for the 21st Century

Eric P. Wiertelak[1] **and Julio J. Ramirez**[2]
[1]*Department of Psychology, Macalester College, Saint Paul, Minnesota 55105.*
[2]*Department of Psychology and Neuroscience Program, Davidson College, Box 7136, Davidson, NC 28035.*

Paralleling the explosive growth of neuroscientific knowledge over the last two decades, numerous institutions from liberal arts colleges to research universities have either implemented or begun exploring the possibility of implementing undergraduate programs in neuroscience. In 1995, Faculty for Undergraduate Neuroscience (FUN) partnered with Project Kaleidoscope (PKAL) to offer a workshop exploring how undergraduate neuroscience education should proceed. Four blueprints were created to provide direction to the burgeoning interest in developing programs in undergraduate neuroscience education: 1) Neuroscience nested in psychology; 2) Neuroscience nested in biology; 3) Neuroscience as a minor; and 4) Neuroscience as a major. In 2005, FUN again partnered with PKAL to revisit the blueprints in order to align the blueprints with modern pedagogical philosophy and technology. The original four blueprints were modified and updated. One particularly exciting outgrowth of the 2005 workshop was the introduction of a fifth curricular blueprint that strongly emphasizes the integration of the humanities and social sciences into neuroscience: Neuroscience Studies. Because of the interdisciplinary nature of neuroscience, an education in neuroscience will prepare the next generation of students to think critically, synthetically, and creatively as they confront the problems facing humanity in the 21st century.

Key words: blueprints; concentration; major; minor; neuroscience education; neuroscience studies; neuroscience training; undergraduate neuroscience education

In 1995, at the midpoint of the "Decade of the Brain," Faculty for Undergraduate Neuroscience (FUN) partnered with Project Kaleidoscope (PKAL) to host a meeting entitled, "Interdisciplinary Connections: Undergraduate Neuroscience Education" at Davidson College. Seventy participants and workshop leaders explored what form an ideal undergraduate education in neuroscience might take. Given the diversity of colleges and universities, representing a wide range of institutional strengths and resources, the participants concluded that best strategy would be to craft several models of neuroscience curricula, which remain true to several fundamental objectives that capture the elements of a sound undergraduate neuroscience education. These principles include: 1) Promoting critical and integrative thinking; 2) Promoting communication skills orally and in writing; 3) Illustrating the interdependent nature of the sciences; and 4) Imparting an understanding of the resources and limitations of the scientific enterprise as regards our society's biomedical, economic, and ethical challenges (discussed in Ramirez, 2005). By the end of the conference, the participants proposed four "Blueprints for Neuroscience Education" that provide guidance to institutions interested in exposing their undergraduate students to the wealth of knowledge and methodologies that constitute contemporary neuroscience.

In 2005, at the ten year anniversary of the Davidson conference, FUN and PKAL once again partnered to assess the state-of-the art in neuroscience pedagogy at the conference entitled "Undergraduate Neuroscience Education: Leadership, Laboratories and a Curriculum for the 21st Century," which was hosted by Macalester College. Over 100 participants representing institutions as diverse as Agnes Scott College in Atlanta, GA, and the University of California, Los Angeles contributed to discussions centered on ideal models for undergraduate neuroscience education. After an intensive three-day exploration, the participants settled on models of neuroscience education that reflected those proposed at the 1995 meeting, although several of the blueprints were expanded and updated to reflect contemporary neuroscience as well as areas that are undergoing significant evolution. Consequently, we here update the original "Blueprints for a Neuroscience Education" (as conveyed by Ramirez et al., 1998) and introduce one particularly interesting blueprint on "neuroscience studies" that strongly integrates humanities and social sciences into a neuroscience curriculum. The blueprints that were discussed at the Macalester gathering are: 1) Neuroscience Nested in Psychology; 2) Neuroscience Nested in Biology; 3) Neuroscience as a Minor; 4) Neuroscience as a Major; and 5) Neuroscience Studies. Although the blueprints adopt different strategies in educating undergraduate students, the course sequences described below offer a progression from introductory level courses through advanced level courses, with each level building on the intellectual foundation and investigative skill set established at the earlier levels.

NEUROSCIENCE NESTED IN PSYCHOLOGY

The curriculum designed for a neuroscience program nested in a psychology department was structured into three levels, introductory, intermediate, and upper. Each of these levels has its own goals. The courses chosen to meet these goals are sometimes very specific, such as taking an experimental design and statistics course, and at other times are accomplished by taking a few courses from a list of alternatives. There are also a number of collateral courses, classes taken in other departments, that should

be included so that the interdisciplinary nature of neuroscience is fulfilled.

