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Developing and Maintaining a Successful Undergraduate Research Program

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Developing and Maintaining a Successful Undergraduate Research Program

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Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

ACS Books Department

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Editors' Biographies

Timothy W. Chapp

Timothy W. Chapp is an Assistant Professor in the chemistry department at Allegheny College in Meadville, PA. He received his B.S. in chemistry and biology from St. Lawrence University and completed his Ph.D. in chemistry at Dartmouth College, working with Professor David S. Glueck. Following this he was a Visiting Assistant Professor at Hamilton College for two years before starting at Allegheny College in 2012.

His research interests are in the area of homogeneous catalysis with a current focus on the study of chiral recognition between metal host complexes and racemic water-soluble phosphine guests in aqueous biphasic systems.

Mark A. Benvenuto

Mark Benvenuto is a Professor of Chemistry at the University of Detroit Mercy, in the Department of Chemistry & Biochemistry. His research spans a wide array of subjects, but includes the use of energy dispersive x-ray fluorescence spectroscopy to determine trace metal elements in land-based and aquatic plant matter, in relation to the use of such materials in phyto-remediation of soils.

Benvenuto received a B.S. in chemistry from the Virginia Military Institute and, after several years in the Army, a Ph.D. in inorganic chemistry from the University of Virginia. After a post-doctoral fellowship at The Pennsylvania State University, he joined the faculty at the University of Detroit Mercy in 1993.

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Chapter 1

Introduction

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Conducting undergraduate research is both challenging and rewarding. However, the path to achieving a thriving research group is not always straightforward. In very general terms, the introductory chapter describes the motivation for carrying out undergraduate research and also highlights some constraints that are institution or subdiscipline specific. The authors of subsequent chapters address these topics in more detail and provide their own unique context.

> Wisdom is not a product of schooling but of the lifelong attempt to acquire it. — Albert Einstein

Professors and research advisors have always endeavored to make the opportunity to gain new knowledge available to their students. However, new knowledge takes different forms. From a student perspective, it comes from reading textbooks and primary literature or attending classes and seminars. Professors share in these activities with their students, but they know that physically taking part in the acquisition of new knowledge through active research is where the true excitement begins. For many, if not all, faculty members research is the source of passion for chemistry, and sharing it with a rising generation of chemists often comprises a substantial part of the decision to pursue a career in the field of undergraduate education.

In a traditional classroom setting there is an upper limit on how effectively passion can be communicated and transferred. Frequently it is not until mentor

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and mentee share a laboratory space that this transfer, and thus transformation, can take place. Research can easily become the most intense form of education, as the student works one-on-one gaining firsthand experience in the laboratory while learning how to design and carry out new projects. Additionally, involvement in such projects relates the undergraduate student's education to problems, situations, and a greater understanding of the world. Notably, there is often renewed vigor for learning in the traditional classroom setting as the new researcher realizes that education is not simply a passive activity. In recent years, there has been a growing realization and more formal recognition of the fact that performing real, hands-on research is one of the most effective ways to enhance the learning experience.

Few would now argue against the fact that student participation in research improves learning, but how does one provide and implement such an opportunity in a primarily undergraduate environment? At a very basic level, advances in instrumentation and equipment, as well as a change in culture over the past few decades, have made it possible to construct worthwhile undergraduate projects and pursue them to completion. Proof of the former is seen in the way computers have become coupled to instrumentation, so that even less-experienced users — such as new undergraduate researchers — can utilize them and produce meaningful data. Proof of the latter can be seen in the dedicated funding that national agencies and private organizations have made available to researchers at predominantly undergraduate institutions (PUI) (*1*, *2*). However, just because the instrumentation and funding exist to carry out undergraduate research projects does not mean that every institution will be able to access these resources.

In a general sense progress has been promising, but it must be acknowledged that each PUI brings with it a certain set of challenges and opportunities. These are influenced by several factors including, but not limited to, a curricular framework for training undergraduate researchers, student demographics, available instrumentation, and institutional support. It is unlikely that any PUI has the perfect combination of the above factors, therefore this book seeks to provide information and first-hand accounts of how other successful educators have met the challenges presented by their institutions.

Within the following chapters there are a variety of answers to the question posed above. A handful of the authors describe departmental approaches whereby progress toward research excellence is a built-in learning outcome for most if not all courses. Summer research is encouraged and there is often a culminating senior project with which students have the opportunity to demonstrate the new knowledge they have acquired in the classroom and the research laboratory. Such an approach requires like-minded faculty who are dedicated to such a curriculum, as well as significant investment of institutional and external resources.

