RESEARCH CORPORATION FOR SCIENCE ADVANCEMENT
Cottrell Scholar Award Application

EDUCATIONAL PROPOSAL: *Each applicant is expected to propose a plan that has promise to improve undergraduate science education. This is an opportunity to share the philosophy and principles that guide you as a scholar-educator. Competitive applications must include concrete examples of efforts to date, your educational plan, and how that plan supports and complements your department's undergraduate educational priorities. Your educational plan must be substantive and demonstrate a long-term commitment to your role as a scholar-educator. RCSA program officers screen educational plans/proposals initially, and only those that pass this screening are submitted to peer review of both the education and research proposals, giving equal weight to both.*

STATEMENT OF THE PROBLEM, SIGNIFICANCE OF THE PROBLEM, AND YOUR PLAN OF PROCEDURE (Describe your department's recognized areas of educational priorities and explicitly detail how your plan fits. State clearly the problems or issues you wish to address and how they relate to any ongoing work. Cite precedent. Carefully outline the importance of your plan and the impact it may have on your undergraduate students. A viable approach should be given, including examples from your own experience and/or from the literature. Indicate ways in which the completion of this work has a broader impact. Use Arial 11 point font. Limit to four pages.)

My teaching plan proposes to adopt quantitative tools to address problems outside traditional branches of science. American Institutes for Research (AIR) reported the increasing need for numeracy skills in all aspects of adult life—family, employment, and community [AIR 2006]. AIR and several other studies [National Science Foundation 2006] also find U.S. College students significantly lack quantitative skills compared to their peers around the world. While I acknowledge the finding, based on my teaching (although limited) experience in both American and non-American setting, I also appreciate the fact that students from American Universities tend to get a more rounded education cutting across different disciplines compared to their global counterparts. This is particularly important in today's multi-disciplinary world where an individual is required to learn techniques and concepts that are not necessarily direct application of college curricula. Students having diverse background equipped with critical, and deductive reasoning skills are better trained to adapt under these conditions. This is my motivation to integrate quantitative reasoning in our education while tackling practical problems that reside well outside the mainstream textbook problems.

A field of physics called "statistical physics" although originally developed to address problems of physics and chemistry, is finding a wide range of application in non-traditional complex problems — modeling financial market, vehicular traffic, disease propagation and control, snow flake formation, networks in communications and social sciences, [Mantegna 1995, Halpinheally 1995, Chowdhury 2000, Dorogovstev 2002, Sethna 2011] and in biology [Phillips 2008]. The understanding of complexity and its origin is a fundamental challenge for modern science and statistical physics provides the perfect tool to tackle these problems. Simple-as-possible methods, which capture the essential mathematical features necessary to reproduce complexity, are increasingly being used to obtain insights into such problems. Thus introduction of these problems serves the dual purpose of inculcating quantitative skills as well as addressing problems form diverse fields not addressed in traditional curricula.

I will introduce this multi-disciplinary training in two settings: **A)** developing a seminar course (First Year Seminar) for freshmen students, **B)** a course in Physical Biology for advanced undergraduates. My research proposal demonstrates application of physics to model biology, a field that is increasingly being invaded by statistical physicists. However, my broad interest in statistical physics extends well beyond biology: modeling several complex problems such as polymers, liquid crystals, magnets, and onset of traffic jam. Thus based on my vast experience on statistical physics modeling, I feel I am perfectly suited to translate these ideas into classroom setting. There is currently no such course in our University. I believe varied topics beyond usual science application will attract both science and non-science majors. There will be "something for everyone". My past experience on First Year Seminar, perfect playground for these ideas, witnessed enrollment of business, anthropology, music, criminology, communication, environmental science, and traditional science majors. Below I describe the details of the two classes to achieve my goals.

