COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 11-1		FOR NSF USE ONLY
NSF 11-533	07/01/11	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)		
DGE - IGERT FULL PROPOSALS		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				614209054	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY?
060772160	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Connecticut	University of Connecticut 438 Whitney Road Ext. Storrs, CT. 062691133
AWARDEE ORGANIZATION CODE (IF KNOWN) 0014175000	
NAME OF PRIMARY PLACE OF PERF	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
University of Connecticut	University of Connecticut 438 Whitney Road Ext. Storrs ,CT ,062691133 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions): ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **IGERT:Language plasticity - Genes, Brain, Cognition and Computation**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 3,499,625	60 months	07/01/12	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
- ☒ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date Planned
  PHS Animal Welfare Assurance Number A3124-01
- ☒ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number FWA00007125
  Exemption Subsection Pending or IRB App. Date Pending
- ☒ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
  FI JA SP TW
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Psychology	343 Mansfield Rd Storrs, CT 062692231 United States
PI/PD FAX NUMBER 860-486-2760	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME James S Magnuson	DPhil	2001	860-486-3622	james.magnuson@uconn.edu
CO-PI/PD Carl Coelho	DPhil	1982	860-486-3622	carl.coelho@uconn.edu
CO-PI/PD Roslyn Holly Fitch	PhD	1990	860-486-2554	hfitch@psych.psy.uconn.edu
CO-PI/PD Kenneth R Pugh	PhD	1989	203-432-2460	pugh@haskins.yale.edu
CO-PI/PD William B Snyder	PhD	1995	860-486-0157	william.snyder@uconn.edu

IGERT: Language Plasticity - Genes, Brain, Cognition, and Computation

PI: James Magnuson; **Participating institutions:** U. Connecticut; Haskins Laboratories

A. SUMMARY

We propose a pioneering training program linking linguists, psychologists, neuroscientists and behavior and molecular geneticists in a new synthesis of cognitive and biological approaches to human language. A unified, developmental systems theory of language is within reach, given advances in cognitive and biological domains, but prerequisite deep theoretical and empirical links between fields are missing. We will transform training in language science with a team-based model to course- and hands-on research-based training to prepare scientists in these domains to communicate, collaborate, and innovate. Innovations from this cognitive-biological synthesis will address societal challenges in education, technology, and health.

Intellectual Merit. Language represents a uniquely human feature spanning evolution, biology, and culture. Understanding human language development and processing has vast implications for basic science, technology, education and health. Familiar cognitive approaches (linguistics, psychology, communication disorders) typically make the simplifying assumption that language can largely be understood as a discrete human faculty. Scientists in these fields acknowledge that full understanding will require theoretical frameworks and empirical research programs locating language within the larger organism-environment-population context, but defer that step until some future time when biological fields can be linked with cognitive theories. That moment has arrived.

Behavior and molecular genetics can identify genetic patterns that correlate with human traits. Animal models in behavioral and molecular neuroscience allow true experimental tests to establish causality underlying those correlations. Despite obvious challenges in developing animal models for language, this approach has been instrumental in identifying potential genetic bases for dyslexia. The emphasis in biological approaches to language has been on disorders. Linking these approaches to cutting-edge theoretical and empirical cognitive research programs has the potential to transform both cognitive and biological approaches and to lead to fundamentally new insights into how language development depends on pervasive interdependencies at multiple scales (genes, brain, cognition, behavior, environment).

Theoretical and analytic frameworks for grappling with complex systems exist (e.g., dynamic/self-organizing systems, developmental systems theory) – *so why isn't this synthesis already happening*? The critical obstacles are theoretical and technical differences between disciplines. Most cognitive and biological scientists simply do not know how to talk to each other or read each others' literatures, let alone achieve cognitive-biological synthesis from within their own fields. At the same time, it is not practical to train linguists to have Ph.D.-level expertise in molecular biology or vice-versa. We will transform language science training by providing trainees from cognitive and biological fields specialist expertise in their home domains as well as sufficiently broad and deep knowledge to communicate, collaborate and innovate in multidisciplinary teams. We will do this by integrating course- and hands-on research-based training in a team-based model, in an environment explicitly designed to foster creativity and innovation.

Our core theme is *plasticity*. Plasticity encompasses *change* at multiple levels and timescales – development over the lifespan, atypical trajectories arising from developmental and acquired disorders, and recovery from and compensation for disorders. Disorders provide basic research insights linking genetic, neural, cognitive, and computational levels of analysis, and motivate experimental tests of neurobiological theories in animal models. Understanding language plasticity requires the approach we propose, linking multiple populations (typical and atypical children and adults) and species within a unified theoretical and empirical framework.

Broader Impacts. This IGERT will: (1) prepare new scientists with comprehensive, integrative mastery of diverse fields, and hands-on experience collaborating in multidisciplinary teams, leading to a fundamentally new synthesis of cognitive and biological approaches to language science; (2) provide a model for linking cognitive and biological approaches in other domains; (3) teach trainees/faculty to communicate with educators, policy makers and the public, delivering research in innovative ways that address societal challenges in technology and education; (4) build on existing institutional and faculty efforts to increase participation among historically under-represented groups; and (5) prepare trainees for the increasingly international nature of science through multiple opportunities to make international research connections through visits to participating sites and regular video conferences with those sites.

***Keywords**: Social Science; Behavioral and Cognitive Science; Language*

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

C. PROJECT DESCRIPTION
C.1 LIST OF PARTICIPANTS

No participants have prior IGERT experience. *CDIS=Communication Disorders, LING=Linguistics, PNB=Physiology & Neurobiology; PSYC=Psychology*; ***PSYC divisions****: BNS=Behavioral Neuroscience, CLN=Clinical, DEV=developmental, PAC=Perception, Action, Cognition*

Name (Role), *Affiliation*: Expertise
Magnuson, James (**PI**), *PAC*: Language processing; time course measures (electroencephalography [EEG]/ event related potentials [ERPs], eye tracking); computational modeling
Fitch, R. Holly (**Co-PI**): *BNS*: Animal models of neurodevelopment and cognition; models of neurodevelopmental disruption (genetics, early injury) and developmental disability
Snyder, William (**Co-PI**), *LING*: Child language acquisition; comparative syntax and morphology; syntax-semantics interface; theory of grammar
Coelho, Carl (**Co-PI**), *CDIS*: Discourse; aphasia; traumatic brain injury
Pugh, Ken (**Co-PI**), *PAC, Haskins Labs:* Neurobiology of typical and atypical reading development; functional magnetic resonance imaging [fMRI]
Bortfeld, Heather, *DEV*: Language acquisition; speech perception; neuroimaging (near-infrared spectroscopy [NIRS])
Coppola, Marie, *DEV, LING*: Language acquisition; homesign; language genesis; sign languages
Eigsti, Inge-Marie, *CLN*: Developmental cognitive neuroscience; language acquisition; autism; developmental disorders; neuroimaging (fMRI)
Fein, Deborah, *CLN*, Development; Autism; developmental disorders
Grela, Bernard, *CDIS*: Language development; Specific Language Impairment (SLI)
Grigorenko, Elena, *Haskins Laboratories; Yale Child Study Center; Psychology; Epidemiology and Public Health*: Behavior genetics, genomics, epidemiology, developmental disorders
Lillo-Martin, Diane, *LING*: Language acquisition; theoretical linguistics; sign languages
LoTurco, Joseph, *PNB, BNS*: Neocortical development and neurogenesis; molecular genetics, patch clamp electrophysiology, and cell culture techniques
Myers, Emily, *CDIS, PAC*: Speech perception, word recognition; aphasia; neuroimaging
Naigles, Letitia, *DEV*: Language acquisition; early language processing; developmental disorders
Ramanathan, Pradeep, *CDIS*: Metacognition; memory; computational models; traumatic brain injury; aphasia
Read, Heather, *BNS*: Animal models: sensory/cortical auditory pathway organization and development
Rueckl, Jay, *PAC*: Visual word recognition; Morphology; computational models
Spaulding, Tammie, *CDIS*: Language development; Specific Language Impairment
Tabor, Whitney, *PAC*: Sentence processing; self-organizing/dynamical systems; computational models

International participants: Name, Country, *Institution:* Expertise
Carreiras, Manuel, *Spain, Basque Center for Brain, Language, and Cognition*: Word recognition; reading development and dyslexia; bilingualism; EEG/ERP; computational modeling
Lyytinen, Heikki, *Finland*, *U. Jyväskylä:* Early language impairment detection; EEG/ERPs
Hung, Daisy, *Taiwan*, *National Yang Ming U.*: reading, dyslexia; bilingualism; EEG/ERPs; magnetoencephalography [MEG]; trans-cranial magnetic stimulation [TMS]; fMRI
Malmierca, Manuel, *Institute for Neuroscience, U. Salamanca, Spain*: Animal models; neurophysiology of sensory and cortical auditory pathways
Saito, Mamoru, *Nanzan U., Japan, representing consortium of sites in India, Italy, Taiwan, and United Kingdom*: Theoretical linguistics; comparative syntax; structure of Japanese

C.2 VISION, GOALS AND THEMATIC BASIS

Language is a defining element of human experience. Science has only begun to uncover the genetic and neurobiological foundations of language development, the mechanisms that allow humans to achieve robust, adaptive perception across incredible variation in signal and environment, the biological, environmental, and experiential factors that support or disrupt language development, or the nature and limits of **plasticity** evident in life-long development, as well as linguistic recovery from acquired disorders, such as traumatic brain injury. This basic-science understanding has the potential to address many societal challenges, including technological, educational, and clinical challenges. Achieving this understanding will require new methods and theoretical frameworks, and tools and knowledge of familiar cognitive-level approaches to language – linguistics, psychology, communication disorders – as well as those of biological disciplines such as behavior and molecular genetics, and behavioral and molecular neuroscience. Enormous challenges must be overcome before a synthesis of these fields can be achieved: scientists must be able to communicate across disciplinary boundaries before they can collaborate; new methods and theories are required for cognitive-level domains to address systematic individual differences; new methods and theories are required for all disciplines to grapple with the complex genetic, neural, cognitive, and environmental interactions on which language development depends; and a unifying theoretical framework is required to link cognitive and biological approaches to language.

Our IGERT training program is inspired by the realization that the necessary disciplinary elements for this synthesis have recently emerged, and that we have the necessary personnel, expertise, and theoretical vision at our institutions to achieve it. We have assembled faculty from 7 Ph.D. programs (cognitive: LING, DEV, PAC, CLIN, CDIS; biological: PNB, BNS; see p. 1 for key) with skills and methods needed to launch a new cognitive-biological synthesis approach to language. The missing element is a formal training program, and a critical mass of trainees eager to participate in this pioneering endeavor.

In the rest of this section, we outline our vision for a new *systems approach* to language that unifies cognitive and biological approaches, and plans for fostering innovation, achieving global perspective and our project objectives, and plans for monitoring and assessing progress.

C.2.1 Current approaches and limitations. Cognitive-level disciplines have provided a foundation for describing and constructing theories of language development, processing, and disorders through observation, experiments, and computational simulations. Cognitive theories predict behavior, and experimental observations are used to falsify or refine theories. This strong relationship between behavior and inferred cognitive mechanisms is schematized in Fig. 1 with a bidirectional arrow. The focus in these domains is typically characterizing the modal language system, or the modal symptomatic profile for some disorder. Cognitive neuroscience provides data about which brain regions, on average, are selectively active during a particular task. This weaker link is indicated with a dashed line. Connections between cognitive theories and genes or environment are even rarer and weaker.

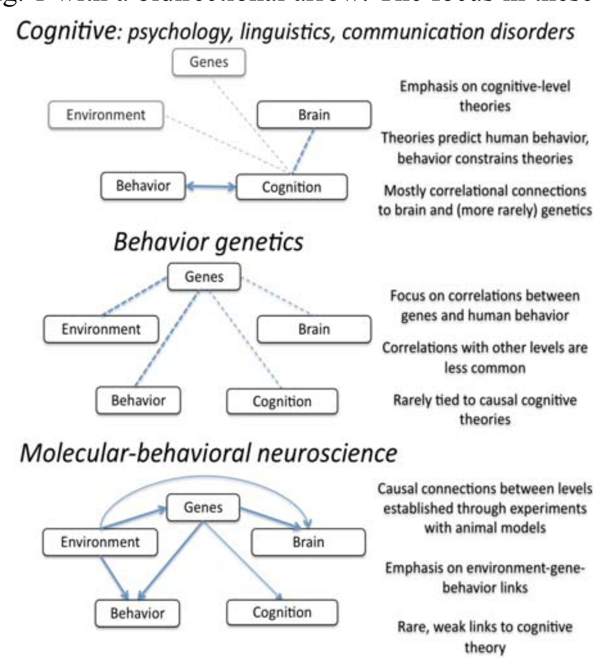

Fig. 1: Scope of approaches to language science.

Limits of cognitive approaches have been made clear in large part by work with atypical populations. Systematic individual differences in linguistic and nonlinguistic abilities within language disorders (e.g., dyslexia, autism spectrum disorders, aphasia) have challenged long-held assumptions that variation around modal linguistic *phenotypes* (an organism's expressed/ observable traits) is noise, and that language can be considered largely independent of other cognitive, social, and environmental factors. Long-standing distinctions, such as Broca's (expressive) vs. Wernicke's (receptive) aphasia, are falling away given evidence for continuous rather than discrete deficits. Nascent examinations of individual differences in *typical* populations confirm that systematic variation and interdependence of linguistic and other cognitive domains is true of language development in general. Just describing this variation at the cognitive level will require a radical methodological and theoretical shift from modal phenotypes to a dynamical systems approach, which provides the means to assess change over time in distributions influenced by multiple dimensions at multiple time scales.

