Introduction and Background: A Challenge in Undergraduate Science Education. The starting point for this proposal is the increasing dissatisfaction of medical educators with the undergraduate science curriculum for students who will enter medical school. A significant proportion of this dissatisfaction is focused on the chemistry component of the premedical curriculum—particularly organic chemistry. This dissatisfaction centers on the perceived lack of relevance to medical education of the science courses taken by premedical students. The Dean of Medical Education at Harvard framed the challenge: “I support greater efficiency and a tighter focus on science that ‘matters’ to medicine. … Instead of the current chemistry sequence, colleges should expose premedical students to general chemistry, organic chemistry, and biochemistry in a 2-year sequence that provides the foundation for the study of biologically relevant chemistry.” [1] Responding to the same concerns, the Association of American Medical Colleges (AAMC) and the Howard Hughes Medical Institute (HHMI) carried out a joint, comprehensive assessment of the continuum of premedical and medical science education. The document that emerged from this study, “Scientific Foundations for Future Physicians” [2, 3a], stressed the importance of outcomes (competencies) in premedical and medical education. For the eight competencies listed for incoming medical students, the document included a large number of specific examples that involve chemistry. Greg Petsko, President of ASBMB, pointed out [3b] that the success of this endeavor will to some degree be driven by the degree to which the Medical College Admissions Tests (MCATs) reflect these competencies. To provide a new curriculum for students who will face “the old MCATs” would be a problem. Fortunately, the AAMC will reform the MCATs (MR5 initiative) by 2013.

Just before this initiative was publicized, we at Purdue had begun to think along the same lines. Our focus included, but was broader than, the community of premedical students. The Biological Sciences Department would like their students to have completed general chemistry, organic chemistry, and biochemistry within two years so that they can enter more quickly into advanced biology courses, and, most importantly, so that they can have an earlier foundation for undergraduate research. Moreover, they called for undergraduate chemistry courses that were more relevant to the biological sciences than tradi-
tional chemistry courses. At the same time, a revision of the undergraduate prepharmacy curriculum was underway, with the logistical objective of allowing prepharmacy students to complete general chemistry, organic chemistry, and one semester of biochemistry in four semesters, and with the educational objective of greater relevance to the clinical sciences. There is no question that academic pharmacy, veterinary medicine, and dentistry will all embrace the general goals of the AAMC/HHMI recommendations. Consequently, we at Purdue were faced with a convergence of educational objectives, and we resolved to seek a common solution for undergraduate chemistry for the biological sciences as a joint project of the Biological Sciences Department, the Chemistry Department, and the School of Pharmacy.

In surveying the academic landscape to see what efforts are in place at other colleges and universities, we found that, as the AAMC/HHMI report suggested, undergraduate chemistry offerings are predominately the traditional ones: one or two semesters of general chemistry followed by two semesters of organic chemistry. While more biological and clinical relevance has been creeping into these courses and into the textbooks that support them, the courses are surveys that contain a significant amount of chemistry that is irrelevant to biology, and the organic courses focus on the reactions that form the foundation of synthetic organic chemistry. Nevertheless, some innovative models are emerging. For example, in the Oberlin model, students take a one-semester general survey of organic chemistry followed by a one-semester “specialty” course in either materials, bio-organic chemistry, or synthesis and mechanism. Other isolated examples exist. The Committee on Professional Training (CPT) of the American Chemical Society (ACS) has suggested the Oberlin model as a possible solution to the accommodation of the diverse interests being served by undergraduate organic chemistry courses. [4]

Our response to the challenge, for which we are requesting support by this Experiment Grant, is called “UC2BS”—the Undergraduate Chemistry Curriculum for the Biological Sciences. This effort consists of three parts: (1) a new, four-semester, curricular model; (2) an enhanced, research-based laboratory component; and (3) a new type of learning resource.

1. The Curricular Model: We propose a curricular model that is different from the “Oberlin model.” We believe that our objectives, and those of the AAMC/HHMI reports, could be met more effectively
with a life-science-oriented chemistry curriculum from the very beginning. Such a dedicated chemistry curriculum is justified by the large number of life-science students. (Within the four 2-semester organic chemistry sequences at Purdue [three in the Chemistry Department, one in the School of Pharmacy], which serve almost 1000 students, 60% of the students plan majors or careers in some aspect of the life sciences.) A similar situation occurs at many universities. We also believe that this curriculum, if successful, could serve as a model for a life science-based chemistry curriculum throughout the country.

Therefore, we propose a new chemistry curriculum that will consist of a one-semester general chemistry offering, a two-semester organic chemistry sequence, and a one-semester biochemistry course. The proposed sequence is not a watered-down curriculum. It will be intense, and it will be rigorous. It will differ from current chemistry curricula in topical selectivity and educational objectives. Its guiding light will be the AAMC/HHMI recommendations.