A) First Year Seminar "Non Linearity, Butterfly Effect, Randomness, Complexity and Life": Reality often deviates from simple linear relations where additive rules do not apply. In such non-linear systems it is possible to realize high degree of sensitivity. Small changes can cause large change in the output, also known as "butterfly effect". This is the essence of chaos. Such non-linear systems are also associated with emergence of interesting patterns including fractals. On the other hand uncertainty is the essence of life and the natural language for statistical physics. The world around us is greatly influenced by whims of nature. Natural processes like formation of embryo, snow flakes, propagation of forest fire, traffic jam, onset of diseases are all governed by the laws of probability and statistics. Thus, randomness is a recurring theme in diverse field, appreciation of which should be an essential part of education for students. In the past I taught students a seminar course focusing solely on aspects of randomness and uncertainty. However, chaotic and probabilistic worlds are intimately related due to uncontrollable changes in the outcome of a chaotic system as a result of small change in the input. This is evident in many real life systems (see below) that exhibit exotic concepts such as cooperative ("all or none") behavior, synergism, tipping point (high sensitivity); these are essential features of complexity. Numerous real life problems well outside the realm of traditional theoretical physics and mathematics are fertile grounds to test these ideas. Thus I want to modify my previous seminar class by integrating these diverse problems where students will learn concepts and the role of non-linearity, chaos and uncertainty in daily life.

High school algebra and intuitive mind is the only pre-requisite for the class. I will spend first few weeks to introduce the basics of these ideas and probability theory to bring everyone up to speed with necessary mathematical background. I will then draw examples from applied problems of broad interest where stochasticity is important: example problems will include "drunken walker", propagation of forest fire, weather fluctuation, stock market modeling to name a few. Emphasize will be on how to think quantitatively about these problems and analyze real life problems by computer simulation. Utilizing computer models will be a perfect match to the younger generation's love of computer games (see destination trip section for more details). In my seminar class in the past, one of the sample problems that were extremely popular among students was modeling chocolate chip cookie factory. We simulated chocolate chip cookie production with the help of random number tables to sprinkle chocolate chips in a cookie modeled by a two-dimensional lattice. Students were rewarded with cookies while solving the problem. The later half of the class will consider illustrative examples from physical sciences that are of broad interest - mixing of oil-water, magnets, liquid crystals (responsible for LCD displays) and application to biology. In the biological world, I will demonstrate how modern science unravels tricks of DNA, protein and associated randomness that is intimately related to diseases and cure. My research on biological toys such as switches and their role in decision-making, importance of biological clocks will be perfect examples of cooperative systems. They will be introduced in class setting with the help of computer animations generated in our lab. Wherever possible we will complement course content with educational videos such as "DNA: secret of photo 51"(discovery of double helix), movies from NOVA ("Cracking the Code of Life").
In a nutshell, students will learn how to think about problems beyond their comfort zone and familiarize themselves with modern problems and their complexity and challenges.

Developing quantitative skills and critical thinking by model building: Each new topic will be first introduced in class highlighting qualitative features. Subsequent discussion sessions and assignments will address quantitative aspects of the problem. I will introduce sample problems in class and show them how to think about building models for simplified "toy" systems. These "toy models" will be used to understand the underlying features of complex systems. We will try to learn the behavior of these systems using lattice models and simulation. Due to time restriction students will do simple enumeration of these models in class. However, they will be expected to use computer and several available online servers/applet to simulate these models. Students will be asked to actively participate and question such ideas, criticize and analyze results based on the model. They will be required to infer basic ideas from such simulation movies that I believe will be engaging and instructive. One such example is simulating traffic jam in a 1-dimensional lattice by setting up rules and varying model parameters. This way students will learn emerging patterns and concepts such as tipping point, cooperative behavior in a first hand manner. However, the course will also give students ample opportunity to think about new problems. As mentioned below, for their projects, they will have to build their own model and scrutinize. Other students will provide feedback on projects of their peers (see assessment). This will teach them how to think and analyze a given problem, identify the big picture and research.
Something for everyone: Integrating topics from different areas will be particularly appealing to a diverse student population. I will achieve this by two methods: i) students will carry out projects of their own interest,

EDUCATIONAL PROPOSAL: *(continued)*

ii) I will organize field trips to regional scientific and business establishments.