Evidence from behavior and molecular genetics has demonstrated that genotypic factors (*genotype* being an organism's potential traits, whether expressed or not) play a large role in language development (as in all aspects of development) by identifying gene-disorder connections. Establishing these connections depends on having rich phenotypic descriptions of the fullest possible range (i.e., low-to-high ability, typical and atypical) for biostatistical analysis. The more detailed our neural, cognitive, and behavioral characterizations of individual differences (phenotypes), the more precision we provide for genetic analysis. Evidence from human behavior genetics is necessarily correlational, but causal relations among genes, environment, neurodevelopment, and behavior can be established with experiments using animal models in behavioral and molecular neuroscience. Linking animal models to human language is of course challenging, but such work has already been instrumental in identifying genes implicated in dyslexia (e.g., Galaburda, **LoTurco**, Ramus, **Fitch**, & Rosen, 2006).

The contributions biological disciplines are making to the identification of genetic risk factors for language disorders also inform us indirectly about the genetic basis for typical language development; genes that contribute to risk for dyslexia, for example, likely contribute to normal reading development. The potential for these fields to contribute directly to the basic science of language are limited by the lack of deep connection to cognitive literature, methods and theory. For example, findings that seemingly disparate cognitive and linguistic abilities correlate with similar genomic patterns should lead us to develop theories of how and why those abilities may be linked. Such connections would foster investigations motivated by theoretical predictions rather than primarily by disorders. This would provide a link – currently almost completely lacking – from cognitive disciplines to neuronal- (rather than brain regions measured with fMRI) and genetic-scale foundations of language.

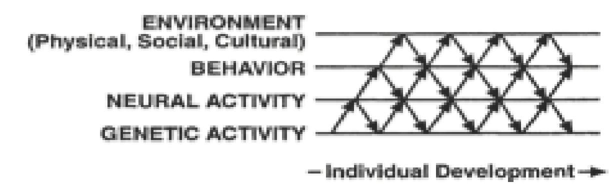

Figure 2: Gottlieb's (2007) schematic of "completely bidirectional" interactions in probabilistic epigenesis.

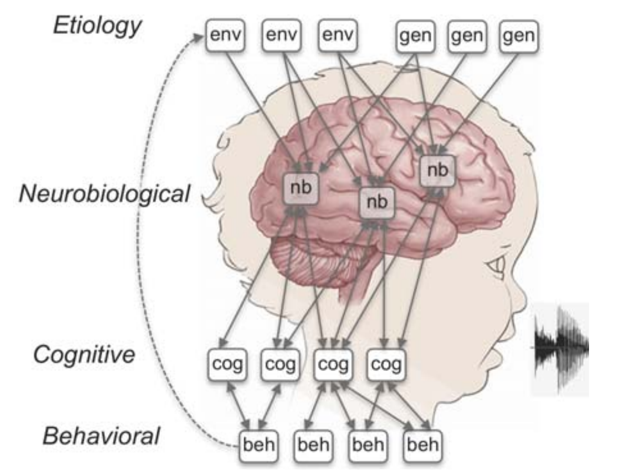

Figure 3: The same etiological context can result in disparate phenotypes, and a single trait can result from different contexts, due to complex, many-to-many mappings from genes to intermediate (neurobiological, cognitive) and behavioral phenotypes. Understanding this organism-environment system requires the multi-level, multi-population, and multi-species approach we propose.

Forging these connections will require a new, comprehensive theoretical framework. This framework must tackle head-on the complex interactions of language development. Scientists in biological disciplines have long recognized that there are dynamic, inextricable links among genetic, neural, and behavioral development and an organism's environment. Fig. 2 schematizes one such conceptual framework, Gottlieb's (2007) *probabilistic epigenesis*. On this view (closely related to *developmental systems theory* and *systems biology*), genes do not *determine* developmental outcomes. Rather, development is a constructive process, shaped constantly by bidirectional influences of epigenetic (extra- or beyond genetic) organismal and environmental factors at multiple scales, and phenotypic traits emerge from these complex interactions. Fig. 3 (based on Bishop & Snowling, 2004) illustrates why this is crucial. Environmental and genetic factors modulate neurobiological traits, which modulate cognitive traits, which manifest in behavior. Interactions among intermediate phenotypes (quantifiable characteristics between gene and behavior) and from behavior to environment lead to complex interdependence among levels. Some traits follow from discrete etiological conditions. More commonly, similar traits arise from many, often dissimilar etiological conditions. Conversely, a gene may map onto one trait, but more commonly, maps onto multiple traits. Similar relationships hold between neurobiological, cognitive, and behavioral phenotypes. These many-to-many mappings follow from context-conditioned dynamics among environment, genes, neurobiology and behavior.

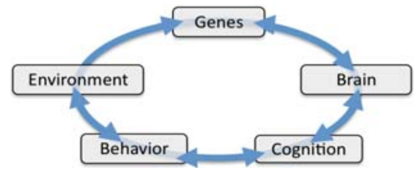

Fig. 4: unified systems approach.

Scientists in cognitive domains may be aware and explicitly acknowledge that language science will eventually have to address these complexities. In communication disorders, for example, we know that risk factors for developmental language disorders are predicted at birth by factors like low apgar scores or birth weight. This is prima facie evidence that deep understanding of language development will require grappling with nonlinguistic neurobiological factors, but the tools, technology, and theory needed to span the gulf between cognitive and biological approaches to language have been out of reach – until now.

C.2.2 A unified systems approach to language. Fig. 4 schematizes our vision of the unifying theoretical and empirical framework required to synthesize cognitive and biological approaches to language. We need experimental investigations of forward and backward influences among environment, genes, brain, sensation/cognition, and behavior, couched in a unifying theoretical framework where these dimensions form a loop. Rather than linking genes directly to behavior, we can achieve a deeper understanding if we use cognitive theory to organize behavioral data to detect patterns and systematicities that would not otherwise be apparent. For example, the implications of links between low working memory and poor theory of mind (understanding of others' mental states, crucial for conversational implicature) were not immediately obvious, but can be related by a psychological theory in which theory of mind depends upon specific aspects of working memory and other cognitive functions (**Eigsti** & Schuh, 2008), leading to new insights into cognition as well as the disorder.

The great challenge, though, is building this unified theoretical approach to language science given that it cannot be done within a single discipline, a single population or even a single species. The range of variation within typically developing individuals is often insufficient to constrain biostatistical analyses needed to assess which genetic patterns associate with behavioral, cognitive, or neurobiological phenotypes. Including populations with acquired or developmental disabilities as well as typical populations provides greater variation and thus a much stronger foundation for genetic analysis. The greatest challenge is comparisons of species. How does one achieve an animal model of human language?

While it is likely that language-specific (and human-specific) genes modulate in part the development of neural systems underpinning language, it is certain that language represents one of the most pleiotropic (where genes influence multiple traits) domains of human behavior. Numerous neural regions provide "scaffolding" to language functions (memory, attention, sensory processing). These regions in turn develop under the modulatory regulation of independent genetic factors, with homologs to most of these found in other mammalian species. As such, any genetic factors that turn out to be "uniquely human" modulators of neural and language development will likely represent a small subset of the factors in play in the developmental trajectory of human language. The hypothesis that language is built on cognitive functions and neurobiological structures that are shared across species is bolstered by the growing list of genes implicated in human language disorders that exhibit homologs in rodent and avian species (e.g., Bishop, 2009; Galaburda et al., 2006; Fisher & Francks, 2006; Paracchini et al., 2007).

C.2.3 Achieving synthesis requires the 6-part research strategy described next and in Fig. 5.

1. **Cognitive theories** (linguistic, psychological, computational models) organize and explain behavior across ages and typical and atypical populations. In particular, we search for nonlinguistic cognitive, social, and sensory factors on which language development depends.
2. **Functional brain region** data (functional magnetic resonance imaging [fMRI], electroencephalography [EEG] and near-infrared spectroscopy [NIRS]) are measured in experiments motivated by cognitive theory, with the goal of going beyond localization to an understanding of what

functions are actually performed in selectively activated circuits. Constraining computational models from the cognitive level based on spatiotemporal brain data is a key part of this process.

3. **Behavior genetic** analyses correlate genes and environment with behavioral, cognitive, and neural phenotypes, in the context of cognitive-based theories. An obvious tenet of behavior genetics is that the more data one has describing phenotypes, the more likely it is that correlations will be discovered. Data mining a large battery of linguistic and nonlinguistic assessments has the potential to turn up unexpected connections, and so inform cognitive theories. However, the more precisely an experiment isolates a theoretically relevant linguistic or nonlinguistic ability, the more informative genetic connections will be, and this will be a primary benefit of strengthening links to cognitive theory (rather than the modal focus on disorders).
4. Genes identified by behavior genetics and environmental variables are experimentally manipulated in **animal models** using methods of **molecular and behavioral neuroscience.** Linking patterns causally to human language requires close integration with human cognitive and neurobiological data and theory. Successful integration depends on maximally analogous behavioral and imaging techniques with humans and animals. Data from paths in steps 3 and 4 are used to create theories of how environment-gene factors drive development of intermediate neural and cognitive phenotypes, and how those manifest behaviorally.

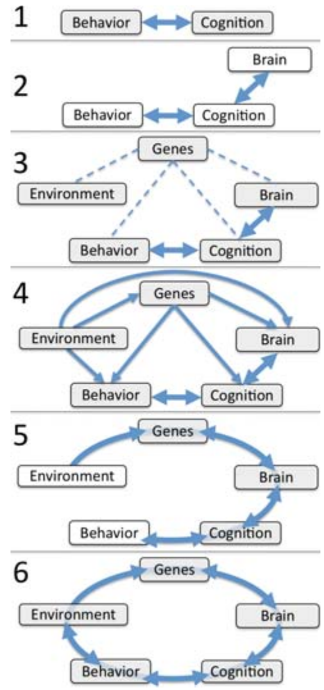

Fig. 5: achieving synthesis.

5. Human developmental studies (correlational) are coupled with animal studies (experimental) to examine how behavior feeds back to affect gene expression and all other levels – closing the loop (panel 6).

C.2.4 The necessary ingredients. To launch this synthesis, we need several key ingredients. The first is in place. IGERT funding would allow us to assemble the others.

☑ Faculty with cutting-edge research programs in linguistics, psychology, communication disorders, behavior genetics, and molecular and behavioral neuroscience motivated to achieve this synthesis.

☐ Formal mechanisms to establish communication and collaboration bridging disciplines (C.2-C.4).

☐ Scientists with sufficient knowledge of participating disciplines to understand fundamental theoretical and methodological principles. The training program is designed to achieve this with IGERT trainees, but this is also needed for current faculty. So our IGERT program must also **transform our faculty**, by providing formal and informal means for them to acquire this knowledge (C.4, C.5).

☐ Theoretical and analytic tools to grapple with complexity. *Dynamical systems theory* (also known as nonlinear dynamics or chaos theory), and in particular *self-organizing systems theory*, provide these tools. Originally developed in mathematical physics, this conceptual and analytic framework has had large impact in fields such as chemistry, evolutionary biology, and only recently has gained momentum in cognitive science (e.g, Thelen & Smith, 1994). Indeed, Indiana University recently initiated an IGERT applying dynamical approaches to psychology, neuroscience, and robotics – demonstrating the novelty and need for applying this framework to cognitive science. (Our proposal differs in striving for a unifying theoretical framework integrating the levels of analysis addressed in the Indiana IGERT with those of systems biology. This is feasible because we restrict our focus to language, whereas their efforts are united by theoretical approach rather than a unified theory.)

☐ Cohorts of Ph.D. students from participating disciplines immersed in a training program organized around this synthesis. Given the years of training required to achieve true depth in each field, it is not practical to train all students to specialist-level expertise in all disciplines. Instead, our training (C.4, C.5) will prepare them to engage in integrative research collaborations spanning conventional disciplinary boundaries. **Students are the most important ingredient**. They will literally bridge labs, making cross-disciplinary research possible. Their training will prepare them to pursue and exceed our vision when they leave our program and establish their own labs.

☐ Hands-on training in participating fields and in the practice of innovation; detailed next (and C.4, C.5).

A unique perspective. While our empirical-theoretical vision builds on important trends in cognitive and biological domains, and in some ways echoes earlier efforts (Elman et al., 1996; Thelen & Smith, 1994) the synthesis we propose is unique. A handful of research programs exist that tackle aspects of the synthesis in Fig. 4, but we are not aware of a single training program similar to ours, in language or any other cognitive domain. The biological scope of most cognitive scientists' research programs *tends* to end at the level of functional neuroimaging, and neuroscience and genetic approaches to cognitive domains *tend* to focus on correlations with disorders and rarely provide strong constraints on cognitive theories.

C.2.5 Fostering innovation in trainees and faculty. The framework outlined in Fig. 5 will require a high degree of innovation not just from trainees but also from faculty. While some of us are already engaged in research collaborations that stretch beyond conventional disciplinary boundaries, none of these achieve the full loop. Doing so will require the ability to cross disciplinary boundaries, innovating new theoretical and experimental approaches that will span disciplines, populations and species. This will require carefully planned educational and research activities, as we discuss in following sections. Our success depends on establishing an environment that facilitates creativity, innovation, and discovery – as well as the ability to transform the results of basic research into components of possible solutions to societal challenges (in, e.g., technology, education, and language disorders).

Our starting point is the report of the NSF Innovation and Discovery Workshop (Schunn et al., 2007). As the report reviews, several cognitive and social factors can facilitate or impede innovation. Key factors that support innovation include training in innovative processes, a mixture of solo and group brainstorming and planning, autonomy, diverse teams (in terms of expertise, background, and demographics), strong team identity, and an environment that permits one to fail often and early (Amabile & Khaire, 2008; Paulus & Brown, 2007; Sawyer, 2007). Our infrastructure is designed accordingly.

