

Forming A Biomathematical Learning Alliance Across Traditional Academic Departments

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Abstract

Across the nation, many generalized programs have focused on retention of minority students in the sciences with varying degrees of success. Paradoxically, this challenge exists despite expanding career opportunities in industry, academia, and government for those skilled at the intersection of biology and mathematics. Here we describe a cross-departmental learning alliance (iBLEND- an Integrative Biomathematics Learning and Empowerment Network for Diversity) which directly targets these recognized challenges. Our goal for the iBLEND project is to have significant spillover effects for our university by developing new interdisciplinary collaborations that benefit our students. The iBLEND is a proactive, intensive approach to bridge campus chasms for both faculty and undergraduate students by positively influencing academic programs through interdisciplinary training coupled with strong

evaluation and assessments. By leveraging our recent surge of competitive research activity, innovative instruction, and collaboration, the iBLEND advances our transformation to the next level by establishing a broader bridge for our undergraduates at the interface of mathematics and biology. In working together, the math and biology students learned to bridge language barriers inhibiting interdisciplinary explorations. Students were closely involved with faculty mentors in core laboratories and developed cross-disciplinary research skills that enhanced their post-graduate career opportunities. Using systems biology tools combined with targeted mathematics classroom work, students merged data from their lab bench experiments with mathematical models to determine how various changes impacted an overall organism and its functions. The students had hands-on training with a myriad of computational simulations, data mining and data analysis tools needed in approaching their projects.

Keywords: modeling, simulation, computational biology, mathematical biology, science education

1. TARGETED STUDENT PARTICIPANTS AT A CRITICAL TRANSITION POINT

North Carolina Agricultural and Technical State University (NCATSU) is a historically minority-serving land-grant institution with an overall enrollment of approximately 10,000 undergraduates. Currently, the Biology Department has over 300 majors and the Mathematics Departments has over 100 majors. Undergraduates in both departments are over 90% African American representing a diverse talent pool for broadening participation in science. Since NCATSU is the largest Historically Black College and University (HBCU) in the United States, we are aware that overcoming under-representation in biology and mathematics is difficult (Moses, 2001). African-Americans, in particular, remain significantly underrepresented as compared to the percentage of undergraduates at majority institutions who go on to pursue graduate degrees and professional career fields in science and mathematics. For instance, given the mission as a land grant HBCU, our entering freshman are admitted having a wide-range of prior high school success (Table 1). NCATSU began participating in the Wabash National Study of Liberal Arts Education in Fall 2007, with 722 freshman students (nearly half the incoming freshman class) completing a series of assessments in Fall 2007, and 315 students in this same cohort completing a related series of assessments in Spring 2008. In the Wabash National Study (2009), when NCATSU was compared to majority institutions of similar size, the vast majority of biology freshmen initially expressed high aspirations for science careers, including medical/dental professions. On the other hand, too many NCATSU freshmen exhibited deficits in critical thinking and writing, as compared to freshmen at other institutions participating in the same study. These data are routinely disseminated as evidence in multiple ways to faculty, highlighting the need for excellent teaching, strong interdisciplinary training, and high-quality biomathematics-related research. Here we focus iBLEND activities (Figure 1) relative to deep learning that crosses beyond conventional boundaries between biology, mathematics, computer science, physics and chemistry disciplines.

Table 1. High School Rank of Entering NCATSU Freshman

Top Fifth	2nd Fifth	3rd Fifth	4th Fifth
281	456	537	469
12%	20%	24%	21%

Data (2008) published within NCATSU factbook <http://qed.ncat.edu/ir&p/availabl.htm>.

Our proactive, intensive approach helps to bridge the chasm between students already on a competitive graduate school trajectory and those who otherwise would be less competitive for graduate biomathematics study. In Figure 1, we depict our integrative iBLEND model, which is a comprehensive pipeline that serves students nearing high school graduation through entry into graduate school. Our integrative pipeline model adopted the notion that undergraduates need a solid support base for “structures, strategies, and activities that bridge numerous divides, such as high school and college, general education and the major, introductory and advanced levels, and experiences inside and outside the classroom” (Klein, 2002). Our integrative pipeline model (Figure 1) goes beyond competing for the attention of incoming “highest tier” students, many of whom would seek graduate school regardless of being in a focused program. Instead, our integrative model not only raises the bar for the incoming high-performing students, but seeks avenues that can amplify the overall supply of students who emerge from NCATSU on a competitive trajectory for biomathematical graduate study.