i) Diverse class projects will be of broad interest: Students will be required to research on a project while enjoying the freedom of choosing a topic of their personal interest. This will replace final exam. They are allowed to use existing statistical data or create their won "toy model" using example problems discussed in class to identify and reproduce complexity of the problem. Students will use online and class tools to simulate such systems. This has the added advantage of introducing Peer instruction [Mazur 1997] and addressing even a broader set of problems not addressed by the instructor in class. Some of the possible interesting projects including sample examples from the past are:
1) Analysis of weather pattern, temperature fluctuations and uncertainty in weather forecast.
2) Analysis of fluctuation patterns of particular stocks, of interest to students investing in the market.
3) Modeling probability of accidents on ski-slope using a lattice model.
4) Collecting data and analyzing traffic pattern (highway and downtown Denver).
5) Uncertainty in disease propagation by contact and by vectors (mosquito) using lattice model.

ii) Destination trips and interaction with local business and educational establishments: One of the appealing aspects of the class will be interaction with local government and business establishments. In past we made trips to Denver science museum. However, we are now planning to make trips to more non-traditional destinations. Parts of the award will be used to support such destination trips supplementing support from our University. Some of the illustrative destinations and their unique features are below.

1) National Center for Atmospheric Research: This is a national facility located in Boulder outside Denver. One of the most attractive features of this facility is several educational videos and computer demonstration lab. This lab features engaging 3-dimensional animation of computer generated models of weather including formation of storms, hurricanes, and global warming. Trip to this facility last year was well received by students irrespective of their background and major interest.

2) Denver Traffic Control Center: I plan to organize a trip to the traffic control room that monitors highway and local traffic around Denver. Students will get an introduction and access to impressive computer facilities that are used to monitor and control traffic lights, in real time, in case of a traffic jam due to baseball game or other major events. Ideas of complexity and self-organized criticality can be best appreciated with such real time demonstrations. This will complement toy models discussed in class. I also plan to contrast the pattern of road traffic with air-traffic by visiting the Denver International Airport. I already communicated with appropriate authority at the establishment who expressed interest to organize such a trip. The goal is to experience complexity of the air traffic control as well as traffic of baggage after passengers check in their luggage. I made personal trip to the Denver traffic control room to gauge feasibility and learn appealing features of the facility that will be instructive and engaging to students.

3) Visitors from Janus Capital Group: Janus capital is a research driven investment company based in Denver. I will invite financial analysts from the establishment to give class presentation outlining real life challenges in modeling stocks, general research strategy to understand volatility of market. This would be particularly popular among business students. I consulted relevant personnel about such possibilities.

B) Course in Physical Biology for advanced undergraduates: My second goal to achieve quantitative modeling at a more rigorous and advanced level constitutes designing a class on Physics of life. This class will consider example problems illustrating applications of physics and quantitative reasoning to several biological problems. With increasing interest among physical science students to pursue a career in biophysics, the course will be of immense help among students in our University. I am developing an equivalent graduate course for our recently launched doctoral program in Molecular and Cellular Biophysics. Several of our physics majors as well as a few chemistry and biology majors approached me expressing their interest in a similar undergraduate class. This demonstrates a significant interest and importance of a course of this nature, absent in our present curricula. I will emphasize "biology by numbers" [Phillips 2009]. Students will learn how to apply statistical physical principles to model polymers, macromolecular structures, reaction kinetics, genetic networks, hydrodynamic principles in crowded environment to name a few example. I will primarily use the book by Phillips [Phillips 2008], supplemented by other reference materials and books wherever needed. I believe a course in biophysics that is evolving at a pace faster than ever with new knowledge and discoveries directly translating from lab, needs more than a textbook. My own research interest and knowledge in the field of biophysics would help constantly morph the material and supplement course content with recent results from journal articles on a regular basis.

Advising undergraduate students to carry out Honors thesis:

Undergraduate students in the Honors program at the University of Denver (DU) will carry out parts of the research proposal and other biophysical problems ongoing in our lab for their Honors theses, for which they will be further trained in scientific writing and presentation skills. ***Part of the award will be used to provide summer stipend for these students***. I supervised two students and currently mentoring three undergraduates working on their Honors thesis.

Thus due to the inherent interdisciplinary nature of the biophysics class and Honors thesis topics described above, students will have opportunities to perform multidisciplinary projects, integrating physical modeling techniques, judicious applications of simulation packages, with the basics of biophysics and statistical physics.