Innovation skills can be taught. We will institute training for IGERT trainees and faculty, and other interested members of the UConn community, primarily through annual workshops conducted by **Kristian Simsarian** (Computer Science Ph.D., Royal Institute of Technology, Stockholm), chair of the Interaction Design program at the California College of the Arts (CCA), and a fellow at IDEO (an internationally renowned innovation consulting firm). (See also innovation plans in C.4-C.5.) Dr. Simsarian will help us maximize our innovation environment, teaching concrete skills (e.g., best practices for brainstorming, which include a mixture of individual and team-based activity), and the process of identifying societal challenges to which our research may be relevant and then communicating basic science results in ways to facilitate application. **Emily Nava** (Linguistics Ph.D., USC) of Rosetta Stone (makers of software for language learning) will conduct sessions on innovation in language technology, and opportunities for trainees to pursue careers in industry. **Margie Gillis** (Ed.D., U. Louisville) is president of Literacy How and a senior scientist at Haskins Labs. Dr. Gillis will conduct workshops on how the path between basic science and educational practice can be shortened through direct contact between scientists, educators, and the public. Most of this 2-day workshop will be specific to our IGERT program. It will also include presentations by Dr. Simsarian, Dr. Nava, Dr. Gillis or others that will be open to the UConn community and to the public, as a starting point to foster innovation institutionally.

Group identity will be promoted by activities such as annual "IGORs" (**IG**ERT **Or**ientations), retreats (IGERTREAT), and conferences, and the weekly IGERT Talk Shop (all described below). ***Team identity*** for smaller groups will be fostered by the innovation incentive competition described below.

Collaboration infrastructure. Another crucial element for innovation is infrastructure that implicitly and explicitly promotes collaboration (Amabile & Khaire, 2008). We will create physical and virtual spaces to promote collaboration. The physical space will be the *IGERT Studio*, housed in a large former classroom that is part of the Psychology Shared Electrophysiological Resource Laboratory (PSERL, directed by PI Magnuson). PSERL is located in a building adjacent to both Psychology and Linguistics. A few Psychology and Communication Disorders labs are located there, but the building does not "belong" to any department, making it a neutral space that can be associated with IGERT. The room is occasionally used for PSERL hands-on instruction in EEG, but it will be configured to have a mix of lounge- and workspace for IGERT trainees. It will include some desks with workstations, but most of the space will be occupied by light sofas, chairs, and worktables that can be reconfigured quickly for individual or group work. "Smart" mobile whiteboards will be available to promote brainstorming and other discussion. The Studio will also be the site of weekly trainee lunches or dinners.

The virtual space will be an IGERT web server using open source Wordpress tools. Wordpress is an open-source platform for webpages, blogs, wikis, and a social networking platform ("Mingle"). These tools will allow trainees and faculty to develop their own web-based collaboration tools. Wordpress can be configured to permit flexible password-controlled access, so that groups of students can maintain their own private shared tools, our IGERT community can share another set of pages, and we can also publish open-access pages, blogs, etc., to share with colleagues elsewhere and the public. IGERT personnel and trainees will be encouraged to use Mingle as an internal social network where they can informally yet privately bounce ideas around, update each other on progress, and so forth.

Addressing societal challenges. Innovations from our IGERT program will address multiple societal challenges. (1) It will open new channels of communication between scientists through concerted formal and informal mechanisms designed to help us bridge disciplinary boundaries. Interdisciplinary connections may be difficult to detect because they are masked by differences in method, population, and domain culture. Humans are notoriously poor at detecting structural analogies, even in fairly simple problem solving domains (Gick & Holyoak, 1980). Hence, superficial differences can have pernicious, self-reinforcing effects that build walls between fields, making it increasingly unlikely that connections will be detected, even if domains converge on similar questions, damping potential for innovation and discovery. The innovation of preparing linguists and molecular neuroscientists, for example, to bridge jargon and other cultural obstacles in order to synthesize a new view of language, will have societal impact by accelerating discovery across domains. (2) Students and faculty will communicate directly to community members through outreach efforts. A formal outreach course provides the foundation (C.4). Students and faculty will establish dialog with policy makers, educators, parents, and industry, communicating scientific results and learning from those groups what challenges they face that science could address (thus, contact with these groups also presents an opportunity to discover new potential societal benefits). (3) A gulf has existed between basic human language science and language technology for decades, with the former providing few practical insights for the latter. Many language technology solutions (based on statistical mining of training corpora) break down in situations where humans readily adapt (to new accents, ambient noise, etc.), suggesting that human perception operates on different principles. Our research efforts linking, e.g., animal models in auditory neuroscience to development of speech perception have the potential to provide insights that could radically improve language technology. In addition, we will work with Dr. Simsarian (IDEO, CCA) and Dr. Nava (Rosetta Stone) to place students in industrial internships that will help identify technological challenges our research might address, and with Dr. Gillis (Literacy How) to place students in education and public policy internships.

Our ***innovation incentive competition*** will play a central role in our innovation efforts. Innovation will be defined as the product of creativity, with the goal is to discover a new approach, question, phenomenon, or other solution in basic science, education, outreach, or a societal challenge. We will use a tiered system in which individuals or teams of trainees apply for incentive grants (funded by the innovation incentive budget, augmented as needed by UConn funds; see C.5), and where smaller grants in particular allow trainee autonomy and impose minimal constraints. Faculty will participate in advisory roles in "inspiration" and "discovery" grants, and can be PIs for "seed" grants. We will encourage applications to include connections among IGERT Ph.D. programs and any other IGERT components (e.g., global perspective, broader impacts). Applications for incentive funding will be reviewed by the research committee two times per semester. Advisors will "check in" rather than "check up" on incentive-funded progress (maintaining autonomy), and if trainees are struggling, seek ways to help them maintain progress (important, given that salient progress promotes work satisfaction which promotes innovation which promotes intrinsic motivation – and more progress; Amabile & Kramer, 2011).

Autonomy is important, but junior students will need structure and guidance. This will be provided by

IGERT courses (C.4), which culminate in team-based innovation applications, and frequent workshops on innovation. Projects will ideally be tied to students' Ph.D. research programs and form the foundations for dissertation research. Since many of these will be team projects, the research and academics committees (C.5) and Ph.D. advisors will meet to ensure an appropriate balance between team and individual efforts.

"***Inspiration grants***" will be small ($500-2000) grants to individuals or teams. One-page applications will describe a general theme (e.g., "experiments in sentence processing", "better ways to communicate scientific results to the public", "develop parallel conditioning paradigms for rats and human adults", "training in multi-voxel pattern analysis", "implications of mammalian cochlear processing for speech recognition technology", "increase participation by underrepresented groups", "make the IGERT Studio more innovation-friendly"). Trainees will be encouraged to pursue risky ideas in which failure can be detected early, so they can rapidly modify their approach and try again. These grants will allow considerable autonomy, an improvisational approach, and 'permission to fail,' key ingredients of innovative environments. Trainees will submit progress reports each semester. Further funding will require that funds were used toward innovation – not that efforts were successful. This is not the norm in academic funding, where comprehensive plans are required to obtain funding and where continued funding depends upon substantial, published progress – a norm that inhibits innovation (Sawyer, 2007). (Professional development grant writing primers [C.4] will prepare trainees for that norm.)

"***Discovery grants***" will be up to $10,000. The emphasis will be on teams with diverse disciplinary expertise (given greater efficacy compared to individuals or homogenous groups; Sawyer, 2007). In addition to a theme, applicants will articulate how their activities will do one or more of the following: lead to progress towards the unified language systems theory in Fig. 4, improve education or outreach, or address a societal challenge. Applicants will describe how their team and plans provide necessary ingredients for innovation, and how they will organize their efforts around the science of innovation. Once funded, applicants will have autonomy to adjust plans and to pool funding with other inspiration or discovery teams. Only radical changes (changing themes) will require checking-in with the research committee. As with inspiration grants, discovery teams will submit brief progress reports each semester.

"Seed grants" to faculty-led teams will be supported primarily by UConn funds (C.5). These will be awards to new collaborations spanning disciplinary boundaries. Preference will be given to applications with the most "stretch" (e.g., linguistics + behavioral neuroscience > developmental psychology + communication disorders), and with the greatest potential for innovation.

Innovation Showcase. While intrinsic motivation is the most crucial element in individual progress and work satisfaction, it can be supported and reinforced by public recognition of achievement (Amabile & Kramer, 2011). Each semester, an Innovation Showcase will provide a forum for trainees to present their most innovative work, and awards will be presented for the most innovative projects.

C.2.6 Global perspective will be achieved via internships and regular interaction with **9 international sites** with research interests, instrumentation and faculty related and complementary to our own, using the optional IGERT funding for international internships. Letters of support are included from (1) The Basque Center on Cognition, Brain and Language, Spain; (2) U. Jyväskylä, Finland; (3) National Yang Ming U., Taiwan; (4) the Institute for Neuroscience at U. Salamanca, Spain; and (5-9) Nanzan U.'s "metadepartment" of linguistics, a consortium including UConn Linguistics and departments in Japan, the U.K., Taiwan, India and Italy. Sites 1-3 focus on cognitive neuroscience of language, and provide ready access to tools and expertise that are not available to us in CT (MEG, TMS) or that are at some distance from us (fMRI). U. Jyväskylä also has a significant program in epidemiological genetics. The Salamanca site already partners with BNS in a study-abroad program for undergraduates interested in neuroscience.

Regular **videoconference meetings** with the international sites (and IGERT trainees who are abroad) will provide contact with global perspectives for all trainees and faculty. We will further facilitate global perspective by welcoming **exchange students** from the international sites. Those students will need their own funding, but we will work with the UConn Office of Study Abroad to facilitate local details. Our plans for the international component are described in more detail in Section C.9.

C.2.7 Value added. UConn and Haskins are already home to many language scientists with interdisciplinary interests. Faculty and students from CDIS, LING, PAC, DEV and CLIN meet weekly at our Language and Cognition Brownbag. Many are already engaged in collaborations that span traditional academic boundaries. However, these are "easy" collaborations among researchers with closely aligned interests and training, in projects that do not require student effort or do not require students to stretch beyond their Ph.D. program training. While even more "easy" connections could be made, more tantalizing connections feel just out of reach. Many of us have had conversations after talks, excitedly pointing out connections between our research and a colleague's that just an hour earlier had seemed unrelated. Most conversations end with the realization that the connection cannot be made, for want of students with interdisciplinary interests and training who could bridge faculty research programs.

These conversations have become even more frequent as those of us in CDIS, LING, PAC, DEV, and CLIN tentatively approached our colleagues in PNB and BNS and Dr. Grigorenko at Haskins/Yale to discuss working together on this IGERT proposal. Skepticism evaporated as we discovered many connections and the vision of a unified theoretical and empirical framework emerged. But bridging disciplines is a significant challenge. Students rarely enter BNS with strong interests in language, and students in other programs seldom arrive with significant background in neuroscience. The major motivation for this IGERT is to establish a transformative training program that will attract students with interdisciplinary interests and prepare them for a career of boundary-crossing collaboration, while simultaneously catalyzing the enormous potential for "hard" (methodologically and disciplinary long-distance) collaborations, leading to the theoretical and empirical framework of Fig. 4.

C.2.8 Objectives. (1) We will recruit ~**27 Ph.D. students**, and strive for **100% retention** and Ph.D. conferral through multiple methods of gauging student progress and assessing and addressing student satisfaction, including regular meetings with primary advisors, assignment to a second breadth faculty mentor, and student support groups. (2) We will strive to recruit a **diverse student body**, increasing participation by members of historically underrepresented groups in all of our Ph.D. programs. In addition to standard recruiting practices, we will use internet strategies (online newsletter with particular aim at underrepresented groups, Google ads, social networking sites). We will also build on multiple existing UConn programs, and we will endeavor each year to improve diversity in our ranks and to innovate new strategies for achieving that goal (see Section C.4). (3) We will provide students with broad and deep expertise in a home Ph.D. program, and prepare them for collaborative research spanning conventional disciplinary boundaries through classroom- and lab-based training to the methods and principles of the other participating domains. (4) Trainees and faculty will become adept through formal training and hands-on experience in the practice of innovation and connecting research products to societal challenges. (5) We will prepare rigorously trained and productive students to be leaders in the next generation of interdisciplinary language sciences, and place them in strong positions in industry and as postdocs and faculty. **Trainee placement** will be supported by conventional means (ensuring students meet concrete goals for presentations and journal articles), industry internships and contacts (C.2) and indirectly via promotion of the program through advertising and an annual conference. (6) We will achieve these goals through a highly structured and detailed plan for **organization and management**: the PI will rely on an **Executive Committee,** 7 smaller committees, and a **program coordinator** to plan, coordinate and track all aspects of the program (see C.5). (7) Progress and momentum will be measured and promoted through annual evaluations, with oversight from an **external assessment consultant** and **external advisory board** of prominent scientists. (8) We will establish infrastructure and culture necessary for our training program to persist beyond NSF funding. We anticipate that **all elements of the training program will be sustained**, based on faculty and institutional commitment, including the establishment of a new certificate program in Language Sciences. Further, the collaborations catalyzed by IGERT funding (C.3.3) will lead to external funding including support for new trainees and international experience.

