

IGEP: Multi-Scale Transport in Environmental and Physiological Systems (MultiSTEPS)

An Interdisciplinary Graduate Education Program (IGEP) proposal from the Virginia Tech **College of Engineering** (Departments of Engineering Science & Mechanics, Mechanical Engineering, Biological Systems Engineering, Civil & Environmental Engineering, and Electrical & Computer Engineering, and the School of Biomedical Engineering & Sciences), the **College of Science** (Department of Biological Sciences), and the **College of Agriculture and Life Sciences** (Departments of Plant Pathology, Physiology & Weed Science and Biological Systems Engineering).

The core team of MultiSTEPS faculty consists of

- Mark Stremler (stremler@vt.edu) Program Director and Education Coordinator, Engineering Science & Mechanics
- Rafael Davalos (davalos@vt.edu) Recruitment & Diversity Coordinator, Biomedical Engineering & Sciences
- Jeff Kuhn (jrkuhn@vt.edu) Biological Sciences Research Coordinator, Biological Sciences
- Shane Ross (sdross@vt.edu) Engineering Sciences Research Coordinator, Engineering Science & Mechanics
- Pavlos Vlachos (pvlachos@vt.edu) Industrial & International Outreach Coordinator, Mechanical Engineering

The remainder of the MultiSTEPS faculty team consists of

- Maura Borrego (mborrego@vt.edu) Assessment Coordinator, Engineering Education
- Daniela Cimini (cimini@vt.edu) Biological Sciences
- Raffaella DeVita (devita@vt.edu) Engineering Science & Mechanics
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- Linsey Marr (lmarr@vt.edu) Civil & Environmental Engineering
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INTRODUCTION

Fluid-based transport in and/or through biological systems plays a crucial role in many ongoing and emerging issues in the development and health of organisms, the viability of ecosystems, and growth of the global economy, with problems ranging from cancer metastasis to pharmaceutical contamination of waterways and nanoparticle dispersion in the environment. In the coming decade, we will need interdisciplinary researchers poised to tackle these and related challenges that will emerge as technological and medical advances continue to produce novel physiological and environmental challenges.

Biologists typically take a simplified view of transport phenomena, relying primarily on idealized models of steady-state diffusion and/or convection. This point of view may be sufficient for understanding the average behavior of identically cultured cell populations in a simple, well-controlled environment, but it neglects the complexity of transient transport in and through inhomogeneous biological systems, the interdependence of small-scale interactions and large-scale behavior, and the influence of these phenomena on biological function. Engineers are well-equipped to understand, model, and predict transient transport in complicated, multi-scale geometries, but they typically regard the underlying biological system as a “black box” without full appreciation or understanding of the basic biological principles that govern system behavior. Merging the engineering and the biological viewpoints of biological transport will equip researchers to understand, model, and predict the interdependence of transport phenomena and biological function and to drive the next generation of fundamental advances. Of course, some merging of these perspectives at Virginia Tech is being achieved by the School of Biomedical Engineering & Sciences. However, there are many important problems and educational activities in biological transport that lie outside of the biomedical engineering discipline.

The goal of MultiSTEPS is to establish a sustainable framework of interdisciplinary education and research at Virginia Tech that trains future leaders of academic and industrial research to think, collaborate, and contribute at the intersection of the biological and engineering sciences. This program will develop participants who are experts in a core discipline of engineering or biology and who are also proficient in the alternate discipline, with understanding and appreciation of its methods, culture, and perspectives. The MultiSTEPS graduate training program is based on a systematic process of increasingly interdisciplinary coursework, student interaction, community development, and cross-disciplinary research experience and includes ethics and professional development components. Key elements of this program include an interactive seminar series; cross-disciplinary coursework; and a collaborative grant proposal challenge. The MultiSTEPS graduate researchers will be trained as scholars and leaders who are well-grounded and conversant in the fundamentals of both biology and engineering, who are experts in their chosen area of specialization, and who are able to communicate effectively with fellow researchers, policy makers, and the public, both locally and abroad.

The proposed MultiSTEPS Interdisciplinary Graduate Education Program (IGEP) will build on the newly-established MultiSTEPS IGERT program funded by NSF from July 2010 to June 2015. The NSF-funded MultiSTEPS trainees must be US citizens or permanent residents. **IGEP funding is being requested so that the MultiSTEPS team can expand and diversify the current trainee cohort by supporting “affiliate students”, including international students.**

DESCRIPTION

MultiSTEPS trainees will investigate transport phenomena across **three research areas**, with supported research activities spanning these three areas of transport at the *cellular scale*, the *organismal scale*, and the *environmental scale*. Each of these research areas is supported by multiple participating faculty. For brevity, description of the specific research activities is not provided here.