Introductory Level

The goals for this first level were to attract interest and introduce students to the scope and terminology of the field of neuroscience. By taking the introductory course the students become familiar with the mode of inquiry used by neuroscientists. The participants envisioned a number of introductory courses that would meet these goals. Depending upon the particular curricular at each school, one or all of the following courses might be offered. They envisioned that a student taking any one of the following three courses would meet the introductory goals of a neuroscience program nested within psychology.

Courses for Introductory Level [Two Required]

At the 1995 workshop, only one introductory course was recommended for neuroscience nested within psychology. Consensus emerged at the 2005 workshop for two courses at this level.

- Introduction to Neuroscience with lab: The way in which students might be introduced to the study of neuroscience may be through a dedicated introductory course, behavioral neuroscience, physiological psychology, or through a general education course. In all cases, it is highly desirable for this course to be offered by the psychology department, and to feature an extensive laboratory component.
- Introduction to Psychology: It is important that the biological basis of behavior is covered. If necessary, use guest lectures by neuroscience colleagues so that this approach is examined as fully as possible in this survey course.

Intermediate Level

As in 1995, the goals of the intermediate level were to provide students with a deeper involvement in the content of neuroscience, as well as a greater appreciation of the research perspectives used by neuroscientists. In 2005, it was apparent to participants in the workshop that the content "area" of neuroscience had significantly broadened in the years since the original blueprints were proposed. Intermediate-level students should become facile with all phases of neuroscience investigations; conducting library research and designing studies, carrying out physiological procedures important to the discipline and collecting data, and analyzing, summarizing and reporting findings in appropriate formats, including oral presentations and journal article preparation. To do so requires coursework not only in psychology, chemistry and biology, but may well include other fields as well, such as philosophy, computer science, and mathematics.

Courses for Intermediate Level

Multiple courses would be required in this level, including in all cases a course in statistics and research methods. With Behavioral Neuroscience now completed as an earlier requirement, courses here are meant to provide students with more advanced skills and the tools needed for deeper investigation of central themes across neuroscience. Toward this end, completion of organic chemistry and associated lab was advised as a component of the curriculum (particularly for those students interested in the cellular/molecular end of neuroscience), and completion of biochemistry desirable. Within biology, completion of general biology with laboratory and additional training in cellular, molecular, or other laboratory courses such as immunology, alongside coursework in genetics, evolution, or animal behavior will further acquaint students with overarching themes and research methodologies. Additional coursework in psychology should also center on such laboratory-intensive study, such as sensation and perception, cognition, and importantly, principles of learning and behavior. Further psychology-based courses in abnormal, clinical, comparative, and health psychology were all seen as desirable additions to the curriculum as offered by individual institutions. The intermediate curriculum was expanded relative to the earlier blueprint by the recommendation students consider completing one or more courses from a list including neurophilosophy or philosophy of the mind, artificial intelligence, and general physics. Depending on the particular institution, many more courses could be added to this latter group; for example, offerings at Allegheny College feature coursework integrating neuroscience with areas of the humanities.

Upper Level

The goals of the upper level did not change in the years between the Davidson and Macalester workshops: work at the upper level should help the student become an independent scholar. Towards this end the courses taken should include reading and analyzing primary literature, completion of independent research projects that further develop laboratory skills, and intimate course settings emphasizing student-directed learning. Students should be expected to articulate research findings in both a written and oral format, and ideally to do so in a formal setting, perhaps through participation in a local, regional, or national conference. A second theme remained to place emphasis on capstone courses, such as a special topics seminar in behavioral, social, or cognitive neuroscience, senior thesis, or an internship that allows the student to both delve deeply into specific neuroscience content and reflect broadly on the field in general.

Courses for Upper Level

Students completing a neuroscience program nested within psychology should consult closely with faculty advisors to ensure they fulfill both the requirements of a psychology major and the neuroscience program. Two or more courses at this level of study were suggested, to include a true research experience, advanced seminars in special topics, and/or a capstone experience that might be realized as a senior seminar, thesis, practicum or internship.

NEUROSCIENCE NESTED IN BIOLOGY

As in 1995 at Davidson College, participants in the

Macalester conference agreed that the first goal of a neuroscience program nested within biology was preparation of broadly trained biological scientists. This major should, in the course of providing a neuroscience program, also fulfill the distribution requirements of a biology major with a strong, mathematics, chemistry and physics background. In addition, students should complete foundation coursework in neuroscience that would include an introduction to neuroscience and several higher-level courses. To support the major, chemistry should be required, and students planning to go to graduate school should be advised to take one year of organic chemistry in addition to physics and mathematics. While participants at the earlier Davidson conference felt that such a major within the Biology department would most likely evolve into a major or minor in Neuroscience, such a possibility was not discussed at the Macalester workshop.