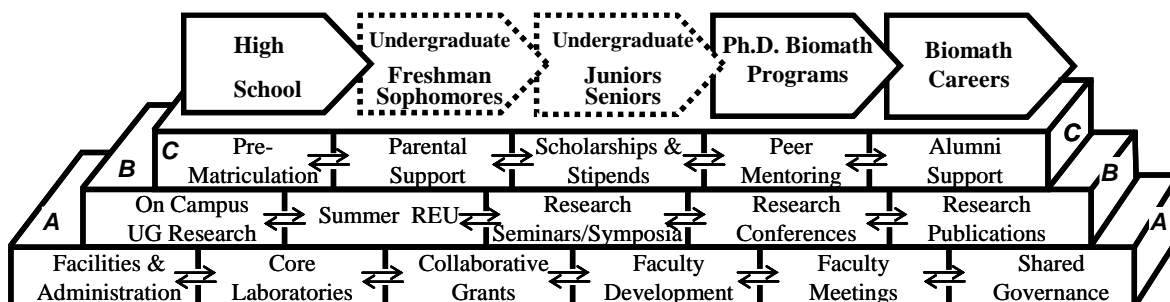


Figure 1. Integrative Biomathematics Learning Pipeline at NCATSU demonstrating common progression agenda and mutually reinforcing activities built on trust, goodwill, cohesion, and shared credit amongst governance structure

2. INNOVATIVE STRATEGIES TO BRIDGE THE GAPS AT THE MATH-BIO INTERFACE

Within our overall current curricula there are too many disjunctions between the content of science and mathematics courses. This decreases the likelihood that our students will make a successful transition to engage advanced course work. Furthermore, students often develop a mistaken impression that mathematics has limited application to biology, and too many of our students emerge from these courses without a coherent picture of the critical links between different science areas (BIO 2010). Hence too many undergraduates fail to gain understanding of the basic mathematics, biology, and chemistry principles by the end of their sophomore year (Swarat et al, 1999). Therefore, departmental alliances, like iBLEND, are needed to extend benefits to a larger number of our students and faculty who might otherwise have disregarded research at the interface of biology and mathematics.

Innovative to our approach is that all of the research projects bring undergraduate researchers to our centrally located Molecular Genetics, Genomics, and Proteomics Laboratory and the Applied Mathematics Modeling Laboratory. Starting in 2004, NCATSU was awarded a capacity building Research Infrastructure in Minority Institutions (RIMI) grant from the National Center for Minority Health and Health Disparities. The purpose of our core lab is to provide interdisciplinary research and training for both undergraduates and faculty. The core laboratories include biologists, mathematicians, and computational bio-physicists, from each of the basic science departments involved in laboratory research. This shared space provides natural opportunities for our undergraduates to fuse conceptual understanding between research and classroom activity. We have found that the core labs provide iBLEND a supportive dynamic sphere for high expectations and academic challenges for our undergraduates. We believe shared spaces are essential to provide natural opportunities for undergraduates to fuse conceptual understanding between research and classroom activity. Hence iBLEND takes full advantage of the capabilities of our newly established Molecular Biology Core Laboratory. The core laboratories also serve as a training ground for faculty to learn new techniques. Recent training activity include including phenotype microarray analysis, DNA sequencing, and RT-PCR. Areas of active investigation include: control of gene expression; molecular pathogenesis; protein biosynthesis and compartmentalization; cell development and differentiation; carcinogenesis; development of cellular resistance to cancer; genetic basis of disease; clinical cytogenetics; molecular mechanisms of mutagenesis; and signal transduction. Ramifications from this research are particularly well-suited for spirited discussion and debate that further establish meaningful relationships between mathematics and biology (Epstein et al., 1997). The strong interdisciplinary research projects and training are built on research strengths of faculty in the Departments of Biology and Mathematics enriched with collaborations with neighbor Research-1 institutions. The central geographic location of NCATSU between Wake Forest Univ., UNC-Chapel Hill, Duke Univ., and NC State Univ., and other institutions provides easy implementation for several day visits and field trips during the academic semesters with collaborating laboratories on our projects (Table 2).