The MultiSTEPS education and training program focuses on both *educating across disciplines* and *partnering across disciplines*, giving MultiSTEPS trainees the interdisciplinary knowledge base and collaboration network needed to conduct transformative research and development at the interface between the biological and engineering sciences. The educational framework is based on three stages of interdisciplinary intellectual development that are guided by previous Virginia Tech IGERT research [1, 2] and other studies [3–5]:

Step 1: Content Mastery and Community Building — This step will (1) provide an educational foundation that prepares the trainees for interdisciplinary collaboration and (2) foster the growth of social networks among the trainees as a foundation for research collaborations across disciplines [6]. Each MultiSTEPS trainee will participate in either a **Biological Sciences Track** (BST) or an **Engineering Sciences Track** (EST) of education and training. These tracks consist of (1) developing a core expertise in a relevant discipline of either biology (BST) or engineering (EST) while pursuing a Ph.D. in a corresponding home department, and (2) developing proficiency in the fundamentals of the complementary discipline.

The coursework for each MultiSTEPS trainee will include **formal instruction in the complementary discipline** and is required to have an emphasis on transport phenomena. A template for this requirement is shown in Table 1 on page 4. *ESM 50xx: Fundamentals of Mechanics* is currently being developed (ESM 5984 in Fall 2010) to provide a graduate-level introduction to foundational material in transport mechanics for students with limited engineering background. This course will be required for BST trainees, and will be recommended to EST trainees as needed. Another requirement is the **Interactive Seminar Series**, a one-credit-hour course that trainees must attend in every semester. Trainees and faculty will meet weekly for both informal social interaction and formal seminar-style presentations. As has been observed in other interdisciplinary training programs, social interactions help establish interdisciplinary networks in support of collaborative research efforts and aid trainee retention by building camaraderie [6, 7].

Step 2: Interdisciplinary Integration and Professional Development — In this step, trainees will be trained to (1) perform high-quality independent research, (2) interact professionally across disciplines, (3) evaluate the social and ethical implications of their research, (4) appreciate the international impact of their research, and (5) prepare for professional aspects of their career. Key activities include a three-part research rotation, a cross-disciplinary teaching experience, a professional development course from the Transformative Graduate Education program, and a MultiSTEPS-specific section of the course GRAD 5134: *Interdisciplinary Research*.

Each trainee’s **research experience** will begin during their first semester in the MultiSTEPS program with **research rotations** through three of the MultiSTEPS research groups. By the end of the third rotation, trainees will **select co-advisors for their continued research activity** consisting of at least one faculty participant from each track.

Step 3: Interdisciplinary Research — Trainees will begin collaborative interdisciplinary research through participation in the **MultiSTEPS grant challenge**. Proposal writing teams will consist of two or three trainee “principal investigators”. Both programmatic tracks must be represented

	Biological Sciences Track	Engineering Sciences Track
A	ESM 50xx: Fundamentals of Mechanics	BCHM 5124: Biochemistry for the Life Sci.
B	BMES 5244: Biofluids CEE 5304: Environmental Fluid Mechanics	BIOL 5884: Molecular Biology of the Cell BIOL 5024: Population & Comm. Ecology
C	BMES 5014: Quantitative Physiology BMES 5304: Biological Transport Phenomena CSES 5594: Water & Chem. Transport ESM 5314: Intermediate Dynamics ME 5404: Fluid Dynamics	BIOL 5034: Ecosystem Dynamics BIOL 5074: Stream Ecology BIOL 5634: Microbial Physiology BIOL 5984: Physical Chemistry of the Cell ENT 5114: Insect Structure & Function
D	MATH 5515: <i>Modeling and Simulation of Biological Systems</i>	
E	GRAD 5134: Interdisciplinary Research (2 semesters)	
F	Interactive Seminar Series (1 hour per semester)	
G	GRAD 5104: <i>Preparing the Future Professoriate</i> or GRAD 53xx: <i>Preparing the Future Professional</i>	

Table 1: Template of the course requirements for the MultiSTEPS program; trainees may request that alternative courses be taken. Formal instruction in the complementary discipline is satisfied by choosing *one* course (in the appropriate track) from *each* of A, B, and C; D–G are required.

on each team. Each team must be co-advised by at least two MultiSTEPS faculty (one from each track), but the proposed research is to be based primarily on the trainees’ own novel ideas. Evidence of how the proposed interdisciplinary research will be sustained through integration with each trainee’s dissertation research must be included in each proposal and will be a review criterion.