The general chemistry and organic chemistry will be coordinated so that there is seamless coverage of important topics between the two sequences. Realistically, some of the topics traditionally covered in general chemistry may be revisited in the earliest part of the organic course—for example, bonding, orbitals, and acid–base chemistry—where these concepts can be reinforced and immediately applied to organic compounds of biological significance. We will begin the transition to this curriculum in the Fall Semester of 2010, and its assessment will be supported in part by resources from this grant.

Topics in the general chemistry course—for example, kinetics, equilibrium, and thermodynamics—will use biological cases as examples, including enzymes, buffers, and metabolic reactions. Furthermore, the course will focus on aqueous solution chemistry relevant to biological systems. The weekly accompanying laboratories will reflect the material taught in lecture or a will entail a CASPiE experience for those students that choose to opt into that section (see below). The course will provide key foundation material for the application of quantitative techniques to biology, which is a focus of the core proposal.

The organic chemistry sequence will use small molecules and laboratory reactions to introduce concepts, but will use biological and/or clinically relevant cases with each topic. The examples provided by the AAMC/HHMI outcomes will guide us. The course will focus more strongly on structure and
reactivity, and less strongly on laboratory synthetic strategy, than a traditional course. The organic chemistry course will introduce early-on the idea of proximity (intramolecularity) and its importance to catalysis. Physiologically relevant functional groups, such as aldehydes, ketones, carboxylic acids, phosphate esters, and thiol esters, will be introduced much earlier than they would be in a traditional course.

2. The Laboratory Component: The laboratory component of the curriculum will involve an increase in the number of laboratories that use CASPiE [Center for Authentic Science Practice in Education], a research-based model, rather than a traditional “cookbook” model. This model was developed by one of the key personnel (Weaver) [5a] with funding from the National Science Foundation and is currently being used in general chemistry at Purdue as well as both general chemistry and organic chemistry at 14 other institutions. The program has been in existence for 5 years and has served approximately 3400 students to date. The CASPiE model for undergraduate research rests on three key elements. The first element is a set of modules written by research faculty that reflect current goals of their work. These modules cover work that can be done by undergraduates working in six to eight three-hour weekly lab periods. The second element consists of peer-led team learning [5b] workshops to support the program. The workshop materials have been adapted to focus on research skills and allow students to learn key ideas ranging from keeping a lab notebook to ethics to how to make a good presentation in an oral or poster format. The workshops are facilitated by undergraduate peer leaders, trained in both the workshops and the module itself, working with a small group of CASPiE students in a discussion setting. The third element of CASPiE consists of instrumentation. Where necessary, this consists of having appropriate equipment for students to use in their own laboratories. But, in addition, the students can avail themselves of networked instrumentation that allows, for particular modules, the efficient collection of research-quality data. We intend to extend this approach into the organic chemistry laboratory component of the proposed curriculum, and to increase the number of CASPiE sections available to students, who will be allowed to “opt-in” to CASPiE laboratory sections. Some of the resources needed to meet this objective will be generated by the greater efficiency inherent in this instructional
model. The teaching-assistant (TA) support saved by compression of 4 semesters’ traditional instruction into 3 semesters of the new curriculum can be applied to the more TA-intensive effort needed to help advance this model. In addition, students in the new curriculum will have enhanced opportunities in undergraduate research through the HHMI Core Grant. A key component of the core grant is the recruitment and involvement of underrepresented minorities and students from disadvantaged backgrounds.