C.2.9 Other activities. In addition to research and educational efforts described in C.3 and C.4, we have designed several other activities to build cohesion among faculty and students. These activities will be supported by $120k/year to be provided to our training program by UConn (see C.5 and letters of support). These activities will include the annual IGOR (**IG**ERT **OR**ientation), quarterly IGERT dinners where a faculty member or trainee will deliver a talk after the dinner, an annual retreat (IGERTREAT) at the UConn Avery Point campus (on the Connecticut coast), an external speaker series, and an annual conference. The retreat will be both a fun event celebrating our progress, as well as an opportunity to take stock as a group with substantial time focused just on IGERT. Semi-annual Innovation Showcases and awards will take place at IGOR and IGERTREAT. The annual conference will adopt a theme related to our IGERT each year, and speakers will include members of our faculty and students as well as a few prominent external speakers. This event will be advertised broadly, serving to communicate our approach to the academic community and also as a potential recruiting mechanism.

C.3 MAJOR RESEARCH EFFORTS

Comprehensive understanding of language plasticity requires detailed, theory-driven behavioral and cognitive neuroscience phenotyping of typical and atypical developmental trajectories, allowing conventional theory testing along with behavior genetic analyses. Unpacking genetic correlations requires experimental investigations with animal models and molecular genetics to reveal neurodevelopmental and environmental contingencies underlying typical and atypical developmental trajectories. Current research programs are well-described by the diagrams in Fig. 1. We will continue these research programs; data from current 'modal' approaches will be instrumental in achieving our vision of a unified cognitive-biological framework (Fig. 4). This vision will begin from current approaches schematized in Fig. 1, using a team-based approach to the research strategy for achieving synthesis (C.2.3).

A team-based approach. Ideally, programs would initially conceived to involve all 6 steps in the research strategy outlined in Fig. 5. Our vision requires collaborative teams of scientists from cognitive and biological disciplines. As discussed in C.4, a team-based approach permeates our course-based training. Each IGERT course will be placed in the context of the vision outlined in Fig. 4, and culminate in group projects where teams write innovation incentive grants (C.2) proposing team-based research projects that integrate cognitive and biological theories, tools, and empirical results.

We can envision literally dozens of projects consistent with this vision that current faculty could carry out in new collaborations (forming the basis for the matrix in Fig. 6). In this section, however, we focus on 6 possible themes for projects that could be proposed by student teams and then refined and implemented by adding faculty advisors to teams.

This approach will be transformative in several ways. **First**, the vision of a unifying theoretical and empirical approach to language will transform language science by forging deep theoretical connections between cognitive and biological approaches.

Second, the team-based approach affords a synergy that is greater than the sum of its parts. Deep knowledge of each cognitive and biological approach to language is required to achieve the vision of Fig. 4. It would be impractical to attempt to train scientists from cognitive and biological domains to become specialists in each domain. Instead, trainees and faculty need deep knowledge of their home domain and sufficient knowledge of theories, methods, and techniques of others to understand those literatures and communicate and collaborate with scientists from the full range of cognitive and biological approaches.

Third, if this approach is to permeate our hands-on research training, we need to transform our approach to dissertation research. Specifically, we will explicitly

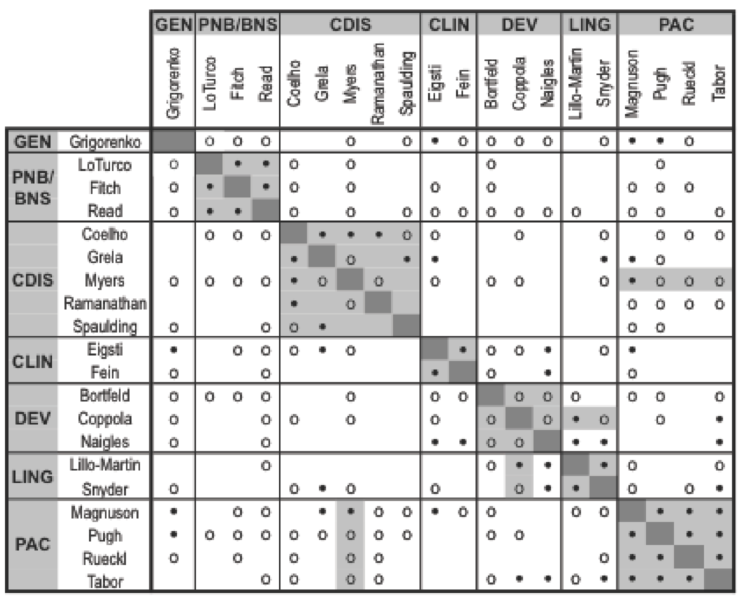

Figure 6: Current and potential collaborations. Black circles: existing research, grant writing, or teaching collaborations. White circles: collaborations IGERT funding would likely catalyze, given students with appropriate interests. Light grey shading indicates collaborations within areas. Most new collaborations would involve 3 or more faculty.

encourage student research teams to propose sets of yoked dissertations. Each student will write a dissertation that is (at least) comparable in theoretical and empirical contributions to typical dissertations in her field. Each student's efforts will include significant independent data collection, analysis and interpretation to satisfy home Ph.D. program standards. However, team members' dissertations will also overlap, with the possibility of including shared data, and with the expectation that theoretical development within dissertations will reflect team effort in addition to each student's independent efforts.

It is easiest to illustrate to how we envision this approach by examples. As we describe our examples, we will also address potential challenges facing a team-based approach to Ph.D. research.

a. Gene-brain-behavior connections in specific language impairment (SLI). Work on gene-brain-behavior connections in typical and atypical language development (**Pugh**, **Grigorenko**) has begun to identify associations between candidate genes, measures of structure and function using MRI, and typical and atypical language development (Palejev et al., 2011). Individual differences in neurochemistry (e.g., region-specific prevalence of metabolites glutamate and GABA) assessed with Magnetic Resonance Spectroscopy (MRS) appear to modulate these gene-brain-behavior trajectories. Building on this work, a team of students advised by **Pugh** in PAC, **Snyder** in LING, **Grela** and **Spaulding** in CDIS, **Fitch** in BNS, **LoTurco** in PNB, and **Grigorenko** could develop linked dissertation projects. The LING student could examine corpora of typical child speech to identify linguistic structures with divergent acquisition trajectories (early vs. late-acquired, or linear vs. "U"-shaped [initially strong performance on the structure followed by a decline and recovery] trajectories), and develop a theoretical account of acquisition processes. The CDIS student could design protocols for typically developing children and children with SLI (who show normal ability in all domains except language) designed to elicit those structures, and assess individual differences in behavior, possibly identifying new patterns of strengths and weaknesses in SLI. The PAC student could design fMRI (for functional region activations) and MRS (for distribution of metabolites) protocols using the same linguistic structures, test typical and children with SLI, and determine whether functional or neurochemical differences correlate with individual differences in comprehension of the structures. Along the way, the CDIS and PAC student could work with **Grigorenko** to collect DNA samples. The students could then work with **Grigorenko** and **Mandoiu** (computer science) on behavior genetic analyses to identify genetic associations with individual differences. The BNS student could use a variety of techniques (e.g., "knockout" mice with candidate genes inactivated, or neurochemical methods to manipulate prevalence of metabolites) to establish the neurodevelopmental details and cognitive abilities causally linked with candidate genes. Discrepancies between animal model results and human data would in turn motivate further experimentation with human subjects.

The division of labor implied by associating topics with students from different areas would not be strict. While students would need to write largely independent dissertations, overlap would be encouraged (e.g., more than one might make use of the behavior genetic results), and students would be encouraged to assist each other in technical aspects of their projects when possible (e.g., the BNS student might take part in neuroimaging. Further, the default expectation would be that all team members would contribute intellectually to all resulting papers and so share authorship. This would boost (but not inflate, as each student would contribute intellectually) students' publications, improving placement.

These are all plausible core projects for dissertations in each field, but each stretches far beyond the normal boundaries of each home discipline. While a remarkable individual student somewhere along the LING-CDIS-DEV-PAC-BNS chain might conceive of one isolated project based on literature reviews in other fields, this linked team approach will be very different. In the ideal case, a group of students would develop the basis for the group project as their final project for a foundations course. Once they had settled on a topic (which might be inspired by the linguist telling the group about a peculiar phenomenon she had noticed in a corpus; or the BNS student might point out that her lab had an excellent rodent model for the genetic basis of working memory, and if the group could find linguistic structures that depend heavily on working memory, they might be able to draw new links; or the CDIS student might report a new relative strength in dyslexic children that showed up with a particular syntactic construction), the students would discuss the projects with their advisors, and then the entire group (students plus advisors) would meet to plan a strategy. Or, the project might emerge more serially, with one student noticing a link from data in an ongoing project to a theory in another field. After finding a collaborator in that field, the two of them might make a connection to a third field, and so on. In such cases, the project might emerge over a period of a few years. Project planning will take this into account.

Indeed, even on the former model, where the team conceives the project together from the start, a challenge will be keeping projects synchronized. To address this, when faculty advisors join research teams, one key responsibility will be to map out timelines for each dissertation, and contingency plans in case any component of the project is delayed (e.g., if behavior genetic analyses are delayed, students working with animal models would need alternative bases for generating genetic or neurodevelopmental hypotheses – and so multiple candidate hypotheses will be required in each dissertation proposal).

b. Working memory and narrative discourse. While working memory is clearly important in language processing, most work on its specific role remains largely correlational (e.g., finding that poor readers have poor phonological working memory), and the specific mechanistic connections between working memory, low-level phonological processing, and high-level language abilities like the production and comprehension of complex narratives, remain largely unknown. One obstacle is that the ranges of abilities and correlations among component language and memory abilities are rather narrow in typical populations (i.e., college students). A CDIS student advised by **Coelho** (who has extensively studied narrative discourse in TBI [traumatic brain injury] and aphasia) might partner with a PAC student working with **Rueckl** on working memory in typical language and a LING student working with **Snyder** or **Lillo-Martin**, in combination with another faculty member working with special populations (**Myers** [aphasia], **Ramanathan** [TBI], **Eigsti** or **Fein** [ASD], **Grela** or **Spaulding** [SLI], or **Lillo-Martin** [sign language]) to employ a comparative population approach. **Grigorenko** could guide the students in DNA collection and behavior genetic analyses. A student working with **Fitch** or **LoTurco** might join the project to assess causal effects on working memory related to genes implicated by behavior genetics.

The CDIS student might seed the project by describing how narrative abilities in aphasia and TBI decline, which aspects are likely to recover spontaneously, which respond to intervention, and how narrative abilities pattern with individual differences in working memory. The LING student could search for systematic grammatical variations in the items used in clinical assessments of narrative ability, potentially discovering grammar-based alternatives to the working memory hypothesis, and/or providing a basis for better understanding the role of working memory in narrative processing. A student in DEV working with **Naigles** or **Coppola** might examine working memory and narrative abilities at different ages, in order to track how the two abilities relate over development. A PAC or CDIS student could work with **Myers** to use structural and functional neuroimaging to identify brain regions damaged in patients, and brain regions in healthy adult controls that are selectively activated in narrative processing. The student team could partner with **Grigorenko** to collect DNA and perform behavior genetic analyses. As in the previous example, the behavior genetic results would provide a foundation for causal hypotheses to be tested in animal models. A PAC student and/or a CDIS student working with **Ramanathan, Tabor** and/or **Rueckl** could construct an abstract connectionist (neural network) learning model that would simulate a working memory mechanism and essential aspects of sentence processing. Examinations of how the two mechanisms interact over learning in the model would help motivate a theory of how working memory interacts with discourse processing. Those students could then work with a BNS student (supervised by **Read**) to extend their model to a neurobiologically plausible model of the brain regions involved and the types of circuits within those regions, with the goal of refining animal model hypotheses and experiments. Next, a BNS student (working with **Fitch**, **LoTurco**, and/or **Read**) would devise animal model experiments motivated by the results at other levels. Discrepancies between animal model results and the computational model or human data would in turn motivate further simulations or human experimentation. Again, the topics associated with each discipline would constitute plausible core dissertation projects. Together, the projects would provide the basis for an integrated cognitive-biological theory of working memory in language development and processing.

c. Plasticity after brain injury: implications for the basis of speech. Aphasias (language production and comprehension difficulties that result from brain injury) have been a major source of neuropsychological data about the neural basis of language, beginning with the documentation of seemingly distinct receptive and expressive aphasias by Broca and Wernicke in the 19th century. Over the last 150 years, it has become clear that an entire continuum of deficits occurs, from nearly purely expressive to nearly purely receptive to anything in between, and that there is a strong but not complete correlation between injury location and observed deficits. The fact that individuals arrive at similar levels of ability despite substantial individual variation in the precise neural tissue supporting language processing suggests that there is substantial plasticity in the neurobiological development of language. This variation likely follows from small and large differences in environment, genes, neurochemistry, other cognitive abilities, and experience. In addition, following stroke, there is substantial individual variation in recovery from aphasia. Some patients experience substantial spontaneous recovery, while other patients with similar injuries do not. Some patients respond well to intervention, and others do not. While understanding these variations would have obvious clinical applications, it would also have large basic science implications for our vision of an integrated cognitive-biological theory of language.