In our core laboratory clusters, the iBLEND research and training are coupled with mechanisms that reduce barriers to student success. As many of our students are first generation college attendees, there is a wealth of life experiences and personal connections to these projects that give real-world research purpose and provide students with every opportunity to succeed in biomathematics (Muller and Kerbow, 1993). The lab research described above is specifically designed to overcome pre-conceived notions concerning advanced mathematics or computationally-rich courses. This is particularly true for minority students where underrepresentation in research careers goes back to a complex interplay of socio-economic forces that impact academic achievement (Lowe, 1999). Used appropriately, mathematical models can represent pathways in a physically and biologically realistic manner and generate novel and useful hypotheses (Aldridge, 2006). The modeling intellectual focus and tools span the range from prediction to identification of mechanistic structures. This research theme is specifically structured to complement the individual strengths and circumstances of each research mentor. Students gain a better understanding of the governing processes at the molecular, cellular, and organismal level

through mathematical analysis of the overall dynamical system models and various numerical methods and simulations. The student iBLEND intellectual focus is on the development of mathematical skills in set theory, linear algebra, differential equations, number theory, numerical analysis, stochastic and deterministic processes, topology, and computational mathematics. This aids in the development of analytical argumentative strategies to better understand high-throughput biological data which includes molecular genetics, host-pathogen microbiology, comparative and functional genomics, phylogenetics, plant physiology, ecology, and genomic instability and oncology.

3. KEY ORGANIZATIONAL STRUCTURE AND INSTITUTIONAL ENDORSEMENTS

Because of the many positive impacts, some even beyond intended project goals (Goins, 2009), iBLEND has significant buy-in from administration, faculty, and students. We gain buy-in from stakeholders by: (1) working from the ground-up with administration to promote campus-wide biomathematics research and training; (2) fostering associations between research and regular undergraduate academic courses; (3) creating and disseminating biomathematics teaching and learning modules and (4) enhancing learning community support at the interface of mathematics and biology. Since 2006, NCATSU has hired 8 new faculty (5 in Mathematics, 3 in Biology) with significant biomathematical research portfolios to share with undergraduates in iBLEND. Hence, we have a solid cadre of faculty and staff pursuing research and shared discovery at the interface of mathematics and biology, and all are part of this proposed work.

These measures that have increased undergraduate research and research training included:

- Collective math-biology departmental faculty conceptualization and crafting of grant proposals
- Emphasis on faculty and student development in research and pedagogy
- Provision of collaborative math-biology departmental retreats to foster new ideas
- Emphasis on freshman orientations specific for biology and math majors
- Distribution of bio-math shared documents through centralized computer servers
- Broadening team-taught bio-math courses and research contributions
- Providing a weekly bio-math seminars and annual bio-math and scientific research symposia

Furthermore, we have access to multiple research laboratories within a 50 mile radius (Table 2), as NCATSU is one of the seventeen public constituent institutions in the University of North Carolina (UNC) System. For our students, we leverage benefit with our partnerships through faculty research collaborations and 2-way scholarly exchanges of resources, training, and seminars. These established links represent a mutual win/win between NCATSU and Research-1 partner institutions and laboratories. Many of our research collaboration partners (Table 2) have Ph.D. graduate degree track programs, and therefore, iBLEND is viewed as a productive program to bring in underrepresented minority undergraduates having specific competencies related to mathematical biology.

Table 2. Biomathematics Partners in Training and Learning

<i>Guest Seminar/Workshop</i>	<i>Specialty Area Topics</i>
BioQUEST	Case-IT/ Excel Simulations
NESCent	Multiple aspects of evolutionary biology
NIMBioS	Numbers Count
Pittsburgh Super Computing	Integrated Computation and Curriculum Development
MAA-PREP/NCSI	Biomath modeling workshop
iPlant Collaborative	Computational Biology for Educators
Shodor/Super-Computing	CSERD and Pathway Portal of NSDL
Wake Forest	Aspects of Computational Biophysics and Proteomics
UNC-CH Bioinformatics Ctr	Bioinformatics Research and Tools
Ohio State MBI	Multiple aspects of Mathematical Biology
UNCC	Programming Language R, PYTHON, MATLAB
Wake Forest	Computational Lectures and Development

