Cross Disciplinary Neural Engineering (CDNE) Training Program
Guide for Students

Understanding how the brain works and treating brain disorders are challenging tasks that need future leaders in neuroscience research. At the Center for Neural Engineering, we invite bright and ambitious graduate students to join the Cross Disciplinary Neural Engineering (CDNE) training program funded by NIH. Through the program the graduate students will learn to work across the disciplinary boundaries of engineering, sciences, mathematics, and human brain health, with the ability to communicate and understand deeply the needs of their collaborators, and thereby able to produce lasting advances in both basic neurosciences and human brain health.

Training program objectives include:

- Cross-disciplinary scientific literacy skills and ability to communicate across disciplinary boundaries.
- Ability to lead and work within scientifically diverse groups.
- Proficiency in advanced data analytic and statistical techniques, as well as experimental design, that span engineering and device development, theoretical modeling as well as neurophysiology and human brain health applications.
- Competence in quantitative reasoning skills that include proper use and understanding of statistics, application of statistical inference; differentiation between statistical and physically meaningful effect sizes, and inclusion of methodological and instrumental limitations in quantification, experimental design, analysis and inference.
- Competence in identifying and addressing ethical concerns that might emerge in their research.

The students will thrive in an environment created by a group of highly collaborative faculty working at the forefront of neural engineering, computational neuroscience, and human brain health.

CDNE training elements are extensions of students disciplinary/departmental graduate programs. Current graduate programs contributing to the program include: Anthropology, Biomedical Engineering, Electrical and Computer Engineering, Engineering Science and Mechanics, Mathematics, Mechanical Engineering, Neuroscience, and Physics.

Training Curriculum

The CDNE program elements encompass students' full graduate career. Training elements include a three core courses to provide common grounding in neuroscience, neural engineering, and quantitative / statistical data analysis; cross-disciplinary research with collaboration between at least two mentors' research groups; regular participation and leadership in journal clubs; self-paced completion of cross-disciplinary training modules; participation in the CDNE all-group meeting; and guided submission of external fellowship applications.

A general progression of students through the program is described in Table A, along with their corresponding sources of support. Acceptance into the training program can be made as early as at the time of admission into a PhD program. Ideally, students will apply to the program by the end of their second year of their graduate program.

Year	Support	Training Activities
1-2	Institution fellowships / Research Grant / Teaching Assistantship	• Complete home graduate program core courses & CDNE required courses; • Pass graduate Qualifying Exam; • Rotations and/or research with potential mentors; • Selection of doctoral advisor(s); • Participation in CNE seminars and Journal Clubs. • Write individual grant proposal (ideally submit for funding).

3	Training Program / Research Grant / Fellowships	• Participate in CDNE activities including:
		  • Weekly All-Group-Meetings
		  • Journal Clubs;
		  • CNE Seminar
		• Resubmit individual grant proposal as needed.

4	Training Program / Research Grant / Fellowships	• Participate in all CDNE activities; complete 12 (cumulative) individual training modules; Lead 1 semester of Journal Club.
5	Research Grant / Fellowships	• Participate in all CDNE activities; take leadership in all-group meetings. Ethics Discussions required. Assist with recruitment of future trainees.

Table A: Progression of Trainees and support sources through Graduate and Training programs. Note that students coming in through MD/PhD programs, or having started with an MS, may be advanced

The CNDE is designed to serve as many of the trainees within the CNE as possible. Training support for the majority of trainees will come through standard channels of teaching and research assistantships, outside fellowships, and program-derived fellowships.

Graduate students associated with the Center are encouraged to participate in CDNE activities throughout their training. **Trainees should apply to the program within their first two years.** Formal admission to the program will be granted following completion of the CNDE required courses, passage of PhD qualifier exam in their departmental graduate program, submission of a preliminary plan of study/research that fulfills CDNE program content and requirements, and identification of primary and collaborative mentors. Details below.