On learning about aphasia in a "Foundations" course (C.4), and the fact that ischemic strokes are a major cause, a student from the **Fitch** lab might suggest a project based on that lab's mouse model of "middle cerebral artery occlusion" (MCAO) unilateral ischemic strokes. In initial work, the lab has gone beyond typical studies of MCAO neuropathology (cell death progression, microglia, caspases) to measure comprehensive pre- and post-injury neurobehavioral profiles. After injury, MCAO mice showed rapid auditory processing deficits (silent gaps but not simple tones were harder to discriminate), and deficits in sensorimotor learning. They also showed deficits in spatial and non-spatial learning/memory (maze) tasks. To uncover the basis for this interesting constellation of deficits, a student working with the MCAO model could: examine to what degree the implicated abilities overlap in neural and genetic bases (by inactivating candidate genes in knock-out strains, or using more focal lesions); assess what genetic, neural, and environmental factors predict propensity for or timing of spontaneous or intervention-based recovery; and how these factors interact with age at injury. The student could then partner with a CDIS student from **Coelho**'s lab. Hypotheses as to the genetic basis of stroke recovery could be tested in human patients using cognitive experimental methods, measures of response to intervention, and behavior genetics to compare precise 'neurobehavioral' profiles of patients with their genomic heritage.

d. Hyperlexic vs. typical trajectories in reading development. Hyperlexia is a rare occurrence in ASD where a child exhibits a stereotyped interest in reading aloud (decoding) that leads to remarkable proficiency at this skill. (Stereotyped interests are a hallmark of ASD; some children develop intense interests in music, others in train schedules, etc.) Hyperlexic children (3-6 years old) are able to read complex, adult-level single words with nearly perfect accuracy, and in some cases, can even read adult-level texts with high levels of accuracy and nearly normal prosody, but always with low comprehension. This inverts the normal timeline of reading development, where the phonology-semantics mapping is established prior to intensive contact with orthography. As such, hyperlexia presents opportunities to examine the implications of phonology-semantic connections, the neural organization of language, and possible genetic features that correlate among hyperlexic children (vs., e.g., hyperlexia emerging through 'accidents' of experience that lead the child with ASD to develop a special interest in decoding).

A student in CLIN (supervised by **Eigsti** and **Fein**) might suggest the topic to a student project team. The team might then devise a project in which children with hyperlexia, other children with ASD and repetitive interests in another kind of procedural skill (e.g., playing a musical instrument), and other children with ASD and repetitive interests in a knowledge domain likely to be shared by many typically developing children (e.g., dinosaurs). Typically developing control groups would include age-matched children and children matched on skill (for reading or music performance) or knowledge of dinosaurs with ASD children. All groups would be exposed to print (reading aloud, and passive listening as printed words appear on a screen and are pronounced), music, and dinosaur knowledge tasks, as well as batteries of linguistic and nonlinguistic assessments and experimental tasks. These groups would allow hyperlexic and typical reading to be compared, as well as hyperlexia to be compared to another procedural stereotyped interest, and to a conceptual stereotyped interest (dinosaurs). The CLIN student would take the lead on recruitment, assessment, and conventional behavioral results (e.g., speed of processing or ability to focus attention in each domain). A student from PAC supervised by **Magnuson** could contribute

EEG-based methods for a measure of large-scale changes in neural firing in response to each domain. These methods could be especially useful with younger children and children with ASD, as EEG can provide data even when children fail to make behavioral responses or fail to attend to stimuli (though the actual EEG patterns change under those circumstances. The CLIN or PAC student (or another student) could work with **Ramanathan**, **Rueckl**, **Tabor** or **Magnuson** to implement 2 versions of the "triangle" connectionist model of reading (e.g., Harm & Seidenberg, 2004). One would be trained with a typical trajectory: phonology-semantics mappings would be well-learned before the model is exposed to orthography. In the other "hyperlexic" version, orthography training will begin before phonology-semantics mappings are strong. The networks could then be compared on various dimensions, such as whether semantics play a strong role in irregular sound-spelling mappings (which is normally the case in the model and in human readers). Differences between the models could motivate further behavioral experiments, or tests of the neurobiological model of reading **Pugh**, **Rueckl** and colleagues have proposed based on neuroimaging data. For example, less early reliance on semantics might predict greater activation in hyperlexic children of "non-semantic" brain regions (dorsal pathway and the fusiform 'visual word form area'). Whether this prediction holds or not will be important information for linking the neurobiological theory of reading to the connectionist triangle model. Failures to confirm predictions of the model with neuroimaging would suggest that the computational framework needs to be reconceived.

Behavior genetic testing in this project may not find genetic patterns that map onto specific stereotyped interests. Given the skill-based nature of decoding, assessments would include tasks that tap into implicit memory (the larger domain of memory under which procedural memory falls), one of **Eigsti**'s foci. Indeed, implicit memory has been intensively studied with animal models and that literature can be used to devise human experimental paradigms to target aspects of implicit memory for which genetic, neurochemical, and neurodevelopmental pathways have been outlined in animal models.

e. Grammatical conservatism and language impairments. **Snyder** (2007) has discovered that children exhibit striking "grammatical conservatism" (GC): reluctance to attempt to produce structures when they are uncertain of the structure's precise formulation, such that they produce many more errors of omission than commission. This imbalance of error types suggest that children who are still in the process of acquiring their language can nonetheless use the portions of the language that they have figured out and (i) the language faculty can function surprisingly well before all acquisitional decisions have been made, and (ii) aspects of acquisition may be deterministic – that is, the paucity of commission errors may reflect deliberate inhibition. However, **Tabor** and **Snyder** have recently conducted simulations with self-organizing networks that suggest that absence of commission errors emerges naturally for learning certain types of structures – without any analog to deliberate executive control. The simulations also suggest that at critical junctures over learning, the system can be perturbed such that it settles on an incorrect 'formulation' of a structure and never recover. This suggests a new hypothesis for the basis of some grammatical problems observed in disorders such as SLI.

A student team might propose a research program based on these observations. A student in LING and a student in PAC might use corpora or experiments to test whether predictions from the self-organizing network about which structures should be least susceptible to commission errors. They might partner with a student in DEV to devise experiments to determine whether children who exhibit grammatical conservatism exhibit conservatism in other learning domains (e.g., a tapping imitation task where the rhythms become more complex), and with a student from BNS to develop an analogous task for an animal model. A student in CDIS could use those tasks with children with SLI to test whether those children's consistent errors pattern with the network's predictions of what sorts of structures should be most susceptible to 'incorrect settling,' and again whether conservatism is observed across domains or is language-specific. DNA sampling with each population and species would allow behavior genetic analyses that could uncover genetic correlations with grammatical conservatism. Direct manipulation of identified genetic factors in animal models would allow the team to examine what aspects of cognition and behavior may support this seemingly language-specific behavior.

f. The auditory bases of speech perception. In the past 10 years, advances have been made in our understanding of the neural mechanisms which process the spectral and temporal cues which distinguish the sounds of speech. Studies using animal models have led to a better characterization of how genetic variation leads to differences in an animal's ability to detect spectral and temporal cues in the acoustic signal. The application of imaging technology (NIRS, ERP, and fMRI) in human infants has begun to provide insights into shifts in neural resources over the course of speech acquisition. Development of new imaging techniques has led to a better understanding of the topography of speech sounds in the adult human brain, and to models of the functional roles of frontal and temporal regions in processing the sounds of speech. Despite these advances, the insights gained from animal models remain relatively unconnected to human models of speech perception. Likewise, the functional architecture of adult speech perception is still largely uninformed by models of neural development across the lifespan. In our group, researchers are independently studying the neural correlates of speech perception using animal models of auditory perception (**Fitch**, **Loturco** & **Read**), human developmental cognitive neuroscience (**Bortfeld**) and adult human neuroscience (**Myers**). A student team might observe that these researchers share a common experimental paradigm: measuring neural and behavioral responses to oddball (infrequent) stimuli in the context of a string of standard stimuli, for instance, a 'da' sound in a string of repeated 'ga' stimuli. A team made up of students from BNS, CDIS, DEV, and PAC could propose parallel studies using neural recording and genetic studies in animals, imaging studies in human infants and adults, and behavior genetic analyses as a bridge between them. For instance, using the same stimuli, the team could investigate categorical-type responses to learned speech and non-speech categories in knock-out mice, in infants, and in adults. In particular, the students might focus on a crucial problem like *rate normalization*. Human listeners have amazing tolerance for changes in rate. A sound that is perceived as /w/ under a fast speaking rate is perceived as /b/ under a slow speaking rate (Miler & Baer, 1983). Thus, the system normalizes sound patterns to the context of speaking rate. How humans do this is unknown; understanding how we solve this problem would have large implications for speech technology. Animals could be trained using a conditioning paradigm to categorize phonemes context-dependently as a function of speaking rate. To the degree that the animals are able to map rate-dependent signals (surface acoustics) to rate-independent categories (phonemes), optical imaging studies of rodent brains could lead to new insights into the basis of rate normalization in humans because circuits identified by optical imaging could (a) be further analyzed at the cellular level and (b) be used to hypothesize candidate homologous brain regions in humans that should be involved in rate normalization.

This is just one example of what could be done in this domain. Ultimately, work in this vein will help us gain traction on classic questions in speech perception, such as: How do different neural resources process spectral and temporal properties that distinguish the sounds of speech? How is sensitivity to speech contrasts acquired, in infancy and in second-language learner?

C.4 EDUCATION AND TRAINING

C.4.1 Seven primary components. Our classroom-based training dovetails with our research efforts, immersing students in our motivating theme (understanding language plasticity from the foci of genes, brain, cognition and computation), providing them with foundational training they need to participate in and eventually lead integrative research teams working towards our vision of a unifying synthesis of cognitive and biological approaches to language. **Innovation** and **societal benefit** are emphasized throughout the curriculum. **All** core and elective courses begin by placing the course in the context of how it will help students achieve the empirical and theoretical vision shown in Fig. 4, and all courses culminate in **final group innovation projects**, in the form of innovation incentive grant applications (C.2.5). All courses also include review of innovation workshop principles, practice in group and solo brainstorming, and several include hands-on experimentation, analysis, and/or modeling with cutting-edge techniques. Societal benefit is addressed in each course by recurring discussions of possible impact on policy, education, and technology, and occasional guests from those communities.

Our core curriculum also forms the core of the new **Language Sciences Certificate** program approved by CLAS. The requirements are completion of the 5 Foundations courses and 3 required "J-Term Primers" described below. During IGERT funding, non-IGERT students may apply to the certificate program. The academics committee will review applications. Non-IGERT students admitted will officially become "IGERT associates" and will be invited to all IGERT activities (but will not be funded).

Following NSF funding, the certificate will persist, demonstrating long-term institutional commitment.

(1) Foundational core courses are designed to bring trainees up to speed sufficiently to allow them to become conversant in each participating field and prepare them for specialized training should they wish to pursue it. *This knowledge is the first essential ingredient in preparing students to participate in the empirical and theoretical framework shown in Fig. 4.* Foundational courses will be cross-disciplinary in nature, each with significant content in genes, brain, cognition, and computation. All trainees will be expected to participate in **5 new core courses** (described below). Depending on program, 1-4 of these will count towards Ph.D. requirements (see C.4.3 for strategies for programs with heavy course requirements).

a. Foundations 1: Genomic Sciences, Brain, and Computation. Introduction to themes that are most cross-cutting, most in need of technical background, and least likely for all trainees to have been solidly trained in as undergraduates. This course in particular lays out the vision of the empirical-theoretical framework from Fig. 4, and provides the core knowledge needed to participate in that vision.

b. Foundations 2: Language Structure and Psycholinguistics. Students in this course gain an appreciation for the complexity of speakers' tacit grammatical knowledge, and for the feat of child language acquisition, by constructing explicit, testable theories of grammatical phenomena in unfamiliar languages (e.g., Navajo, Georgian, Mohawk), and testing them against additional data from the language. Emphasis is placed on using theory to answer the logical problem of language acquisition (*How can learning reliably occur, given the seemingly impoverished input that even typically developing children receive?*) to theories of atypical language development. Moreover, by reviewing relationships between linguistic models and brain-inspired psycholinguistic models, the course will provide a foundation for spanning the large gap between neural-level and grammar-level understanding of the world's languages.

c. Foundations 3: Neurodevelopment and Plasticity. Foundations in: neurodevelopmental processes (neurogenesis, migration, synaptogenesis, pruning, and the genetic mechanisms that regulate them); neuroembryology and phylogeny; developmental plasticity (sculpting of cortical circuits through intrinsic and extrinsic experience, teratology, deprivation and re-organization); cognitive neurodevelopment; and genetics of neurodevelopmental pathology (SLI, dyslexia, ASD, Williams syndrome). Such knowledge-sets are necessary for all students to achieve a systems perspective on language development.

d. Foundations 4: Typical and atypical language development. These comparisons will provide a window into mechanisms and processes of language development in 3 ways. (1) For content areas (e.g., lexical, syntactic, and pragmatic knowledge), we will interleave readings focusing on typical and atypical language profiles. (2) We will characterize linguistic knowledge using data drawn from naturalistic approaches, psycholinguistic experiments, clinical assessments, genotype/phenotype comparisons, and intervention/plasticity. (3) We will integrate research on underlying causes/mechanisms of atypical language outcomes with the cognitive and computational processes assumed to be operating in typical acquisition, and illustrate how atypical trajectories and outcomes inform fundamental theory.

e. Foundations 5: Neurobiology of typical and atypical language. The goal of this course is to provide students with the tools to critically evaluate primary literature on the neurobiology of language in both typical and atypical populations, filling important historical and bidirectional gaps between cognitive neuroscience and language impairment research, and emphasizing basic science insights that originated from observations in atypical populations. We begin with methodological challenges and contributions that neuroimaging, computational modeling, and impaired populations present, and complete the course by examining important case studies where data from clinical populations, computational modeling and neuroimaging evidence can be integrated to guide formation of more complete models of language function. Ultimately, students will be conversant with techniques necessary to create multi-disciplinary research programs that integrate the many sources of evidence available to language scientists.

(2) IGERT Talk Shop. A weekly forum for IGERT trainees, associates and faculty to discuss research, international plans, professional development, community outreach, annual assessments (C.6) and other topics. The name is a pun that reminds us of 2 important goals: talking shop, but also critiquing and honing 'talk' skills. Presentation of research from each contributing domain will push students and faculty to (a) learn to present their research to scientists from outside their specialties and (b) "learn to listen" to presentations from outside their specialties. We will enhance exposure to research from other disciplines with discussion sessions aimed specifically at identifying difficulties in communicating across domains. These discussions will make it easier for students to admit communication problems and work together to solve them – an essential skill for working in interdisciplinary research teams.