ASSESSMENT PLAN: *Define expected outcomes of your educational plan. How will your evaluation design provide information to improve your project as it develops and progresses? How will you determine whether your stated project objectives are being met according to the proposed timeline?*

Assessment will be done with traditional methods of giving quizzes and grades. However an interdisciplinary and exploratory Seminar class will heavily rely on several novel assessment techniques. One of them is the end of the quarter project presentation replacing final exam. As part of this requirement students will submit a final report and give a thirty-minute class presentation. This will help students improve writing and presentation skills. I will use many formative assessment tools [Nicol 2006] as well. One of them will be a one-page project proposal due in the middle of the quarter. This will be evaluated based on five criteria: i) description of the problem and background, ii) clearly identifying questions addressed, iii) innovation, iv) approach and v) potential problem and alternate approach. I will organize in-class mock panel discussion of these proposals by their peers. I will be the moderator of the panel discussion. This will serve multiple purposes: a) It will introduce Peer Instruction [Mazur 1997] where students will evaluate proposals of their peers and give critical comments; b) while providing valuable comments to their peers, evaluators themselves will also get examples of high quality proposals and gauge expectations; c) this will further promote students to initiate thinking about their project and identify potential problems at a much earlier stage giving ample time to adjust and incorporate feedback. Furthermore, I will incorporate several in-class questions and problems to evaluate retention as well as keep students engaged during class. I will make students discuss their answers following Peer Instruction technique of Eric Mazur [Mazur 1997]. Moreover, pre-class reading and movies screened will be followed by a debate. These will promote further class participation as well as cultivate reasoning and presentation skills among students. Chalk-talk presentations will be sometimes encouraged for impromptu informal discussion while solving numerical problems. Another mode of assessment will be mid-quarter one-on-one discussion with students about the class and progress of their project. Student feedback during these meetings and end-of-the-quarter evaluation will be used to modify the course. Project presentation and class discussion will be introduced in the biophysics class as well to promote peer evaluation.

If successful I will make several of my course content available online to be used by other educators as well. I will also target local high school teachers to help establish a similar but simpler version of this module. Prof Zink and Prof Calbi in our department are leading efforts to introduce a short summer workshop for high school teachers in the field of condensed matter physics and nano-science. I will collaborate with them to identify potential teachers and students. Another long-standing tradition of our department has been participation in a science theme night at a local amusement park, near downtown Denver. Our most popular demonstrations and topics from this course will be used at this event to engage high school students. I will seek further help from our "Center for Teaching and Learning" to introduce more interactive teaching methods and tools for Peer instruction.

LETTER OF SUPPORT: *Include a letter of support from your Departmental Chair,* **See next page for the letter.**

LIST OF REFERENCES: *(Annotate the proposal with a list of references from the primary literature. Include all authors and titles. If more space is required, attach a maximum of one additional page. Use Arial 10 or 11 point font.)*

Teaching Proposal

1. AIR American Institutes for research, Washington DC A review of the literature in adult numeracy: research and conceptual issues (2006).
2. National Science Foundation, NSB America's Pressing Challenge- Building a Stronger Foundation, *Science and Engineering Indicators* (2006).
3. Mantegna, RN and Stanley, HE Scaling behavior in the dynamics of an economic index. Nature, 376, 46-49 (1995).
4. Halpinhealy T and Zhang YC Kinetic roughening phenomena, stochastic growth directed polymers and all that- aspects of multidisciplinary statistical-mechanics. Phys. Rep., 254, 215-415 (1995).
5. Chowdhury D, Santen L and Schadschneider A Statistical physics of vehicular traffic and some related systems. Phys. Rep, 329, 199-329 (2000).
6. Dorogovstev SN and Mendes JFF Evolution of networks. Advances in Physics, 51,1079-1187 (2002).
Sethna JP Statistical Mechanics: Entropy, Order parameters and Complexity. Clarendon Press, OXFORD (2011).
7. Phillips R, Kondev J and Theriot J Physical biology of the cell. Garland Science (2008).
8. Phillips R and Milo R. A feeling for the numbers in biology. Proc Natl. Acad. Sci.106, 21465-21471 (2009).
9. Nicol DJ and Macfarlane-Dick D. Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. Studies in higher education 31(2), 199-218 (2006).
10. Mazur E Peer Instruction A user's manual. Prentice Hall 1997.