The examples that fall into the category above have reached "critical mass" to sustain momentum and provide research opportunities to many if not all of their undergraduate students. It is clear that such transformations do not occur overnight. At the department level it can take a decade or more of persistent work to establish a thriving research culture at an undergraduate institution. Moreover, once that culture is established, the effort must be maintained to build on the momentum for future students.

These chapters and additional ones provide starting points for developing such a culture at the department level. In several cases the starting point is redesigning introductory or research methods courses to place a stronger emphasis on authentic research and its associated skills. In other cases the establishment of a thriving research group by one faculty member is the catalyst for initiating the departmental transformation. There are also several examples of how to set up an undergraduate research group in departments that place a heavy emphasis on research, and those that place less emphasis on research. Many of these offer roadmaps for developing interdisciplinary research groups or translating resource-intensive graduate-level research to an environment that is resource-restrictive. In still other cases the research has an experiential learning component. For many of the above examples the departmental/institutional role is not always obvious and may not be influential or important. This is a reminder that undergraduate research need not be "institutional" to be successful.

In summary, successful undergraduate research can be accomplished in a variety of different ways and the pages that follow are an example of that. They are also an example of the dedication of faculty members who have committed themselves to undergraduate teaching and research. One of the strengths of this book is the breadth of the contributing voices and writing styles. This stems in part from the nature of the subject matter and the fact that, in some instances, the topic lends itself to a less formal scientific style. As one contributing author put it: "I have authored a chapter before, but it was all filled with equations and reactions, etc. This was in many ways more difficult." The result is that certain chapters have a greater degree of anecdotal advice that gives the feel of an impromptu conversation in the hallway between colleagues, while others have a more formal tone that is reminiscent of a traditional book chapter. As editors we perceived both styles to be equally valuable. Just as there is no one right way to carry out undergraduate research, so too is the case with writing about it. In this way, we hope to appeal to the broadest range of readers.

This book is based on the symposium "Developing and Maintaining a Successful Undergraduate Research Program," which was presented as part of the programming of the Division of Chemical Education at the 245th National Meeting, in New Orleans, Louisiana, in March of 2013. Several excellent talks were given that outlined and discussed both the challenges and the rewards of building and maintaining a research group with predominantly undergraduate students. It is our hope that this volume will serve as a guide and aid to others who wish to pursue research in this way.

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Chapter 2

A Departmental Focus on High Impact Undergraduate Research Experiences

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Undergraduate research experiences have become an integral part of the Hamilton College chemistry experience. The major premise of the chemistry department's curriculum is that research is a powerful teaching tool. Curricular offerings have been developed and implemented to better prepare students for the independence required for successful undergraduate research experiences offered during the academic year and the summer. Administrative support has played a critical role in our ability to initiate and sustain scholarly research programs for all faculty members in the department. The research-rich curriculum is built directly upon or derived from the scholarly research agendas of our faculty members. The combined strengths and synergies of our curriculum and summer research program have allowed us to pursue several programmatic initiatives.

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Introduction

Undergraduate research experiences are an integral component of the Hamilton College chemistry program. We believe that the best way for students to learn science is to be engaged in well-designed, hands-on, investigative laboratory experiences that expose them to the excitement of research, ignite their interest in science and encourage them to pursue research in collaboration with faculty mentors. In the collaborative and intimate research environment, whether as part of courses or during independent research opportunities, students witness our passion for the pursuit of science and research, and mentoring relationships develop. These are the student-faculty relationships, based upon dialogue and discourse, that can powerfully influence students' decisions to pursue careers in science. Furthermore, students deemed "at-risk" of not succeeding in a science major and ultimately underrepresented in our professions — ethnic minorities, women and first generation college students — stand to benefit greatly from these close, interactive relationships (*1–4*). At Hamilton, a small residential liberal arts college with 1850 students, undergraduate research experiences exemplify the close student-faculty relationships and collaborations that we, and many small colleges, believe to be a fundamental aspect of what makes these institutions so attractive and effective.

In 1991, Hamilton College institutionalized undergraduate research by requiring an independent Senior Project of *all* its graduates. It was then, and still is, a distinctive element of the Hamilton College experience. With this campus-wide initiative came a strong commitment by the College to assist in the implementation of the Senior Project. The implementation of the program varies considerably across the disciplines and departments. For chemistry, this meant building a curriculum that prepares our majors for the independence required for a successful senior year research experience. These curricular structures have been essential to the robust undergraduate research program that now exists at all levels, not just at the senior level. Importantly, all of these structures are built directly upon or derived from the successful independent scholarly research agendas implemented by each of the members of the department.