IGERT themes	Innovation	Methods	Programming/ Statistics	E-Prime	Professional Development
Brain Science Primer	Brainstorming 101	Eye tracking Hands-on	R bootcamp	Basics	Ethics
Behavior and molecular genetics of language	Innovation incentive application workshop	NIRS Hands-on	Matlab bootcamp	E-Basic programming	CV and homepage workshop
Historical overview of connectionist models	Pioneers in science	EEG/ERP analysis crash course	Visualizing data	E-Merge and E-DataAid	Interview workshop
Syntactic analysis for nonlinguists	Face time: Ph.D. paths in industry	SPM Primer	Growth curve analysis	Hardware and software timing	Entering Mentoring
Embodied cognition	Face time: Policy makers	Lingustic corpus analysis	Multi-level modeling	E-Prime for EEG and fMRI studies	Grant writing

Table 1: Examples of likely J-Term topics in six categories.

(3) J-Term Primers. The scope of our project is large. Expanding core courses would create difficulties in completing home Ph.D. requirements. We will fill gaps with "J-Term Primers," taught in the January semester break. These will run 5-30 hours over a period of 1-10 days. Three key courses will be required: (a) **Brain Science Primer** (3-day essential coverage of neuroanatomy and neurochemistry), (b) an intensive, 5-day course in **Behavior and Molecular Genetics of Language** to be taught by participant **Grigorenko**, a leading expert on the behavior genetics of language, and (c) **Ethics and responsible conduct of research.** Several possible additional courses are listed in Table 1. These are *examples* of likely topics, and each year, we will offer 4-5 topics. However, we will tailor each year's curriculum to student interests, also leaving open the possibility to expand the topics. "Face time" courses will bring in (or bring students to) policy makers, educators, members of industry, and other community members for workshops on societal challenges. A secondary but important goal of the J-Term program will be to **provide students with teaching experience** by giving them opportunities to lead primer courses. In particular, by the 3rd year, students would be able to teach courses on specific tools or software. Instructors and community visitors will receive modest honoraria.

(4) IGERT elective courses.

New IGERT elective: **Techniques for brain and language (neuroimaging)**, *E. Mencl, Director of Neuroimaging, Haskins*. Introduction to magnetic resonance imaging (MRI) with emphasis on language, covering the physics of MRI, and hands-on fMRI design, acquisition and analysis. Advantages and disadvantages of MRI, EEG/ERPs, and MEG will be discussed. Students will leave the course with an enhanced ability to interpret neuroimaging findings in the context of linguistic and cognitive theory.

New IGERT elective: **Intro. to computational neuroscience**, *H. Read, BNS*. Explores domain-specific and -general aspects of organization in sensory and motor cortices from a computational perspective.

***Enhanced IGERT elective*: Sensory Neuroscience Laboratory.** *H. Read, BNS*. Techniques employed in the experimental investigation of sensory neuroscience, hearing and sound discrimination of human and animals. Computer programming (Matlab) is used to synthesize and process sounds and analyze human psychophysics; human and animal auditory evoked brainstem potentials data. Read will retool this class to make it accessible to non-BNS students and integrate it with IGERT themes.

Enhanced IGERT elective: **Time course methods**, *J. Magnuson, PAC*. Magnuson will retool this hands-on seminar in eye tracking and EEG/ERP developed for his current NSF CAREER award to be accessible to students from all Ph.D. programs. This course has a history of preparing students through hands-on training in service of team-based, real research projects (100% of student projects have led to national conference presentations and/or publications).

(5) Integrative research practicum: Breadth mentorship. To augment course-based training in other domains, students will receive intensive mentorship from a faculty member outside their home Ph.D. domain. In the first semester, students will provisionally choose a secondary domain to focus on in consultation with their home Ph.D. program advisor. If a breadth mentor has not already "emerged" based team-based innovation projects in courses, advisors will help students identify breadth mentors. Students will meet with breadth mentors frequently to discuss progress, relevant literature, and how breadth mentors' domains might inform students' Ph.D. program interests (and vice-versa).

(6) Mentorship training. Trainees will supervise undergraduate research assistants as part of explicit training in research management and mentorship, under faculty mentorship. These may be paid research assistants, undergraduates who register with the trainee's faculty advisor for supervised research credits, or participants in summer REU or NEAGEP programs. (N.B., this is feasible, as there is often a surplus of undergraduates seeking research opportunities.) Trainees will attend J-Term Primers and Talk Shop workshops on mentoring, and meet with advisors to establish plans for research supervision (scheduling, setting goals, training the undergraduate, delivering positive and negative feedback, etc.).

(7) Outreach and Communication: A formal course in communicating with non-scientific audiences, with a required presentation for K-12 students, parents, or educators. The presentation venues will build on similar outreach efforts by Co-PI **Fitch** (with K-12 schools), participant **Eigsti** (with parents of special needs children and special education professionals), and PI **Magnuson's** related efforts supporting his NSF CAREER award (with education- and psychology-related community professionals), as well as contacts made through consultant **Gillis**. Initial meetings will be devoted to meeting with community representatives (e.g., teachers and administrators at local pre- and K-12 schools and public officials; 2 state representatives have agreed to participate). Students and faculty will discuss language sciences with visitors, and get their input as to what they wish they knew, and how best scientists could communicate that information to them. Students choose an audience and topic, and research the topic for a few weeks, including regular meetings with community representatives. This will establish a dialog and lead students to a deeper understanding of the challenges facing their audience, and lead the community members with whom they meet to a deeper understanding of science. Students will then draft and "workshop" talks with each other, their instructor(s), and the IGERT community for a few weeks, culminating in the presentations themselves. Faculty will be encouraged to participate as students (see incentives in C.4.4).

C.4.2 Integration of curriculum and research. Each Foundation course is designed with the vision outlined in C.2 in mind in preparing students to grapple with intricate connections among scales/systems that must be considered for a unified cognitive-biological approach to language science. In addition to infusing each course with each of our four foci, the **academics** and **research committees** (C.5) will meet periodically to identify linkages between current research projects and course content, to illustrate and reinforce for students and faculty the practical implications of their training for research in language science. The **program coordinator** will liaise among faculty and committees to promote these goals.

C.4.3 Typical pathways through training. Fig. 7 schematizes academic and summer workloads over the six 5-year Ph.D. programs (PNB students could participate, but would be more likely to enter through BNS), highlight large differences in required coursework (ranging from the numerous APA-required courses for Clinical Psychology to the many fewer requirements for Behavioral Neuroscience that reflect the fact that BNS research is more labor- and time-intensive) For most programs, one or more IGERT requirements will replace core program requirements (especially in PAC) and/or count as breadth requirements. IGERT funding will make it *possible* for a student in CLN or LING to train for six years if necessary. Under exceptional circumstances, the academics committee may relax course requirements (e.g., for students with high course loads who have substantial background in a foundational area).

C.4.4 Transforming the faculty. Our goals also include transforming the faculty. None of us yet has the level of grasp of the core foci and tools (Figs. 1, 4, 5) that students in our training program will. Faculty participation in IGERT activities and possibly even courses (especially J-Term primers) will enhance our ability to conduct integrative, interdisciplinary research *and* our ability to carry out the planned training program – and improve it. Faculty will also have the possibility to become more engaged with educators, public policy makers, and the general public through our outreach activities. To encourage participation, faculty will receive modest honoraria from the $120K/year UConn funds when they participate in courses and workshops. This will lead to a faculty participation culture. Once this is the established default, we expect participation will continue even when we can no longer provide honoraria.

C.5 ORGANIZATION, MANAGEMENT, AND INSTITUTIONAL COMMITMENT

C.5.1 Organization and management. The PI (Magnuson) will direct the project, and take primary responsibility for monitoring and coordinating progress towards all aims of the project. He will coordinate

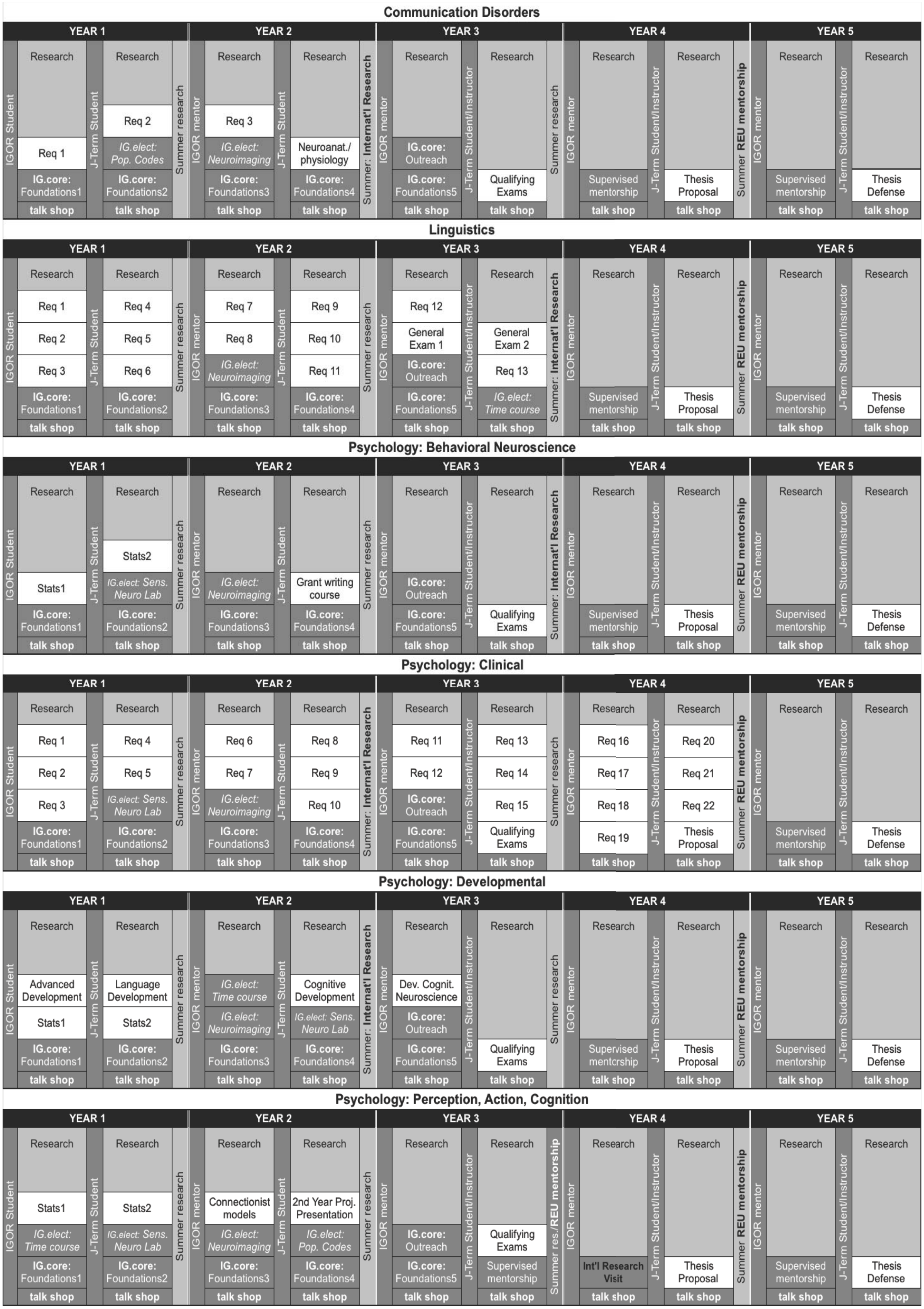

Figure 6: Typical trajectories through IGERT and home Ph.D. program requirements (see C.4.3).

budget and resource allocation, attend NSF PI meetings, and liaise with participating departments and university administration. Program goals will also be supported by seven committees.

i. Executive committee. To ensure fair and efficient allocation of resources and the ability to address concerns in a timely manner, an **executive committee** will meet quarterly. Members will be the PI, Co-PIs and representatives from programs not already represented by a Co-PI (CLN and DEV). The committee will also review progress reports from the other committees, each of which will be comprised of faculty and students. The executive committee will also be the **admissions committee** (see C.5.3).

ii. Recruitment, mentoring, and retention committee (chaired by PI **Magnuson)** will lead efforts to implement plans described in C.7. To summarize, the committee will lead in (a) coordinating with each PhD program regarding strategies for recruitment of US citizens, especially minorities and women; (b) coordinating with Drs. Aggison and Washington and the UConn NEAGEP and LSAMP programs for minority recruitment, mentoring and retention; (c) organizing outreach visits to minority-serving institutions (MSIs) by IGERT personnel; (d) organizing activities for students and faculty from MSIs visiting UConn under NEAGEP auspices; (e) organizing mentoring workshops for faculty; and (f) continually attempting to innovate new methods for promoting recruitment, mentoring, and retention.

iii. Academics (curriculum, education, and training) committee. This committee will be chaired by Co-PI **Snyder**, and will lead efforts to implement and monitor plans described in Section C.4. To summarize, the committee will take the lead in (a) coordinating academic year IGERT curricula; (b) coordinating J-term curricula; (c) liaising with PhD faculty and staff to monitor student IGERT and home PhD progress; and (d) coordinating breadth mentorship assignments and activities

iv. Research committee. This committee will be chaired by participant **Tabor**, and will promote IGERT-related interdisciplinary research. The committee will evaluate innovation incentive applications (C.1). It will also monitor which potential collaborations in Fig. 6 have started each year, discuss with faculty what it would take to launch those collaborations that have not started, and look for other connections between IGERT and non-IGERT faculty and students that would promote the goals of the IGERT. This committee will also seek connections between ongoing research and IGERT course content, and alert faculty to opportunities to integrate discussions of current research in their courses.

v. Program progress and evaluation committee. This committee will be chaired by Co-PI **Fitch**, and will lead plans described in C.6. To summarize, it will take the lead in (a) formulating detailed assessment plans and measures in coordination with the assessment consultant and program coordinator; (b) coordinating plans for external advisory committee visits and activities; and (c) coordinating action plans to follow recommendations of the external advisory committee and assessment consultant.

vi. International committee. This committee will be chaired by Co-PI **Pugh**, and will lead plans described in C.9. To summarize, the committee will (a) assess competitive student applications for international research visits, (b) monitor progress of students abroad and assess each site; and (c) work with the program coordinator to confirm plans for each student's housing, visas, and research plans.

vii. Activities and conference planning committee. This committee will be chaired by Co-PI **Coelho,** and will plan events such as welcome fests for new IGERT trainees, and fall (end-of-semester), spring (J-Term culmination), and summer (end-of-academic year) celebrations supported by UConn funds. The committee will also coordinate planning of the annual conference and annual retreat (C.2).