Participants at the Macalester workshop agreed with those at the earlier workshop that a vital component of the major is to be a research-based curriculum that exposes students to the conduct of neuroscience research. This includes research design and data collection, reading and discussing primary articles from the literature, and presenting their work in both journal writing and oral discussion formats. If at all possible, students should spend a minimum of one semester conducting independent research. Laboratories that accompany courses should be investigative in nature and students expected to participate in both study design and data collection, culminating in preparation of a journal style lab report.

Suggested courses:
It should be noted that, similar to the Davidson workshop group, participants at the Macalester workshop did not specify the number or sequence of recommended courses, but were mindful that the size of the major would vary from institution to institution, depending on the goals and interests of each Biology Department. A particular change was seen in supporting coursework for the major; at the 1995 Davidson workshop, only one semester of organic chemistry was seen as a requirement, and both physics and either statistics or calculus coursework were merely recommended. At the Macalester workshop, participants now indicated that for a neuroscience program nested in biology, an extensive chemistry background including biochemistry, and courses in each of physics, calculus, and statistics should be required.

Required supporting courses:
- Chemistry, courses from introductory through organic and biochemistry
- Physics
- Statistics
- Calculus

Required courses to provide a broad foundation in Biology:
- Introduction to Biology
- Genetics
- Cell Biology
- Animal Physiology
- Evolution

Required Neuroscience Coursework:
- Introduction to Neuroscience (sophomore year)
- Behavioral Neuroscience
- Topical Neuroscience Seminars
- Senior Thesis: Independent research and final report

Encouraged upper level courses:
- Genes and Behavior
- Learning and Memory
- Developmental Biology
- Endocrinology
- Drugs and the Brain
- Sensory and Motor Systems
- Neuroanatomy

Other Suggested Electives:
- Bioethics
- Bioinformatics
- Computational Biology
- Human Sociobiology
- Philosophy of Mind

NEUROSCIENCE AS A MINOR

Participants at the Davidson workshop had engaged in lengthy discussion about the nature and mission of a minor program in neuroscience, and the group assembled at Macalester found similar need. Most participants in the minors/concentration discussion conjectured that the 1995 blueprint for minors was not adhered to at institutions with which they were familiar and suggested that that such programs were more often idiosyncratic to the particular institution, reflecting both the strengths and weaknesses of local department and faculty groups. The participants suggested that a major in neuroscience would more likely provide a stronger foundation in neuroscience education. Some institutions would be ill-prepared to offer a major in neuroscience due to limited faculty and laboratory resources, however, so the minor or concentration would be the most appropriate and responsible structure to implement. What was agreed was that there should be a strong introductory course that, although interdisciplinary in nature, takes as a major goal tying together the various areas of what is called neuroscience for the beginning student. Similarly, the program should culminate in a capstone or other final course that serves to pull together the various approaches and disciplines to which the student has been exposed (based on the coursework available at that institution) under the shared theme of neuroscience. Some discussion also supported the requirement of a research experience, and an undetermined number of supporting courses from across disciplines to include natural and social science and the humanities. This approach and discussion of the minor contrasted with that of the Davidson workshop, which suggested a three course core of courses to the minor: an introductory course in neuroscience (either Neuroscience or Behavioral Neuroscience), a course in philosophy (e.g., Philosophy of Mind), and a course in the social/behavioral

sciences (e.g., Cognition).

Participants at the Macalester workshop did not mirror the earlier Davidson group in discussing the range of possible courses that could be seen as supporting in the minor program. At the Davidson workshop, examples of potential courses for inclusion were: Introductory Psychology, Introductory Biology, Philosophy of Science, Linguistics, Genetics, Molecular Biology, Physical Anthropology, Abnormal Psychology, Artificial Intelligence, Chemistry, Drugs and Behavior, Sensation and Perception, Health Psychology, and Human Sexuality. While participants at the Macalester workshop did not repeat these recommendations, such courses remain reasonable choices, under the discussed requirement for a number of supporting courses beyond the introductory, capstone, and research experience requirements of the minor.