3. A New Learning Resource: One of the problems with any of the approaches to life science-based chemistry is the absence of carefully designed learning resources. Few if any existing textbooks combine the philosophy of the proposed curriculum with the needed rigor. Moreover, the issue of learning resources themselves is on the cusp of a major transition. [6] The significant (and escalating) cost of high-quality production of full-color textbooks (composition, paper, printing, and binding) has forced most publishers to charge exorbitant prices for textbook packages and to institute unnecessarily short revision cycles to “cut off” the effects of the used-textbook market. For example, typical organic chemistry packages (text and solutions manual) sell for nearly $300 and are revised every 3 years. This situation has led to increasing dissatisfaction among students and faculty alike. After suggesting the Oberlin model, the CPT convened a meeting of interested textbook publishers at the ACS meeting in August 2009 with a view toward convincing these publishers to develop textbooks suitable for this model, particularly the second-semester “specialty” offering [4]. The outcome of the meeting reflected the chicken-and-egg nature of the problem: people who develop such courses need the learning resources for their students, but publishers are reluctant to provide such resources without a large established marketable base of such courses. Moreover, the fate of textbooks themselves is, more than ever, in question. Traditional textbooks, or even electronic textbooks on handheld devices, cannot by their very nature take advantage of the many learning-technology tools, such as animations and tutorials, without resorting to ancillary CDs and websites. Publishers are looking for different learning-resource models that can eliminate the high costs of printing and binding. Additionally, we believe that such a learning resource should offer students an archival component of enduring value (much as a textbook is now) that they can use as a reference in later coursework and beyond.
We propose the development and assessment of a modern learning resource for the life-science-based chemistry curriculum. This effort will begin with the organic chemistry resource. Although it is tempting to call this an “online textbook,” it is envisioned to be much more than that. This resource is envisioned to contain instruction, concept animation, structure-visualization tools, autotutorial assistance in problem solving, and evaluation (graded assignments). As currently conceptualized, it will, when completed and published, be offered by subscription. The instructional part of the resource will be provided by download to subscribing students free of charge so that they can have a written resource (i.e., a “text”) of archival value. The electronic nature of the resource will facilitate both correction of errors and updating without the necessity of global revisions. A commercial entity, Sapling Learning Systems, will work with us to develop this resource. Sapling Learning is an innovative online learning company founded by scientists and educators from the University of Texas. Sapling has over 10 years’ experience collaborating with scientists and educators to deliver powerful and effective digital learning products, and is the author and developer behind over 30 technology solutions attached to leading college chemistry, physics, biology, engineering and mathematics textbooks. Sapling Learning has developed market-leading online homework software that has served over 100,000 students and instructors. Sapling Learning is currently lever-aging its software, media, and authoring experience to create the next generation of online textbook. Collaboration with the Purdue faculty for this HHMI project is directly aligned with Sapling’s mission and business direction, and Sapling is uniquely suited to contribute software, content, and years of market experience to facilitate the digital delivery of this curriculum. This proposal provides initial support to Sapling Systems, who will contract with Purdue for deliverables and schedule. The support provided by this grant is a fraction of that required to bring the project to fruition; Sapling will have to invest a significant amount of its own resources in this inherently risky venture. A letter of support from Sapling Systems accompanies this proposal.

Roberts and Company Publishers, an innovative and agile publisher, is interested in marketing innovative solutions to the learning-resource problem. The composition of Roberts’ Board of Directors—leading scientists, educators, and science writers—reflects the strong emphasis on service to the scientific
community. (See http://www.roberts-publishers.com for a description of the Board.) A letter of support from Ben Roberts, President, accompanies this proposal.

The involvement of recognized commercial companies ensures that the learning resource, once developed, will be disseminated to the chemistry community, because these companies will have a vested commercial interest in such dissemination. In addition, the key personnel will make a commitment to present papers to various chemical-education venues as this proposal begins to bear fruit.

The development of appropriate learning resources for the life-science-based chemistry curriculum will involve a significant risk on the part of both the faculty authors and the developers. It is this risk, with a potentially high benefit, that justifies this proposal as an Experiment grant. This grant, if awarded, will represent a partnership of an educational technology company, a major university (Purdue), and a publisher to develop and evaluate such a resource for a life sciences-based chemistry curriculum. The major costs of the grant are for development of the resource and assessment of its value as well as the value of the curriculum.

**A Hypothesis-Driven Approach.** The hypothesis is that the UC^2^BS curriculum will lead to greater retention of students than observed in years prior to introduction of the curriculum; an increased percentage of successful applications to graduate schools, including M.D./Ph.D. programs relative to prior years; and a documented increase in the percentage of applicants who are successful in gaining admission to professional schools in medically-related related disciplines (medicine, veterinary medicine, pharmacy, etc.) over prior years. We further hypothesize that the online learning tools will increase student success and improve student learning. We also hypothesize that the CASPiE laboratory format will provide students with greater scientific process skills than they would have received in traditional lab formats. (Scientific process skills are those necessary to understand and carry out scientific investigations, such as experimental design, using data to support scientific claims, and reporting scientific results.) Finally, we hypothesize that both the curriculum and a well-executed learning resource will be widely adopted by other institutions; the assessment activities associated with this proposal will provide significant credibil-
ity for the products of our work. Such dissemination will significantly enhance the likelihood that the objectives of the AAMC/HHMI study will have been met.

The logic model incorporating these hypotheses and the resulting outcomes into an assessment plan are presented in the assessment section.