C.5.2 External advisory board. Seven prominent scientists with substantial experience in leadership roles in institutions or large grants whose domains of expertise span our core themes of genes, brain, cognition and computation have agreed to serve on our external advisory board. The board will conduct an annual 2-day site visit. Day 1 will be devoted to meeting with students and faculty for progress reports and research updates, and review of the project assessment (C.6). On Day 2, the board will hold a closed meeting to generate a preliminary evaluation and later present it to the IGERT executive committee.

C.5.3 Admissions. Each January, IGERT faculty will recommend applicants to their Ph.D. programs for IGERT admission. The Executive Committee will review these applications and present recommendations to all IGERT faculty. To serve the goals of recruiting highly qualified trainees from each domain and equitable distribution of resources, the primary considerations will be (a) applicant qualifications, (b) applicant interest in and clear ability to contribute to IGERT aims, and (c) roughly proportional admission of students from each program to the program's proportion of IGERT faculty.

C.5.4 Institutional commitment. Our proposal is strongly supported by UConn (see letters from the dean of the College of Liberal Arts and Sciences [CLAS], and vice provost for research [VPR]). Most notably, CLAS and VPR have committed $120k per year in additional unrestricted funds to support the training program. We will use these funds for purposes including: to provide research seed funds (C.2), pay innovation consultants, provide honoraria to faculty who teach J-Term Primers (C.4), support teaching by Yale faculty (Mencl, **Grigorenko**), and support a biannual conference related to our IGERT theme. VPR will also cover tuition and fees during IGERT funding beyond the $10,500 allowance, and departments have committed to supporting IGERT trainees at departmental levels after IGERT funding.

C.5.5 Possible obstacles. Our training program plans are very ambitious. The foundation for achieving our goals is the distribution of oversight and planning among the PI and 7 committees. This distribution prevents burdens from being concentrated on a few individuals. However, our faculty already have many demands on their time, and we it will take active effort to keep faculty and their home departments motivated and invested in the IGERT program. The PI and evaluation committee in particular will strive to track and quantify the benefits to each participating home Ph.D. program (student funding, possibly increased research products per student and faculty member due to increased collaboration), and to communicate this to the departments and to the administration. Another potential stumbling block are differences in methods, theory, nomenclature and training culture among Ph.D. programs. As discussed in C.4 (Talk Shop), we will tackle this head-on, with regular group discussions on each area's assumptions and how well founded they are, the limitations of each area, and what each area can gain from the others.

C.5.6 Sustaining the training program. At the end of NSF funding, we anticipate that **all elements of the training program will persist**, based on faculty and institutional commitment (cf., the new Language Science Certificate). The training program (especially the formal course content) will be sufficiently established to be self-sustaining, and the collaborations catalyzed by IGERT funding (C.3.3) will lead to external funding including support for new trainees and international research experience.

Spring: Data collection	Early fall: Data analysis	Mid-Fall: Setting goals, addressing challenges	Late Fall: Data update

Evaluation committee and **assessment consultant** supervise data collection
• Student surveys
• Faculty surveys
• Progress measures
• Retention measures
• Productivity measures
	• **Evaluation committee** and **assessment consultant** analyze data from previous spring, report to **Executive Committee**
	• **External advisory board**
	  • Reviews data
	  • Meets with students and faculty to assess research progress, morale, etc.
	  • Prepares recommendations
		• **All committees** review evaluation data and recommendations and report progress, challenges, and goals to **Executive Cmte.**
		• **Recruitment, Mentoring & Retention Committee** also reviews progress with NEAGEP and LSAMP personnel
		• Based on progress evaluation and **external advisory board** recommendations, **executive committee** establishes goals for coming year, **PI** presents progress report, goals and challenges to the entire IGERT community
			Evaluation committee and **assessment consultant** update data listed below, report any emerging concerns to **Executive Committee**
			• Progress measures
			• Retention measures
			• Productivity measures

Table 2: Annual assessment timeline and responsibilities.

C.6 PERFORMANCE ASSESSMENT / PROJECT EVALUATION

C.6.1 Responsibilities and timeline. The Evaluation Committee (C.5) will lead assessment and evaluation activities with the aid of an external assessment consultant and the program coordinator. The consultant will be explicitly tasked with providing an objective accounting of progress towards goals. We will also leverage the expertise of the external advisory board by presenting them with our objective progress measures and asking for recommendations for how to meet or exceed goals, and address challenges that arise. The timeline of activities is summarized in Table 2.

C.6.2 Assessment measures. Assessment towards goals will be organized around goals for four target groups: trainees, faculty, institutions, and society. Data will be collected from application records and from the following groups of individuals: IGERT trainees, applicants who declined admissions offers, IGERT faculty, non-IGERT faculty, and non-scientific audiences. Quantitative measures will be based on surveys using 7-point rating scales (e.g., each trainee will rate each IGERT component on a scale from 1=poor to 7=excellent). Qualitative measures will also be obtained, by asking respondents to comment on various program dimensions. The majority of the goals to be assessed, the indicators to be used to gauge progress, and proposed strategies for addressing challenges are summarized in Table 3. We will also draw on the expertise of the external advisory board for progress assessment, as described in Table 2.

C.6.3 Assessment analysis. In collaboration with the assessment consultant, the evaluation committee will summarize the survey results each year, and compare performance to previous years, with particular attention to downward trends. Rather than setting specific numerical goals for, e.g., research products per trainee, we will use mean performance of all students in each Ph.D. program as the baseline for IGERT trainees from each program. Surpassing this baseline will be a secondary goal, with the primary goal to meet the baseline level with interdisciplinary research products reflecting the IGERT theme. A similar approach will be taken to most program metrics. With respect to recruiting from underrepresented groups, our goal is to make significant progress towards (a) NSF national averages for specific programs (from http://www.nsf.gov/statistics) when program baselines fall below them, and (b) US population averages. Setting high goals will motivate us to improve our recruiting, but we shall also consider year-to-year improvements, and those over the course of the program compared to our initial baselines, to be progress.

C.7 RECRUITMENT, MENTORING AND RETENTION

How many individual trainees will be supported over the course of the 5-year award?	~27
How many years of funding will trainees receive?	24 months of IGERT funding each
How will students be supported when they are no longer receiving NSF IGERT funding?	Summer funding from institutional support funds; academic year RA- and TA-ships
From which departments will NSF-funded trainees receive their degrees?	Psychology, Linguistics, Communication Disorders [all research Ph.D. programs]
Institution at which trainees will be enrolled	University of Connecticut

C.7.1 Recruitment. Publicizing our IGERT quickly and effectively will be a priority. Our primary communication channel will be a website (**Magnuson** is the webmaster for his department and can rapidly launch an IGERT website). We will also use conventional means, such as letters and brochures to colleagues and relevant departments, other targeted mailings (e.g., to undergraduate cognitive science groups located by querying colleagues and web searches), and announcements at conferences, such as the

	Goal	Measures	Improvement strategies
Trainees	High quality IGERT student body with diversity of domain, gender, ethnicity, ability and disability	By program, #'s of applicants, #'s qualified for admission, accepted, matriculated, and declined;demographics of each; survey 'matriculaters' and 'decliners' as to where else they were accepted, and what we might improve recruiting	Make plans based on student feedback; increase faculty visits to minority-serving institutions with NEAGEP personnel
	Plasticity theme and 4 foci: understanding of scientific implications, tools and methods across domains	Performance in *Foundations* courses; targeted questions in student survey	Develop additional J-term primers for lagging students; assess instructors
	Deep understanding of secondary domain	Performance in relevant courses: Evaluation by breadth mentor; targeted student survey items	Assign 2nd breadth mentor; Encourage coursework in 2nd domain as possible
	Progress and expertise in home Ph.D. domain	Performance in relevant courses, timely completion of program milestones; advisor's evaluation; targeted student survey items	Participation in professional development workshops (time management, etc.); strategy meeting of mentors with Academics Cmte.
	Progress towards IGERT completion	Timely completion of requirements; development of integrative research	Same as above
	Produce interdisciplinary research	Advisors' reports of progress toward developing research; actual research products (presentations, articles, grant applications)	Same as above
	Preparation for mentorship	Faculty advisors' assessments of student's mentorship of undergraduate researchers; undergraduate researchers' evaluations; targeted student survey items	Provide constructive feedback; increase faculty supervision; seek additional mentorship opportunity
	Ability to communicate across disciplinary boundaries	Performance in IGERT lunch talks, as gauged by group feedback session at the talk, and offline by mentors and academic committee	Students will be encouraged to present annually; struggling students get presentation coaching from faculty, more talk opportunities
	Ability to communicate to non-scientists	Performance in outreach course, as gauged by faculty and by feedback surveys from non-scientific guests	Same as above
	Professional development skills (grant writing, CV prep., interview skills, reviewing, website...)	Participation in appropriate J-term primers; existence of personal homepage; targeted questions in student survey	Encouragement to participate in appropriate primers
	Become skilled in practices that promote creativity, innovation and collaboration, including connecting research with societal challenges	Competition for innovation incentive funds, completion of project, assessment of innovation consultant	Increase hands-on opportunities for innovation; additional training with innovation consultant (Dr. Simsarian of IDEO and CCA)
	Satisfaction with and fulfillment from program	Survey asking about strengths and weaknesses of each IGERT component, of primary and breadth advisors, and student's assessment of her own preparation for an independent, interdisciplinary research career	IGERT committees will strategize as to how to address concerns that emerge, in consultation with the External Advisory Board
Faculty	Catalyze new interdisciplinary research	Presentations, articles, grant applications related to IGERT; new collaborations initiated; targeted faculty survey items	Research committee will identify potential collaborations among faculty
	Improve mentorship skills, especially for underrepresented groups	Student feedback described above; faculty participation in mentoring workshops; targeted questions in faculty survey	Independent of performance, all faculty will be encouraged to participate in mentoring workshops led by UConn NEAGEP personnel
	Engagement with IGERT theme and foci	Participation in IGERT activities and interdisciplinary research	Should not be a problem, but if it is, the Exec. Cmte. will encourage faculty to participate
Institutions	Awareness of IGERT theme and related research by non-IGERT faculty	Attendance of weekly talks and annual conference by non-IGERT faculty; surveys of non-IGERT faculty, rating utility of IGERT activities and asking for input on how to improve	Advertise talks broadly using UConn, Haskins, and Yale listservs, web calendars, websites, etc.; jointly sponsor IGERT colloquia with appropriate departments
	Improvement of infrastructure for integrative, cross-disciplinary research	Use of IGERT-linked equipment by non-IGERT faculty from multiple programs; interdisciplinary collaborations related to our IGERT theme with non-IGERT faculty; targeted items in survey for non-IGERT faculty	Remind non-IGERT faculty that equipment is available for interdisciplinary research; Research committee will consider non-IGERT faculty in potential collaborations
Society	Dissemination of IGERT-related research to non-scientists	Number of presentations made via outreach course and other mechanisms; number and kind of non-scientist audiences we reach; number of hits and queries at our IGERT website; targeted questions in surveys for non-scientific audiences	Encourage students and faculty to make additional presentations, and to contribute blog-like (but polished) research postings to the IGERT website
	Increased participation by underrepresented groups in Ph.D. training and beyond	Diversity of trainees described above; participation in summer research experiences for undergraduates, especially those from underrepresented groups	Encourage faculty to participate in NEAGEP recruiting activities and summer research programs for undergraduates
	Connect research innovations to societal challenges	Number of innovation incentive projects that connect to societal challenges; number of other projects that do	Work with innovation consultant (Dr. Simsarian of IDEO and CCA) to enhance these efforts

Table 3: Program goals, measures, and improvement strategies.

Society for Neuroscience (SFN), the Cognitive Science Society, the Psychonomic Society, the Cognitive Neuroscience Society, the American Psychological Association (APA), and the Association for Psychological Science (APS). We will use other less conventional electronic means, such as targeted Google ads (using UConn funds), listserv postings, and social networking pages.

We will build on existing UConn programs designed to increase participation in science and academics by members of **historically underrepresented groups**: **First**, we will partner with the Northeast Alliance for Graduate Education and the Professoriate (NEAGEP), an NSF-funded organization of universities in New England, NJ and PA in partnership with institutions that serve many individuals from underrepresented groups (Bennet College, NC; Jackson State U., MS; Lincoln U., PA; Medgar Evers College-CUNY, NY; U. Puerto Rico, Mayaguez). We will work with UConn NEAGEP directors (Drs. Aggison and Washington) to (a) inform NEAGEP partner institutions about the IGERT and our online newsletter, (b) recruit IGERT and other trainees by sending faculty and student representatives with NEAGEP personnel on outreach visits, (c) design UConn-based IGERT recruiting events, (d) welcome NEA summer research interns from minority serving institutions (MSIs) into our labs, (e) conduct technology workshops on cognitive neuroscience, computational modeling, and language sciences for NEA interns and visiting MSI faculty from. In activities with students and faculty from MSIs and students from underrepresented groups at UConn our primary aim is to give these students a close look at research careers, in hopes of inspiring them to pursue advanced training in STEM fields – whether with us or elsewhere. Aside from the value these interactions provide to visitors, they also serve recruiting goals by giving MSI students and faculty first-hand knowledge of our program; some visiting students may apply to our program, but they and the faculty may also recommend our program to other students at their home institution. Further, whether these students apply to our program or not, their internships will provide our IGERT trainees and faculty with important mentorship experience (C.7.2).