Student Recruitment and Retention — Recruiting, mentoring, and retaining a diverse group of talented, well-prepared students is crucial to the success of this program. The recruitment and retention effort will be coordinated by Dr. Davalos, and he will be mentored by Dr. Bevlee Watford, a former NSF program manager and the Director of the Center for the Enhancement of Engineering Diversity (CEED). Based on the experiences of Dr. Davalos and Dr. Watford as members and active, successful recruiters of underrepresented groups, the key to successful recruiting lies in exposing prospective students to the opportunities provided by this program through personal interactions at a group of targeted universities.

Some of the MultiSTEPS IGEP recruitment activities will leverage those for the MultiSTEPS IGERT program. A MultiSTEPS website has been established (www.multisteps.esm.vt.edu), recruitment materials have been developed, and recruiting activities are being conducted at selected US institutions and scientific conferences.

The MultiSTEPS IGEP program will specifically target international students through established relationships between Virginia Tech and a few leading international institutions, including the Technical University of Denmark (DTU), the Wageningen University and Research Centre (WUR), and the Technical University of Darmstadt (TUD). The Virginia Tech College of Engineering has established faculty relations with DTU and WUR and has established a dual-degree graduate program TUD (with ME). Currently there is a frequent exchange of faculty between Virginia Tech and these institutions (funded by existing means). The VT-ME Department is also an NSF REU joint site with TUD; undergraduate students are working on collaborative summer research projects between the two sites. We will leverage the success of these ongoing programs to recruit international students as MultiSTEPS trainees. Recruitment will also take place through

interactions with prospective students at international scientific conferences.

Continued Support — The MultiSTEPS IGERT program will be supporting a total of 24 PhD students (6 new trainees per year for 4 years) for a training period lasting a minimum of 24 months. We propose that the MultiSTEPS IGEP program support 4 additional PhD students per year. Ideally this support will also be for a training period lasting 24 months that covers the core educational and research activities described above. After completing this core program, students will continue their PhD research under the supervision and support of their chosen co-advisors. Continued support beyond the initial training period is expected to come from the co-advising faculty and/or the trainee's home department as appropriate. We anticipate that the interdisciplinary research being conducted by each trainee as a part of this program will lead to external research support. One excellent example of how we expect this mechanism for enhanced collaboration to result in additional external funding is the recently awarded NSF Emerging Frontiers in Research and Innovation (EFRI) grant to study complex microsystem networks inspired by internal insect physiology (NSF Award 0938047, PI J. Socha). The awarded proposal grew, in part, out of discussions between MultiSTEPS faculty during preparation of the original IGERT proposal.

Program Assessment — Assessment will be centered around the advances we expect to be promoted by interdisciplinary training [3, 8] and the development of professional and interpersonal skills, which research has shown to be essential to scientific collaboration and overall professional success (e.g. [9, 10]). We will also assess the ability of the MultiSTEPS program to recruit and retain a diverse population of trainees. Assessment activities are being coordinated by Dr. M. Borrego and are being overseen by an external evaluator and consultant, Dr. Deborah Olsen.

A detailed assessment plan with specific activities, goals, metrics, and timelines for each cohort of trainees has approved by the Virginia Tech Institutional Review Board. We will be using a mixed methods approach with quantitative close-ended measures, open-ended semistructured interviews, and “real-world” performance data. Data will be collected longitudinally, and MultiSTEPS trainees, faculty, and departmental chairs will all be included in the evaluation so that we can triangulate their respective vantage points and assess the broader impacts of the program.

REFERENCES

- [1] K. Drezek & D. Olsen, The impact of interdisciplinary training on doctoral students' epistemic beliefs: interdisciplinary understanding as a graduate educational outcome (submitted).
- [2] D. Olsen, B. Bekken, K. Drezek & C. T. Walter, Teaching for change: Learning partnerships and epistemological growth, *Journal of General Education* (under revision).
- [3] V. Boix Mansilla & E. Duraising, *J. Higher Education* **78**, 215 (2007).
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- [5] V. Boix Mansilla, *Change* **37**, 14 (2006).
- [6] D. Rhoten, A multi-method analysis of the social and technical conditions for interdisciplinary collaboration, Technical report, Hybrid Vigor Institute, San Francisco (2003).
- [7] L. Anthony, M. Palus, C. Maher & P. Moghe, *J. Engineering Education* **96**, 141 (2007).
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- [9] A. Austin, *J. Higher Education* **73**, 94 (2002).
- [10] Wulff and A. Austin, *Paths to the professoriate: Strategies for enriching the preparation of future faculty*, pages 46–73, Jossey-Bass, 2004.