A summary of the CDNE Curriculum is presented in Table B. In years one and two, prior to full admission to the program, trainees are required to complete two foundational courses that provide grounding neuroscience and neural engineering, and one in statistics or neural data analysis.

Starting in training Year 3, Trainees will be required to participate weekly in the All-Group Meeting; participate in at least 1 journal club per semester, and lead a journal club for a semester in Year 4; participate in the annual CDNE retreat; prepare an external fellowship grant application by the end of Year 3; and complete 12 training modules by the end of Year 4.

Access to CDNE training elements and activities, including journal clubs, training modules, and the retreat, are available to trainees from Year 1.

Each of the training elements are described in the following sections.

Note that core elements of the training program involve group activities of the trainees and their trainers. In years 3 and 4 of the program, regular participation by the trainees is expected in these activities. In particular, the All-Group-Meeting, the CNE seminar, and our planned fellowship writing course will be held on Wednesdays in the meeting rooms adjacent to the CNE space in the MSC, timed so that trainees from HMC can travel by shuttle.

Course/activity	Topic	Years
Foundational Courses (both required)	ESC 525: Fundamentals of Interfacing with Brain Neuro 520: Cellular and Molecular Neurosciences	1,2
Course in Statistics or Neural Data Analysis (one required)	ESC 555: Analysis of Neural Data A 500 level Stats course (including Stats 500-502; 512-3; 515) Alternate statistics/data analysis focused courses may be accepted under petition to program directors/statistician.	1,2
CDNE Required Activities:		
All Group Meeting	Weekly meeting of trainees, trainers, and statistician. Once per month is a programmatic lecture. Other weeks involve presentations of ongoing research and discussions of experimental design and statistical design.	2-5
CNE Seminar	Weekly seminar with local and invited faculty presentations	all
Journal Clubs	Cross-group meetings to discuss and provide critical cross-disciplinary interpretation of current scientific literature. JCs are organized around themes such as NeuroTechnology, Computational Neuroscience, Systems, Brain-Computer Interfaces, etc.	all
CNE Retreat	Faculty Lectures; Student Presentations	all
Professional Development (BOTH REQUIRED)		
Grant Writing	Advanced training and submission of a grant proposal. Informal Course.	3
Responsible Conduct of Research (RCR)	Penn State offers a Scholarship and Research Integrity Program (SARI) on such topics as publication practices, conflicts of interest, mentoring, research misconduct.	1,5

Table B: Summary of CDNE Training Curriculum.

Required Courses

The required courses serve the objectives of preparing the trainees to work at the boundary between engineering, mathematics and neuroscience. Each is three credits, can serve as either required or technical electives in the students' home graduate programs.

Two of the required courses are **foundational courses** that present two different views of topics in neuroscience; they provide a core set of disciplinary language for students working at the boundary between neuroscience and engineering.

- **ESC 525: Neural Engineering: Fundamentals of Interfacing with Brain (3 Credits):** The course explores theoretically and quantitatively the biophysical basis of neural function, measurable signals, and neural stimulation, and the electrochemical nature of the electrode tissue interface.
- **NEURO 520: Cellular and Molecular Neuroscience (3 Credits):** An introduction to neurons, glia, and the molecular basis of brain function.

To prepare the students to work in a quantitative and statistically sound approaches, they must complete at least one course on modeling of data. Acceptable courses include:

- **ESC 555: Neuroscience Data Analysis (3 Credits):** This course covers the biophysical origin and measurement of brain signals, the theoretical background of modern analysis methods and their practical implementation to brain signals, and introduces a toolbox of mathematical and computational techniques to analyze electrophysiological, optical and anatomical data. Topics covered include spectral methods, neural encoding and decoding, information theory and image analysis.
- **A 500 level Stats Course:** A 500 level Stats course (including Stats 500-502; 513-4; 557). Of particular interest are:
    - **Stat 500: Applied Statistics (3 Credits).** Descriptive statistics, hypothesis testing, power, estimation, confidence intervals, regression, one- and 2-way ANOVA, Chi-square tests, diagnostics.
    - **Stat 501: Regression Methods (3 Credits).** Analysis of research data through simple and multiple regression and correlation; polynomial models; indicator variables; step-wise, piece-wise, and logistic regression.
    - **Stat 502: Analysis of Variance and Design of Experiments (3 Credits).** Analysis of variance and design concepts; factorial, nested, and unbalanced data; ANCOVA; blocked, Latin square, split-plot, repeated measures designs.
    - **Stat 513/514: Theory of Statistics I (3 Credits) / II (3 Credits).** (I) Probability models, random variables, expectation, generating functions, distribution theory, limit theorems, parametric families, exponential families, sampling distributions. (II) Sufficiency, completeness, likelihood, estimation, testing, decision theory, Bayesian inference, sequential procedures, multivariate distributions and inference, nonparametric inference.
    - **STAT 557: Data Mining (3 Credits):** This course introduces data mining and machine learning methods, major software packages, and their applications. Topics covered in this course include linear classification/regression, logistic regression, regularization and dimension reduction, decision trees, and mixture models.
- **Alternate courses may be accepted for statistics through consultation and petition with the Program Directors and Program Statistician.**

CNDE Trainees are expected to completed both ESC 525, Neuro 526, and a stats course by the end of year 2 of their departmental programs.

The CDNE All-Group Meeting:

The CDNE All-Group Meeting (AGM) is a weekly 90-minute group meeting that requires attendance for all trainees. The AGM will serve a number of functions: a) presentations of once-per month programmatic lectures or interactive activities that serve the core training elements of the CDNE; b) discussions of experimental design and statistical analysis of data c) formal presentations of elements of trainees' ongoing experiments.

The AGM is scheduled weekly on Wednesday mornings so that most trainees can participate as expected. The Program Director and Associate Director, and Statistician will regularly attend.

These elements are described below:

a) Programmatic Lectures: Four times per semester, programmatic activities that address one of the follow topics will be presented. Activities will be scheduled and designed by the Curriculum Committee, and led either by the trainers, the program statistician, or outside experts. The format for these activities is lecture and/or interactive discussion.

Trainees will be given preparatory readings or assignments ahead of these sessions, and a short follow-up writing assignment that will also be used for curriculum assessment. Note that the same lecture will not be repeated more than once every 24 months.

Topics for the programmatic lectures include:

a. Ethics Discussion
b. Statistical Frameworks for Research Design and Data Analysis
c. Scientific Rigor
d. Cognitive Bias

Detailed objectives of these topical presentations address particular RFA-referenced elements and are therefore discussed under those headings below.

b) Experimental design and statistical data analysis discussions: Twice per month, All-Group Meeting sessions will begin with a short (10-15 minute) topical discussion by the Program Statistician on some elements of quantitative modeling of data, or by other faculty on aspects of research to include a range of good practices, lab safety, data management, writing techniques, presentation skills, etc. The rest of the session will be an organized discussion of trainees' ongoing research challenges, including statistical or design challenges, etc., meant especially to reinforce implementation of statistical and quantitively approaches, reproducibility and rigor in research. These discussions will be centered around assigned short presentations by trainees.

c) Formal Presentations: Once per month the All-Group Meeting format will focus on critical phases of each trainee's research. During those periods, typically two funded trainees will be assigned to present and defend to the other trainees, their mentors and a panel of at least 3 other CDNE trainers. The format of these sessions will be:

a. A 15-minute pitch of a core element of the trainee's research – from the basic hypothesis or challenge, to the experimental and statistical design, to the data analysis, to the results and associated interpretation.
b. A 5-minute question period with priority given to trainees where all questions are directed at places that lack clarity or establishment of facts about topic or background.
c. Each of the other trainees then has 2 minutes to state both the strengths and potential weaknesses of the presentation.
d. The faculty panel and at least one senior (>Yr. 4) trainee will give expert opinions on the strengths and weaknesses of the research at that stage, with a gauge of whether they would advise for publication or application for funding.