Second, We will partner with the UConn LSAMP (Louis Stokes Alliance for Minority Participation) program to communicate with UConn minority students about STEM careers and our IGERT in particular, and to make contact with other LSAMP programs nationally.

Third, We will partner with UConn REU (Research Experiences for Undergraduates) programs to recruit undergraduates to participate in IGERT-related summer research and IGERT-based workshops on research careers and preparing for graduate school.

Fourth, Similar opportunities will be provided to women via the UConn Women in Math, Science and Engineering (WiMSE) program for undergraduates (participants **Fitch**, **Read**, and **Eigsti** are active in this group). IGERT labs will host WiMSE students, and invite them to attend our research/grad school workshops. Additional recruiting efforts for women will include electronic outreach to organizations such as the Association for Women in Science (AWIS), the Association for Women in Computing (AWC), and on-campus Psi Chi, and Honor organizations serving undergraduate women in the STEM disciplines nationally (see http://womeninscience.org/resources for a full listing). On-line mentoring organizations such as "GirlGeeks" and "MentorNet," as supported by our faculty participants, will provide further national access to young female candidates. Finally, we will target service and education groups within prominent professional societies, such as "Women in Neuroscience (WIN)" within the SFN.

Fifth, an uncommon target of our efforts to include underrepresented groups in our IGERT will be Deaf students working on aspects of sign languages. Two IGERT affiliated faculty members (**Lillo-Martin** and **Coppola**) are fluent signers, and work closely with Deaf scholars. The ability to communicate directly with signing faculty members is an important consideration for prospective Deaf students who might be interested in the particular approach to language taken by our community. We will take several steps to recruit Deaf students as trainees. First, we will advertise the program to lists and groups frequently used by those conducting research with sign languages, including the SLLS-list (Sign Language Linguistics Society), the SLLING-list (Sign Linguistics), and the conference on Theoretical Issues in Sign Language Research (TISLR). We will also travel to schools with good populations of Deaf students (including Gallaudet University and the Rochester Institute of Technology) to publicize our program. In addition, our website will provide information in American Sign Language to indicate our earnestness in reaching out to ASL users. Deaf students who join the IGERT program will be provided with complete interpreting services by UConn's Center for Students with Disabilities. Interpreting will be provided at informal events such as discussion groups, as well as courses and talks, to ensure full integration of Deaf students into the IGERT community. The students will be mentored by at least one of the signing faculty members, in addition to their academic and breadth advisors (in case they differ).

Sixth, we will strive *each year* to identify additional national and regional outreach partners (e.g., the Hispanic Association of Colleges and Universities; the American Indian Higher Education Consortium).

C.7.2 Mentoring. Professors often bemoan their lack of training in teaching. The same is true of mentoring. To promote active development of mentoring skills, IGERT faculty will be encouraged to attend mentoring workshops organized by the UConn NEAGEP office. We will also organize a regular mentoring meeting. The initial meetings will be organized around the book, "Entering Mentoring" (Handelsman et al., 2005), which promotes general mentoring skills and also addresses mentoring challenges related to mentoring members of underrepresented groups. We will also provide mentorship training to IGERT trainees (via J-Term Primers and supervised mentoring experiences).

C.7.3 Retention. According to a recent report by the American Speech, Language and Hearing Association (ASHA) (http://www.asha.org/practice/multicultural/recruit/litreview.htm) poor retention in graduate training programs is often associated with (a) absence of mentors and role models on campus, (b) lack of adequate social support and integration, and (c) lack of professional networking. We will strive for 100% retention and Ph.D. completion by establishing multiple support mechanisms that address these issues for trainees, and in particular, for trainees from underrepresented groups.

Mentors. At least 2 faculty will mentor each trainee: a primary advisor in their Ph.D. program, and a "breadth" mentor from another IGERT-affiliated program. These mentors will be assigned in the first year if students have not selected them. Annual student surveys (see C.6) will provide students with anonymous and non-anonymous means to communicate their own concerns about the program, including mentorship. Students will also meet annually with the academic committee to give and receive feedback.

Role models and peers, and social integration. Students, especially those from underrepresented groups, will be encouraged to take part in NEAGEP workshops on professional development, and to take advantage of counseling and other NEAGEP resources. The UConn campus is culturally inclusive, and students may find social support through the African American, Asian American, and Puerto Rican /Latin American Cultural Centers. Students will find welcoming and supporting student communities in home Ph.D. program, and additional structure and support through the IGERT community. IGERT activities will provide a foundation for bonding with other students and IGERT community members. Annual retreats and regular events with social components (C.2) will foster a strong and supportive community.

Networking. Among the professional development skills we will address in J-term sessions (C.4) will be professional networking. We will discuss its importance, and also give students some "how-to" skills. In their mentoring training, faculty will also be reminded of the importance of networking and discuss strategies for facilitating networking for their students (e.g., simply introducing students to colleagues from elsewhere and giving them a chance to speak). Off-site conferences and the annual IGERT conference at UConn will provide opportunities for in-person networking. We will also discuss the importance of establishing individual web pages and explore on-line opportunities that are emerging through social media and the increasing use of tools like Skype for video-conferencing.

C.7.4 Admissions, staging and funding. We will admit 27 students to the program. Each will receive 24 months of IGERT funding in two 12-month segments. We will support 7 entering students in Years 1-3, and 6 in Year 4. In order not to exceed the annual $700k total costs cap, some students will receive their second year of IGERT funding in their third year (e.g., 5 Year 1 students will receive their second year of support in Year 2, but 2 will receive it in Year 3; see budget justification). The vice provost for research (VPR) will cover tuition and fees during IGERT funding beyond the $10,500 allowance (see letter of support), and departments have committed to supporting IGERT trainees at departmental levels after IGERT funding. Traineeships will be spread across participating programs approximately equally.

C.7.5 Faculty diversity. Eleven of the 20 IGERT faculty are women. None of us are from underrepresented groups. This lack of diversity may have implications both for recruiting and for retention. We will address this issue in faculty mentoring meetings and in workshops with the NEAGEP.

C.8 RECENT TRAINEE EXPERIENCE

Haskins Labs. An NICHD training grant, "Postdoctoral Fellows in Reading Research" (T32HD 007548), has existed for 9 years. It involves integrated research projects and coursework that give fellows skills needed to conduct independent research on typical and atypical reading, emphasizing the challenges and opportunities of translating research to practice. To date, 10 fellows have completed the 2-year program. The T32 scientific infrastructure already in place will directly benefit IGERT students at UConn.

C.9 INTERNATIONAL COLLABORATION

C.9.1 International partners. We will build on strong international connections several of our groups have already established. Although we are limited to listing five in this proposal, we in fact have strong connections with additional research groups in France, China and Israel. The five we have chosen to partner with formally for this IGERT reinforce and complement our local strengths. Each of these groups has agreed to welcome our students for research internship experiences, and to make available laboratory and other university resources, and facilitate with pragmatic local details, such as finding housing. We will reciprocate by welcoming students those sites send on funded research internships to UConn. We will briefly describe the five sites and how they complement our training programs; we then outline our plans for international experiences (selecting and preparing students for visits, and monitoring progress).

Basque Center on Brain, Cognition, and Language, San Sebastian (Donostia), Spain. Although this center was only established in December, 2008, it is already emerging as an international center of excellence in cognitive neuroscience, and particularly, cognitive neuroscience of language. This rapid rise is due to extremely strong local government support, and the leadership of Dr. Manuel Carreiras, a renowned expert in human language processing. Dr. Carreiras has assembled a stellar team of junior and senior scientists; most are from Spain, many are from elsewhere in Europe, and a few are from other parts of the world. As Dr. Carreiras describes in his letter, students will have access to EEG/ERP, fMRI, and MEG, as well as to leading experts in applying these tools to cognitive neuroscience. Access to MEG and fMRI will be particularly important for many of our students, as we do not have MEG in Connecticut, and our access to fMRI is in New Haven and Hartford (60 and 35 miles from Storrs). Also, a research visit in a region where many residents are bilingual in two very typologically different languages will afford unique opportunities to students with interests in bilingualism and cross-linguistic phenomena.

University of Jyväskylä, Finland. Dr. Heikki Lyytinen leads multiple centers and research groups with a focus on linking neural measures of language processing to (a) genetic markers and (b) predictions of current and later language impairment. Dr. Lyytinen and his colleagues are international leaders in the study of neural and cognitive underpinnings of language ability and disability, and behavior genetics of language. The Jyvaskyla National Dyslexia Study, which tracks high-risk children from birth to age 10, has set the standard for the field, producing many discoveries about early brain and behavioral markers of language disorders. This group has also done seminal work in employing hand-held devices for language remediation, a project that has already been expanded into many languages and cultures. Moreover, the group is highly experienced in hosting international guests; visiting students will be able to observe their neural, genetic and behavioral methods first-hand, and collaborate with Dr. Lyytinen and his colleagues.

Institute for Neuroscience, University of Salamanca, Spain. Dr. Manuel Malmierca and BNS faculty have created a study-abroad program for UConn students interested in neurophysiology. Dr. Malmierca's institute is well-prepared to welcome IGERT trainees, and can offer course-based training, lab-based training, and language immersion via home stays with local families. This site will clearly have much to offer BNS students interested in auditory neurophysiology, and will also be an excellent mechanism for students in other programs to participate in a neurophysiology lab rotation.

Nanzan Linguistics Consortium, based at Nanzan University, in Nagoya, Japan. The Nanzan Consortium is designed to be a worldwide "meta-department" of leading Ph.D. programs in theoretical linguistics. Faculty and Ph.D. students interact regularly at workshops held at member institutions: Faculty offer mini-courses, and graduate students present their current research. Graduate students can also spend a semester or a year as a visiting student at other member institutions. Founded by Dr. Mamoru Saito at Nanzan University, the Consortium also includes Siena University in Italy, Cambridge University in the U.K., National Tsing Hua University in Taiwan, EFL University in India, and UConn.

Institute of Neuroscience and Laboratories for Cognitive Neuroscience, National Yang Ming University; Institute of Cognitive Neuroscience, National Central University, Taiwan**.** This consortium, led by Dr. Daisy Hung, will provide students with access to cutting-edge cognitive neuroscientific instruments (EEG/ERP, fMRI, MEG) and to internationally recognized scientists. It provides students interested in cross-linguistic research access to speakers of Mandarin Chinese and indigenous Taiwanese languages. Moreover, ongoing research on acquired and developmental language disorders parallels research from UConn and Haskins, allowing allows students to ask questions regarding universals and language specifics in the neural pathways for language.

C.9.2 International opportunities at home. Our primary international activities will be foreign research visits, but not all students will be interested in or able to take on such a visit. Furthermore, individual students will not be able to visit *all* partner sites. We will leverage international connections to expose students to research cultures in multiple countries by hosting regular 'cyber-seminars,' using cyber-enabled meeting rooms to teleconference with international partners. These will include reciprocal research talks, as well as informal discussion sessions on scientific issues and issues relating to cultural differences in the way research is done, as well as "calls home" from students in the midst of international visits (to update us on their progress and tell us about their experiences living abroad).

C.9.3 International opportunities abroad. Students will be encouraged to identify scientific and cultural reasons to seek an international internship. Our goal is for students to obtain an international perspective, and to complete a publishable project, ideally under the supervision of a foreign researcher whose areas of expertise complements those of our Connecticut faculty, and/or utilizing tools and methods unavailable to them at UConn. They will be strongly encouraged to work closely with their local mentors and their foreign mentor in preparing their application. The default visit will be 8 weeks, which can be extended (to allow sufficient time for data collection and other activities) or shortened as needed.

C.9.3 Selecting students for foreign research visits. Students will apply for foreign research visits by submitting a 2-3 page proposal articulating scientific and cultural motivations for visiting their chosen site and including several other details: identification of a mentor at the foreign site, a research plan with a timeline including goals and deadlines for preparing experimental designs, stimuli, etc., prior to traveling, and how the research plan relates to the IGERT theme and foci, and to NSF's *Broader Impact* dimensions. Letters of support from local and foreign mentors will need to accompany applications. Applications will be reviewed by the International Activities committee, with approximately 6-8 visits possible each year. The committee will provide constructive feedback on successful and unsuccessful applications.

C.9.4 Preparing for foreign research visits. First, IGERT faculty will visit each site in Year 1 to discuss plans, explore each area, and to try to anticipate challenges that may confront students in each setting. In subsequent years, faculty will visit each site at least once when a UConn student is in residence in order to evaluate the success of each site first-hand. Second, each student will be required to do some modest research on the history and culture of the foreign site. Students will be strongly encouraged to seek language training (although English will suffice at each of our five lab sites). Third, local mentors will work closely with students to make sure they are meeting the deadlines they set for themselves in their application so that they can hit the ground running when they arrive for their research visit.

C.9.5 Monitoring student progress while abroad. A checklist with a series of questions designed to elicit frank descriptions of strengths and weaknesses of the international experience will be used to assess student progress weekly (by Skype or email). Students abroad will give at least one 'cyber-seminar' to report back to the IGERT community on their life at the foreign site in and out of the lab.