The curriculum is the purview of the faculty and should reflect what we value most. Our department has remained committed to offering courses that provide in-depth treatment of foundational chemistry as well as explore breadth and application. The Hamilton College chemistry major is offered as an American Chemical Society accredited degree, attesting to the breadth and depth of the offerings (*5*). Within this context, we continue to experiment with ways to incorporate discovery-based learning into the curriculum, which takes shape as components of courses and laboratories, full courses and guided research experiences. In addition to the content coverage goals that we have for our various courses, we seek to address the following objectives that we believe better prepare our students for the independence required for a successful student-faculty collaborative research experience (*6*):

- Search, read and evaluate primary scientific literature;
- Design a research project with well-articulated specific aims and a specific research plan;
- Synthesize target molecules using published protocols;
- Employ appropriate instrumentation and techniques for the characterization of compounds;
- Develop understanding of ethical, environmental, civic and safety issues associated with chemistry and laboratory experimentation;
- Communicate the nature of the chemistry and its significance.

Examples of projects that have been developed to address these objectives are included later in this chapter.

The summer research program at Hamilton has grown steadily over the past 20 years. In 1994, Hamilton College had seven undergraduates participating in summer research projects, all with faculty members exclusively from the sciences. With the support that summer of a Howard Hughes Medical Institute award, this number grew dramatically and the seeds were sown for continued growth. In the summer of 2013, over 200 students were engaged in undergraduate research experiences on our campus across many disciplines. In the Chemistry Department alone, we have had as many as 54 summer research students in a single summer and typically they number in the mid-30s. These summer research experiences are an opportunity to invite students into our research programs at a time when they are not distracted by other obligations. We currently provide students with a $400 per week stipend and offer summer housing for $28 per week. Stipends are funded from a variety of sources, including grants awarded to the institution, research grants awarded to individual faculty members, and internal institutional funds. Faculty members decide for themselves the starting dates and duration of the summer projects for their own research groups. All students participating in summer research are required to present a poster at our annual Summer Science Poster Session held during Family Weekend in the fall.

With growing student interest and active College support, a strong summer research program has become an integral part of the life of the College and the Chemistry Department. All members of the department mentor students during the summer. Significant work is accomplished during this focused period advancing the research agendas for the faculty members involved and providing significant training and experience for their student collaborators. For extended periods of time during the summer, some faculty members and their research groups travel to national laboratories where students use state-of-the-art instrumentation and interact with experts in their specific research field. In addition to the scholarly outputs that come in the form of papers published, presentations at professional meetings and research grants funded, the summer is an important time for generating momentum. One of the significant differences and inherent difficulties of doing research at an undergraduate institution is that momentum is hard to create and sustain. Attracting younger students to the summer research program provides the opportunity to build momentum and establish continuity for the laboratory, generally, and for a particular project, specifically. Many students

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choose to return in subsequent years to continue working on their projects. The summer also creates great momentum for rising seniors who will continue their projects into their senior year as the focus of their thesis research.

The summer program serves the department in other important ways. Our summer students get the opportunity to work closely with their faculty mentor and research group for an extended period of time. The formal and informal interactions that are built into the collaborative nature of the summer leads to an *esprit de corps* that develops over the course of the summer and is often carried into to the academic year. Furthermore, students are introduced to very focused research projects over the summer and often come back to the classroom with a different sense of their own role as chemists because they have had the opportunity to see the difference between studying chemistry and doing chemistry. This can have a dramatic impact on how they perform academically in subsequent chemistry courses.

Success begets further successes. The present curriculum has been established and implemented over the past two decades by the authors of this chapter and several other colleagues who have passed through our department. Support from the Hamilton administration has been essential to helping us attract and retain excellent faculty members, staff and students. The administration has also supported our program aggressively by building state-of-the-art facilities, providing support personnel for instrument methods development, maintenance and training, chemical safety and hygiene, management of our high-end computational center and a dedicated institutional grants officer. The administration has supported grant proposals with matches when needed and have responded to unusual requests that challenge standard procedures and processes. For instance, after a departmental review in the mid-90s it was clear that we needed to bolster computational activity in the department. The administration supported a senior-level hire that brought a computational chemist to our department who subsequently initiated the development of one of the best-equipped and productive computational chemistry programs at an undergraduate institution, as detailed later in this chapter. In another instance, Hamilton was awarded a $500,000 equipment grant that was spread over five years. The administration provided the required match up front so that the equipment could be purchased within the first year and a half of the grant. This enabled us to begin involving students and generating data and publications much earlier than would otherwise have been possible.