Interestingly, comparison of the Davidson workshop blueprint to the less-structured minor discussed at the Macalester workshop reveals enduring themes, despite the perception of the participants at the discussion on neuroscience minors at the latter conference that institutions were not following the 1995 blueprint. Consider that the Davidson group had arrived at a model with the following characteristics: The minor should incorporate an introductory or capstone course, require a lab experience, contain courses from the social and natural sciences and the humanities, and include a substantial number of disciplines. The Macalester group expressed similar goals for the minor, suggesting a research experience alongside introductory and capstone coursework and other supporting courses from across disciplines. One example of such a model is the Neuroscience Concentration at Davidson College (www.davidson.edu/neuroscience) that uses a three-tiered approach, involving a six-course requirement. All students who concentrate in neuroscience are required to take a laboratory-intensive, survey course in Behavioral Neuroscience, which has a prerequisite of either Introductory Psychology or Introductory Biology. The students then advance to the next level of courses from which the students must choose from one of two options (though they are highly encouraged to take both) in Functional Neuroanatomy (with an intensive clinical component) or Cellular and Molecular Neuroscience (with an intensive laboratory component). The students then must choose three or four elective courses (depending on whether they take all three courses to complete the concentration). The students have a wide range of courses in biology, chemistry, mathematics, philosophy, or psychology to choose from that dovetail with the emphasis students wish to pursue in neuroscience. One hallmark feature of the laboratory-intensive neuroscience courses offered as part of the concentration is that the laboratory experiences are inquiry-based and require the students to engage in research beyond the typical three-hour lab period. All students who concentrate in neuroscience are required to complete one independent research course as part of this sequence, which serves as an integrative capstone experience for the neuroscience concentration.

NEUROSCIENCE AS A MAJOR

Participants at the Macalester workshop were largely in agreement with the general structure of a freestanding neuroscience major as conceived by the earlier Davidson group. Changes to the original blueprint were minimal, more reflecting the increasing scope of the field, and the increase in what courses might be now seen as supportive of the core curriculum. The Macalester group reconfirmed the mission statement for the freestanding major adopted at the Davidson workshop a decade earlier: that the neuroscience major is aimed primarily at students who desire to go on for further training in graduate school (in neuroscience or some related area), medical school, dental school, or veterinary school, but could also benefit students who went on into other occupations or professions as well.

Discussion at the Davidson workshop had been characterized by disagreement among the group participants regarding which and how many general science courses should be included in a neuroscience major. What contentions existed among the Macalester group discussants were more related to physics and biochemistry requirements, which resulted in these courses being named not as requirements, but rather highly recommended among the elective courses. As at the earlier workshop, it was agreed that recommending electives continues to be an important area of faculty responsibility in advising majors; as some populations within the major— such as pre-medical students may be best served by including physics and biochemistry classes, while other students with different goals may derive greater benefit by taking more electives in psychology or disciplinary areas more relevant to their particular post-college goals.

The following introductory level courses were ones that participants at the Macalester workshop thought were vital for a freestanding neuroscience major: an Introductory Biology course that featured genetics, cellular/molecular, anatomy and physiology content, General Chemistry through Organic Chemistry, Introductory Psychology, and a course in statistics and research methods. At the intermediate level, only courses in Cellular/Molecular Neuroscience and Behavioral, Systems, or Integrative Neuroscience, each with labs were seen as part of the core curriculum. Advanced courses would vary depending on areas of faculty expertise, but should include a research-oriented course (which could be conceived of as independent study, summer research experiences, or senior thesis) and a special topics courses or seminars. Macalester participants agreed with the Davidson group that four to six electives should be chosen for inclusion in the student's major plan in consultation with the student's advisor. Joining the list of suggested electives of courses in Developmental Neurobiology, Neuroanatomy, Immunology, Cognition, Perception, Biochemistry, Genetics, Molecular Biology, Health Psychology, Learning and Memory, Pharmacology, Neural Networks/Modeling, and Ethology/Comparative Psychology from the Davidson workshop were courses in Endocrinology, Molecular Genetics, Calculus, Philosophy of Mind, Consciousness,

Sensation, Informatics, Bioethics, and Artificial Intelligence.