4. EVALUATION, ASSESSMENT, IMMEDIATE OUTCOMES

The iBLEND represents a proactive, intensive approach in order to bridge campus chasms by positively influencing academic programs through interdisciplinary training and strong evaluation and assessments. We routinely get feedback from math and biology faculty, including data regarding the status of biomathematical courses and accomplishments in connecting the curricula. We are highly interested to know what extent are students exposed to problem-based, active learning activities, and appropriate technology in their courses, particularly those courses taught by the primary mathematics and biology instructors. In iBLEND, student surveys are key. We assess and evaluate students' exposure to relevant technology, problem solving skills, higher order thinking, and explicit connections to biology and mathematics areas (Table 3). Table 3 shows that as an immediate outcome of iBLEND efforts, an increasing number of undergraduates have actively engaged in hands- and minds-on research. Moreover, significantly more underrepresented students from our campus are strongly motivated to continue graduate research. The data suggested that the core lab clusters and iBLEND were key contributors to more students taking the GRE, scoring at competitive levels, and/or applying for graduate school.

Table 3. Student ratings of iBLEND mentoring, level of support, and encouragement.

<i>N=76 iBLEND Participants</i>	<i>Strongly Disagree</i>	<i>Disagree</i>	<i>Neutral</i>	<i>Agree</i>	<i>Strongly Agree</i>
Did the tutoring and mentoring opportunities and services provided by the project strengthen your academic performance?	0.5%	2.9%	13.2%	42.4%	40.8%
Did the Core Genomics Labs and Proteomics Research Cluster positively impact your project efforts?	0.5%	4.3%	20.1%	52.2%	22.2%

My project better enabled me to gain relevant, integrated research experience to make me stronger candidates for graduate school	2.2%	9.8%	31.8%	40.4%	14.2%
The iBLEND study groups were helpful in building a learning community that supported you academically?	5.8%	13.6%	37.6%	29.9%	12.6%
Do you think the academic and research preparation funded by the iBLEND program resulted in taking the GRE, scoring at competitive levels, and/or applying for graduate school?	0.6%	3.1%	20.2%	40.1%	34.1%
Do you think the academic and research preparation funded by the iBLEND program resulted in you being better-trained in biology and mathematics?	1.0%	2.1%	31.1%	43.2%	23.6%

Our recently revised biology major curriculum includes an undergraduate research and a senior capstone project course, both which require students to develop hypothesis-based projects under the direction of a faculty member. Hence, the culture has shifted in that more students anticipate research as a normal part of matriculation and not as a special activity for a select number of students. As a tangible outcome, faculty view mentoring research students as a part of their normal duties and responsibilities and one that brings prestige to the student, the faculty, and the university. More potential and currently enrolled NCATSU students now recognize our university as an institution that prepares students for biomathematics research careers. In 2006 between the math and biology department we had only 20 students doing biomathematics summer research internships. In 2008, the Biology and Math Departments will have over 50 undergraduates going to summer internships related to biomathematics. This group of 5 students, over a 2-year period, presented their biomathematics research at over 35 scientific research conferences. As a noteworthy acknowledgment, 100% of our first cohort of 5 undergraduate students (who graduated from NCATSU) are now pursuing or have been accepted in graduate degree granting programs related to biomathematics. Hence to date we are fulfilling NSF initiatives built around similar goals of increasing engagement, retention, and graduate school admittance for underrepresented students in the sciences at a historically minority university. These data give the faculty a strong understanding of the context and broader mission of the math and biology. Having the iBLEND evaluation efforts has proven critical: (a) for fine-tuning the implementation of programmatic activities to achieve iBLEND program goals, and (b) for tracking performance on outcome indicators to assess progress toward iBLEND program goals.

5. Conclusion.

In conclusion, the iBLEND alliance represents an integrated environment for student and faculty for

contemporary biomathematical research and training. At NCATSU, this alliance has served as a forward-thinking model to other faculty and for sustaining a competitive research environment that includes undergraduates. Through these new partnerships between biology and mathematics we envision major moves forward to improve and expand research and training within the culture of a Historically Minority University.

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