**Advisory Panel.** To ensure that the UC^2^BS focuses on relevant curricular issues, we have constituted an Advisory Panel from within both Purdue and the Indiana University School of Medicine. This panel will advise the key personnel, brainstorm ideas, and critique the results. The Advisory Panel, which has already met once, consists of the key personnel of this proposal as well as the following individuals:

Richard F. Borch, Ph. D., M.D., Professor and Head of Medicinal Chemistry and Molecular Pharmacology, School of Pharmacy, Purdue. Professor Borch is a practicing medicinal chemist whose Ph.D. is in organic chemistry. He also teaches in the early years of the M.D. program at the Purdue site of the Indiana University Medical School. He brings the perspective of the School of Pharmacy, as well as that of an M.D. with knowledge of both chemistry and relevant clinical cases.

S. Kathleen Salisbury, D.V.M., is Professor of Small Animal Surgery and Assistant Dean for Academic Affairs of the School of Veterinary Medicine at Purdue. She is an award-winning teacher with a clinical practice and a superb administrative overview of the entire School of Veterinary Medicine.

Richard F. Kuhn, Ph.D., is Head of the Department of Biological Sciences and Gerald and Edna Mann Director of the Bindley Bioscience Center in Purdue’s Discovery Park. He is a prominent virologist and structural biologist. He brings to the Advisory Panel the interest and perspective of the biology area, and particularly the application of quantitative methods to biology, an area stressed by the core proposal.

Peter T. Kissinger, Ph. D., is Professor of Analytical Chemistry at Purdue University and formerly CEO of Bioanalytical Systems, a biotechnology company. Dr. Kissinger will represent the perspective of the biotechnology industry on the panel.

Craig Brater, M. D., is Walter J. Daly Professor and Dean of the Indiana University School of Medicine. Dr. Brater will either serve or will appoint an interested faculty member of the School of Medicine, to represent the School of Medicine.
Letters of commitment from these individuals accompany this proposal. We may appoint other individuals to the Advisory Panel if appropriate. In addition, the Provost of Purdue University has also provided a letter of support.

**Key Personnel.** The key personnel who will work on this project bring decades of collective experience to this project. Distinguished Professor Marc Loudon (Co-Program Director) will co-lead the effort described in this Experiment proposal. He is a bioorganic chemist and is the author of five editions of a nationally distributed organic chemistry textbook, as well as a co-author of multimedia resources. He has taught organic chemistry to preprofessional students for 39 years, and has won numerous teaching awards, including recognition by the Carnegie Foundation as Indiana Professor of the Year. He served on the Chemistry Panel of the *Biology 2010* study of the National Academy of Sciences, which was commissioned to make recommendations for chemistry curricula for the life sciences.

Professor Dennis Minchella is a member of the faculty of the Department of Biological Sciences at Purdue and is the Program Director of Purdue’s Core HHMI Proposal. He will, as required by HHMI, serve as Program Director for the Experiment Grant in collaboration with the co-Program Director and will assess the curriculum from the Biological Sciences perspective as well as its relevance to the objectives of the HHMI Core Proposal.

Distinguished Professor Jean Chmielewski, another award-winning teacher, is an active researcher in bioorganic chemistry and has taught organic chemistry to students interested in the biological sciences at Purdue for twenty years. Prof. Chmielewski will work with Prof. Loudon in developing the organic chemistry curriculum and learning resource, and will test-teach, along with Prof. Loudon, organic chemistry in the new curriculum.

Professor Christine Hrycyna is a researcher in biological chemistry and an award-winning teacher in both general chemistry and biochemistry in the Department of Chemistry. She will take an active role in planning and teaching the first semester (general chemistry) of the curriculum. She also will teach the 4th-semester biochemistry course. Her research interests in biochemistry, as well as her teaching experience, position her to have significant insight into planning of the curriculum.
Professor David Sanders helped to originate the concept of this proposal. He is chair of the Undergraduate Curriculum Committee of the Department of Biological Sciences, and he teaches advanced biology courses to undergraduates. He will co-lead the effort described in this proposal and provide significant curricular planning and insight from the biological sciences perspective.

Professor Gabriela Weaver originated the CASPiE model for laboratory instruction and has brought it to fruition. She has co-authored two first-year chemistry textbooks. In addition, she teaches general chemistry and, as Jerry and Rosie Semler Director of the Discovery Learning Research Center, is in a unique position to help coordinate a multidisciplinary effort to develop and evaluate the UC^2BS curriculum and learning resource.

Dr. Omolola Adedokun, who will receive partial salary support, has an M.S. in Sociology and a Ph.D. in Education from Purdue. She is an expert in quantitative and qualitative methods of educational research, student assessments, and program monitoring and evaluation. She coordinates the development and implementation of the assessment and evaluation protocols for the educational research and outreach programs facilitated by the Discovery Learning Research Center at Purdue University.

References
4. Shulman, Joel (Committee on Professional Training of the American Chemical Society), personal conversation with the PI.