NEUROSCIENCE STUDIES: A NEW BLUEPRINT FOR A MAJOR OR MINOR PROGRAM

The participants at the Macalester workshop were particularly excited about an emerging program in undergraduate neuroscience education, Neuroscience Studies, which had developed in the years between the Davidson and Macalester workshops. The participants viewed the primary distinguishing characteristic of such programs from other forms of undergraduate neuroscience curricula as an intentional focus on development of the interrelationships of neuroscience with other disciplines across the liberal arts, especially in the social sciences and humanities. Enthusiasm for this concept was particularly keen among faculty coming from primarily undergraduate institutions and liberal arts colleges, because such a concept allowed greater license to consider alternate forms of neuroscience curricula at institutions with smaller faculties or with unique missions. Considerable discussion centered on the neuroscience studies concept, for which Macalester College's program was seen as the primary model and aspects of several other institutions' curriculum, such as Allegheny College's as further exemplars of the concept. While goals for neuroscience studies would vary by institution, such a program, whether configured as a major or minor, would be intended to promote the core mission of liberal arts education, promoting critical thinking, while providing a core body of knowledge in neuroscience. As such, many faculty felt that their respective institutions would benefit from the studies approach in comparison to the existing neuroscience minor blueprint developed at the Davidson workshop in particular. Such a program could provide preparation for entry into graduate training in a variety of neuroscience and neuroscience related fields, and also provide broad training in neuroscience content for students on non-science trajectories. As such many felt that the nature of neuroscience studies strongly supported a mission of educating a more scientifically literate populace while also serving the programs core constituencies, the major and or minor students.

Key to the neuroscience studies curriculum is a strong introductory course that provides not only information that builds a student's knowledge base of "what" is known in neurophysiology, neuroanatomy, and neurochemistry—and the methods of inquiry that have produced this body of knowledge, but importantly, focus on the intersection of neuroscience with other fields. Students should spend considerable time exploring how neuroscience informs other disciplines and interdisciplinary areas, and how neuroscience in turn is informed by other sciences and the humanities. Intermediate level courses should take the student into areas of strong interest that intersect with neuroscience. Areas as philosophy, mathematics, computer science, cognitive studies might be seen as just a partial list for inclusion here, but the primary goal for the student in neuroscience studies should be to return again and again to the themes of what is known and the ways in which one may come to know. Laboratories and research experiences should directly support the individual student's particular path through the major or minor, and a strong consultative relationship with the faculty advisor is essential. In the Macalester model, this portion of the neuroscience studies curriculum includes several courses taken in the contents and methods of inquiry of a particular discipline to provide depth in a particular approach complementary to the breadth of the remaining curriculum. To complete the curriculum, an interdisciplinary capstone experience that is explicitly reflective should be included, particularly one intended to bring the students full-circle to confront the issues first raised in the introductory course. Shared experiences among graduating students, such as strongly student led discussions in a seminar format could be seen as one form of such a capstone, while a dedicated course in the history of neuroscience might be another, equally effective version.

While neuroscience studies was seen as a "new" blueprint, elements of such a major or minor program can be found in the original blueprints developed at the Davidson workshop, and in the evolving nature of the blueprints discussed at Macalester a decade later. So much of the undergraduate curriculum is driven by the particular nature of individual institutions that very few, if any of the programs currently in existence are "mirrors" of the blueprints developed at these workshops. What the development of the fifth, neuroscience studies blueprint accomplishes is to open the dialogue regarding the core mission of undergraduate neuroscience instruction to a larger intellectual space than afforded by the original four blueprints.

CONCLUSION

The tremendous growth in undergraduate neuroscience programs witnessed since the Davidson workshop in 1995 shows no signs of abating. Clearly, the wealth of discoveries that neuroscientists have been making at an unprecedented rate over the last two decades is driving the imagination and passion for neuroscience among undergraduate students. We hope that the updated blueprints presented here will help guide our colleagues as they fine tune their programs and curricula to provide the next generation of neuroscientists with the foundation that will fuel this century's great neuroscience discoveries. More importantly, we believe that providing a strong interdisciplinary education in neuroscience will also best serve society's needs by preparing our students to think critically, synthetically, and creatively about the problems facing humanity. Whether as neuroscientists or as informed citizens they will be well prepared to participate in the global dialogue securing a stable and fruitful future for us all.

REFERENCES

Ramirez JJ (2005) There's a pony in here somewhere! Reflections on integrating teaching and research at predominantly undergraduate institutions. J Undergrad Neurosci Ed 4:E6-E10.

Ramirez JJ, Aanonsen L, Dunbar G, Hill W, Paul CA, Smith D, Workshop Participants (1998) Undergraduate education in the neurosciences: Four blueprints. In Occasional paper on neuroscience (JJ Ramirez, ed.), from the PKAL Workshop Interdisciplinary Connections: Undergraduate Neuroscience Education; July 1995; Davidson College, Davidson, North Carolina, pp27-33, Washington, DC: Project Kaleidoscope.

Received July 15, 2008; revised July 20, 2008; accepted July 20, 2008.
Supported by a Distinguished Teaching Scholars Award (DUE-0426266) from the National Science Foundation made to Julio J. Ramirez.

Address correspondence to: Eric P. Wiertelak, Ph.D., Professor, Department of Psychology, Macalester College, Saint Paul, Minnesota 55105. E-mail: wiertelak@macalester.edu