Each trainee will be expected to present in this forum at least once per year starting in training year 3. At least two sessions of the AGM early in Fall semester will be dedicated to Formal Presentations by senior (>Yr 4) trainees to set the examples for junior trainees.

Trainees are encouraged to participate starting in Year 2, required to participate weekly in Years 3 & 4, and beyond.

Cognitive Bias Training Elements:

You may be surprised to find that human decision-making is frequently irrational, and that even very bright people utilize poor insight into statistics and risk analysis in their decision making, and that this often leads to bias in research. To ensure that members of the Center are all aware of the cognitive processes and how they might affect and bias their decisions in their research, and to encourage frequent & routine discussions and invocations of the concepts of human cognitive biases, CNDE trainees will read Economics Nobel Laureate Daniel Kahenman's book Thinking

Fast and Slow and encouraged to discuss elements through regular both formal and informal activities.

Cross-Disciplinary Training Modules:

One of the core challenges for graduate students involved in cross-disciplinary research is that immersion in discipline-based departmental programs poorly prepares them to work across boundaries to other disciplines with different core knowledge and language.

To address this challenge, the CDNE faculty provide concise training exercises that we call training modules. Each will be targeted to take approximately 10 hours of trainee's time. These modules provide an expert-level *introduction* to particular fields, including core knowledge and the tools used in the fields. Students will be expected to use these modules as an entry to their own self-learning of new disciplines.

Each module will have the objective to provide a trainee with a combination of moderately deep insights into key elements of a particular field along with some useful skills especially in interpreting future observations and interacting with researchers in the module's discipline. Modules will be explicitly designed for trainees coming from outside the discipline. It is expected that a majority of these modules will introduce **quantitative tools or quantitative approaches** to explore and understand both biological data and the materials and devices used to interface with it. These can include computational tools, quantitative data analysis tools, modeling tools, or materials and device characterization tools. Modules will be completed by individual or by cohorts of trainees collaboratively, in consultation with more senior trainees and faculty trainers.

Trainees are required to complete 12 modules. Trainees would typically complete 3 modules per semester in their Years 3 & 4, but they will have access to them earlier and credited when completed.

Journal Clubs:

The CDNE Journal Clubs are weekly multi-PI group meetings that discuss current scientific literature. The general approach is for the paper of interest to be announced ahead of time, and one or more club members to present a summary and lead discussion. These journal clubs bring together persons coming from many different disciplines and knowledge bases. Through them, the researchers develop common language for discussions, and erase blind spots in their knowledge bases. This enables the participants to identify both what parts needs to be explained to others, as well as what are the core questions outside their domains that need to be asked. These discussions lead to insight on where the holes are in the current scientific and engineering fields and opportunities to improve upon them. In keeping with efforts to enhance training in scientific rigor and quantitative literacy, attention is given as much to methodology and approaches as to findings (Casadevall 2016). Additionally, they teach lessons on how critically others will read our own work when we publish.

Example topics for journal clubs in the Center include NeuroTechnology; Neurodegeneration; Computational Neuroscience Group; Brain Computer Interfaces; Systems Neuroscience; and NeuroStochastic Modeling.

Trainees are encouraged to participate in Journal Clubs throughout their careers. CDNE trainees are required to participate weekly in at least one multi-PI journal club or reading group per semester, and lead one for a semester in their Year 4.

Professional Development:

All CDNE students are required to

(A) Twice annually prepare Individual Development Plans and discuss then with their mentors;

(B) Write and submit a formal fellowship proposal by Year 3; and

(C) Participate yearly in an international professional meeting, workshop or short course (starting in Year 3).

Individual Development Plans (IDPs): IDPs are standard tools used by an individual to improve skill sets and chart their progress as professionals. As such they include specific medium and long-term goals, identification of skills to acquire, actions to achieve them, and assessments of progress. The CDNE trainees will be guided on initiating them upon affiliation with the program, and are required to, with assistance, update them annually and discuss with their mentors.