APPENDIX: SUPPORT DOCUMENTATION

The MultiSTEPS program is being actively supported by the participating colleges and departments, as well as by the Institute for Critical Technology and Applied Science and the Fralin Life Science Institute. As evidence of this support, four of the commitment letters for the MultiSTEPS IGERT proposal are attached. We are not soliciting additional college or departmental support as part of this IGEP proposal.



March 4, 2009

Program Directors

Integrative Graduate Education and Research Traineeship (IGERT) Program

National Science Foundation

Arlington, Virginia

Re: Virginia Tech MultiSTEPS IGERT proposal

Dear IGERT Program Directors:

The Virginia Tech College of Engineering, together with the Department of Engineering Science & Mechanics (ESM) and the School of Biomedical Engineering & Sciences (SBES), provides the MultiScale Transport in Environmental and Physiological Systems (MultiSTEPS) IGERT proposal with its highest possible endorsement. This proposal, submitted by the team led by Professor Mark Stremmer, will develop a new program at the interface of engineering and the biological sciences. The team will organize an interdisciplinary education and research program around the themes of transport phenomena in biological systems and its application to engineering concepts. Their idea of pairing MultiSTEPS IGERT trainees across these themes is both innovative and necessary. MultiSTEPS research will lead to the development of new understandings at the interface of engineering and science.

The College of Engineering will enthusiastically provide material support for the proposed project in the form of support for one graduate student per year for 3 years of the project, with the flexibility to use one of these years of support in Year 6, following completion of NSF funding, as a means of sustaining this effort. This commitment follows our recent investments in faculty cluster hires whose goal is to promote new research directions in the engineering sciences, particularly at the interface between engineering science and biology. This focus in faculty hires is represented well in the faculty who are participating in this IGERT proposal. The Department of Engineering Science & Mechanics (ESM) will enthusiastically provide material support for the project in the form of support for one graduate student per year for all 5 years of the project. The School of Biomedical Engineering & Sciences (SBES) will enthusiastically provide material support for the project in the form of support for one graduate student for one year of the project. In addition, SBES will provide access to the new, state-of-the-art video-conferencing classrooms under our control in the new ICTAS Building on the Virginia Tech campus.

Our commitment to interdisciplinary programs is exemplified by the recent creation of ICTAS, a new paradigm for fostering cutting edge, interdisciplinary research. A new campus building opened on March 2, 2009 that will house interdisciplinary research in critical technologies including nano- and biotechnologies. We are pleased to know that ICTAS is also committed to supporting the multiSTEPS program, as communicated to us by the Director of the Institute, Dr. Roop Mahajan.

We have the highest confidence in the scholars involved with this group. They truly represent the high caliber of scholarship, research, education, and outreach that an institution should strive to support, nurture, and engage. We trust that you will find this proposal to be as worthy as we do.

Yours sincerely,

Richard C. Benson
Dean of Engineering
Torgersen Chair

Ishwar K. Puri
Head, ESM

J. Wally Grant
Director, SBES

Invent the Future

March 11, 2009

Program Directors
Integrative Graduate Educational and Research Traineeship (IGERT) Program
National Science Foundation
Arlington, VA

Re: Support of multiSTEPS IGERT proposal

Dear IGERT Program Directors,

The College of Science in partnership with the Department of Biological Sciences would like to express their fullest possible support of the "multiSTEPS" IGERT proposal led by Mark Stremler. In an age when biological problem solving must increasingly rely as much on technical innovation as it does on discovery, we feel that this program will build strong, long-lasting ties between biology and engineering at Virginia Tech.

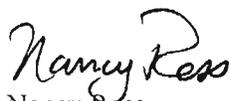
The multiSTEPS initiative fits well with the College's mission to explore and integrate cutting edge areas including nanotechnology, biology, and information science and address public health and human progress. The proposed program will pair talented scientists from biology, chemistry, and agriculture with top-notch engineers to give the next generation of researchers a deep understanding of biology and the sophisticated tools they need to address sophisticated biological problems. Because we recognize the increasing importance of cross-disciplinary training, we pledge to match this IGERT funding with additional support in the form of:

- Six annual graduate student stipends plus tuition from the Dept. of Biological Sciences.
- Three annual graduate student stipends plus tuition from the College of Science.

The additional graduate student stipends we provide will not include teaching duties. The sixth year of funding from Biological Sciences will help extend the trainee grant competition included in the multiSTEPS proposal for the last cohort of trainees.

We have the greatest confidence in the scholars in this group. They recognize the urgent need to reach across traditional disciplinary boundaries to promote a higher caliber of research, education, and outreach. They have all proven themselves as excellent mentors who can train students to bridge the gaps between discovery and application.

Sincerely,



Nancy Ross
Associate Dean
College of Science



Richard Walker
Associate Department Head, Biological Sciences

Invent the Future



September 4, 2009

Program Directors
Integrative Graduate Educational and Research Traineeship (IGERT) Program
National Science Foundation
Arlington, VA

RE: Support of multiSTEPS IGERT proposal

Dear IGERT Program Directors:

The College of Agriculture and Life Sciences (CALs) is pleased to support the multiSTEPS IGERT initiative, a program that promises to further lower the traditional barriers between life sciences and engineering. Our College has a history of reaching across these boundaries. For example, our Department of Biological Systems Engineering is already training both engineers and scientists in ecological engineering, bioprocessing, and the manufacture of food and industrial products from biological materials. Three of the talented faculty members in this IGERT proposal were hired by CALs as part of a cluster hiring initiative at Virginia Tech that concentrates on attracting the best and brightest researchers who cross disciplinary lines.

The multiSTEPS IGERT is thus an excellent fit to our mission of cross-disciplinary training of the next generation of technological and scientific leaders. It provides unique strategies to insure that IGERT trainees are instilled with both a comprehensive understanding of biological questions, and rigorous engineering principles that give deeper insights into fundamental mechanisms underlying biological processes. In support of these IGERT trainees, the College is delighted to be able to offer

- A total of 2 nine-month Graduate Research Assistance appointments for years 4 and 5 of the IGERT program.

We are excited about the proposed program and its potential impacts on research, education, mentorship, and outreach at the university and hope for the successful acceptance of this proposal.

Sincerely,

L. T. Kok
Interim Dean of Agriculture and Life Sciences



- Institute for Critical Technology and Applied Science
- Fralin Life Science Institute

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March 12, 2009

Integrative Graduate Educational and Research Traineeship (IGERT) Program
 National Science Foundation, Arlington, VA

Dear IGERT Program Directors,

Virginia Tech's Institute for Critical Technology and Applied Science (ICTAS) and the Fralin Life Science Institute enthusiastically support the IGERT proposal entitled "Multi-Scale Transport in Environmental and Physiological Systems (multiSTEPS)." This proposal offers a unique collaboration of twenty Virginia Tech professors representing ten departments and four colleges who have backgrounds in engineering, biology, chemistry, agriculture, and environmental sciences. These collaborative research and education efforts promise to combine these diverse disciplines into a common thread under the theme of transport in biological processes.

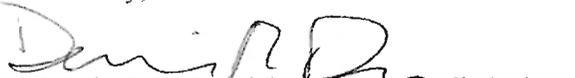
The proposed multidisciplinary effort aligns very well with the mission of the Fralin Institute to gather scientists from different disciplines to address complex biological questions. Similarly, ICTAS is modeled after highly successful university research institutes around the nation to build on the synergies of its faculty for interdisciplinary research pursuits. One research thrust of ICTAS is in the discovery domain of nano-bio interfaces. We believe that the potential for breakthrough technologies in the life sciences through the control of matter at the nanoscale offers huge potential in areas such as in vivo drug delivery, disease sensing, and bio-imaging. Furthermore, nanoscale mechanical devices and sensors allow for the measurement of small forces which are comparable to those exerted by biological interactions. Thus, nanotechnology opens the door for controlled design of molecules at the nanoscale for utilization in vivo in manners that could only be dreamed of even a decade ago.

This IGERT proposal outlines the creation of a model multi-step, graduate training program to prepare future leaders of industrial and academic research to think, collaborate, and solve problems at the intersecting of the engineering and biological sciences, and is thus highly aligned with the missions of both ICTAS and the Fralin Institute. We therefore pledge our support and will work closely with the faculty investigators to develop a long-term, productive partnership with the IGERT Program for the benefit of the scientific and research community. We will provide financial support in the form of:

- One graduate student for years 1, 2, and 3 of this project from ICTAS
- One graduate student for years 1 of the project from the Fralin Life Science Institute.

IGERT students will have use of Fralin Resources including the Fermentation and Protein Purification Facility and a Zeiss Confocal Scanning Microscope. IGERT students will also have use of ICTAS facilities including our state-of-the-art Nanoscale Characterization and Fabrication Laboratory. We are confident that scientists trained in the multiSTEPS curriculum will have an opportunity to gain a deep understanding of both the engineering models that underlie transport and important biological questions multiple levels: molecular, organismal, and environmental. They will continue beyond their training at Virginia Tech to tackle new environmental, agricultural, and health-related challenges of the twenty-first century.

Sincerely,


 Dennis R. Dean, PhD, Director, Fralin Institute


 Roop Mahajan, PhD, Director, ICTAS

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