Fellowship Proposals: Trainees are required to write a formal fellowship proposal by their their third year. The overall content and design of the proposed project will be done in consultation with each trainee's mentors. It is anticipated/appropriate that the same proposal will form the basis or structure for their comprehensive (thesis proposal) exam. Trainees have access to the Graduate school series of 'Grant Writing Workshops.'

Trainees will be encouraged to utilize these applications and apply for external fellowships as part of this activity. Target programs include NIH-F31, Individual National Research Service Award, as well as foundation-supported fellowships such as ones from American Epilepsy Foundation, or the American Heart Association (which also is interested in brain-health).

Not that those applying for fellowships that require research and professional development training components (such as NIH-F series grants) can use the CDNE training elements as core elements of the training portion of their fellowship applications.

Graduate students who successfully complete and submit a competitive external fellowship application receive a Predoctoral Research Fellowship Incentive Award from the Graduate School. The CNE will seek to secure required financial top-ups to make sure that fellowship-acceptances are not a financially losing proposition for the trainees.

Note: There are great professional development experience in writing and submitting grant/fellowship applications. There are some advantages to actually getting one, but these are not determinants of professional success. Trainees are NOT encouraged to resubmit applications more than once.

Meetings and Workshops: All trainees are encouraged annually to attend either a relevant international professional meeting such as the Annual Meeting of the Society for Neuroscience IEEE-Engineering in Medicine and Biology Society (EMBS) Annual Conference, The EMBS-Neural Engineering Conference; Neural Interfaces Conference (NIC) series; or a targeted workshop such as the National Center for Adaptive Neurotechnologies (NCAN) Adaptive Technologies or Marine Biology Laboratory "Methods in Computational Neuroscience" short courses.

Application Processes

Participation in program elements is open to trainees involved in Neural Engineering research across all graduate programs affiliated with the CNDE and the faculty members of the PSU Center for Neural Engineering.

Graduate students can apply to formally be part of the program. Those submitting or receiving individual fellowships can use the program elements as part of their advanced/professional development for the fellowship.

The program also has funding to support a limited number of trainees. Participation in the program is open to others not funded by the program.

Graduate Applicants (prior to matriculation)

Students interested in coming to Penn State for graduate school with the aim of participating in the CDNE training program need to enroll through one of the participating departmental graduate programs. Applicants should clearly state in their application materials this intention, should identify research topics in which they are interested, and identify faculty with whom they would like to work.

Interested candidates are urged to make contact with potential faculty mentors well ahead of submitting their applications. For additional guidance, contact the CNDE Director, Bruce Gluckman (BruceGluckman@psu.edu) and Associate Director Elizabeth Proctor (EProctor@psu.edu).

Application Process – Training Program

Note that activities and elements of the CNDE Training program should be initiated in student's first years of graduate work.

Participation in the AGM is limited to students that have (1) passed their departmental program's qualifier exam (2) completed CDNE required courses.

Please submit the CDNE Enrollment/Admission form, which will ask for

- Name & PSU Email and PSU ID
- Graduate Program
- Date passed qualifier
- Primary Mentor
- Secondary/Collaborative Mentor
- Confirmation of completion of CDNE Required Courses ESC 525 and ESC 526/Neuro 526; course satisfying the Stats requirement.
- As attachment, copy of current CV

Nomination Process – CNDE Fellowship Support

The CDNE program has available a limited number of fellowships to support students participating in the program. While some of these will be used for recruiting purposes, the rest will be allocated based on a combination of advisor nominations and internal constraints related to funding sources.

Full participation and completion of the CDNE training program is NOT limited to those supported with program fellowship.

Nominations process for CDNE fellowship. Nomination packages should include

- Nomination letter from the student's primary advisor
- Description of involvement of the secondary mentor.
- Letter from secondary mentor supporting the nomination and their role.
- Short (1-2 page) statement providing the student's background, research interests, professional goals, identification of a secondary trainer/mentor, and reasons for seeking support from the training program. (co-written between advisor and student).
- Copies of PSU and undergraduate transcripts