Building capacity, as happened with our computational program, is critical for a thriving department. We have continued to acquire an enviable array of state-of-the-art instrumentation through grant writing by individual members of the department. These grants have been awarded to support research and teaching objectives. Upon moving into the Taylor Science Center in 2003, the administration made the strategic decision to match any equipment request in any grant proposal at a 1:1 matching rate. This provided added incentive for faculty members to write grants and signaled to reviewers and granting agencies a significant level of institutional commitment.

The combined strengths and synergies of our curriculum and summer research program have allowed us to pursue several programmatic initiatives. The final

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section of this chapter describes some of the other programs that were initiated to attract stronger and more diverse students to Hamilton.

The Curriculum

The major premise of the department's curriculum is that research is a powerful teaching tool. This idea informs all of the courses to a greater or lesser degree, for the most part in their laboratory component. The general chemistry and organic chemistry classes still fulfill their service role, and in them attention is paid to providing the background needed to support not only the chemistry major but also needs of other science departments and of students interested in the health professions.

Originally the first two years of the Hamilton chemistry curriculum consisted of a standard one-year general chemistry course followed by two semesters of organic chemistry. However, in the late '90s, we changed the curriculum to provide a better framework for integrating research and to challenge our better students. We eliminated the laboratory components of upper level courses, except Physical Chemistry, and created a one-semester integrative, investigative advanced laboratory course. We also began awarding teaching credit for supervising senior theses. General chemistry is offered in accelerated form during the fall term, covering the principal concepts of atomic and molecular structure and bonding, thermodynamics and kinetics, general and acid-base equilibrium, and the behavior of gases and solutions. We created multiple sections of this introductory chemistry course to ensure that our students were receiving the attention they needed. The following spring and fall terms include the two semesters of organic chemistry. In the fourth semester of chemistry, students choose between introductory biochemistry and intermediate inorganic chemistry.

Introduction to Chemistry

Today beginning students have their choice of two one-semester introductory chemistry courses. The first is taught in a typical lecture format in three sections of about 35 students, with a laboratory designed with multi-week experiments that deal primarily with topics often found in General Chemistry courses — analysis of pennies, exploration of some aqueous inorganic reactions involving precipitation or not, and an introduction to chemical and acid-base equilibrium. In addition, the students work in lab groups for three weeks in the middle of the semester to design syntheses for biodiesel fuels from various sources and choose among several methods to characterize each fuel. At the end of the term, students research and carry out and present to their lab section a chemical demonstration, which allows them to begin to explore the literature and how to set up and carry out a reaction, necessary beginning tools for research.

The second introductory course is offered to students who are strongly interested in the sciences and chemistry, and is taught interactively to 25 to 30 students. We assume/expect that the students in this course have had an adequate chemistry background in high school and are ready to look at the

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broader implications of chemistry while simultaneously providing the opportunity for them to review and enhance their capabilities with the principles of general chemistry. The course now regularly includes lectures, readings and discussions on topics related to human and environmental health. The laboratory focuses on projects dealing with chemical toxicology and allows the students to hone their analytical chemistry capabilities, while assessing exposure to a variety of anthropogenic toxins. In the first half of the semester, students do directed one- to two-week projects that teach them fundamental analytical techniques. For the remainder of the semester, students work in pairs to carry out a self-designed study of contaminant levels found in some aspect of their environment. For example, students have measured levels of bisphenol A (BPA), a known hormone mimic and disruptor of endocrine function, in water bottles, cash register receipts or beer samples. They have also investigated a variety of used cooking oils or clothing for the presence of perfluorinated carboxylic acids, compounds used in the production of Teflon and likely carcinogens. In another project students examined a variety of consumer products for the presence of brominated fire retardants. One student-initiated project measured chromium and arsenic exposure from direct contact with pressure-treated lumber. The findings from this project led to the dismantling of playground structures at a local daycare facility and elementary school. The structures were subsequently replaced by units constructed of safer materials. The laboratory experience culminates with the students giving a public poster presentation on the project they have carried out during the semester. The objective of the poster session is to engage the campus community and alert them to the dangers associated with these toxic chemicals. In the course of their projects students carry out laboratory testing and do some in-depth exploration of the literature. By connecting the course material to real world chemistry students can see that the science relates to them in a significant way, which can provide strong motivation for continuing in chemistry and research. The laboratory component of this course was adopted by Science Engagement for New Civic Engagements and Responsibilities (SENCER) as one of their model courses (*7*). While this course was originally designed for well-prepared first year students, we are extremely pleased that a number of less well-prepared students are choosing this course because of the toxicology focus and are motivated to work hard to perform well in this fast-paced course.

The two-semester organic chemistry course, begun during the spring term, provides a variety of laboratory experiences that stimulate students to think about research. The sequence begins with several introductory experiments that develop students' abilities and understanding of some basic laboratory techniques. Almost all of the subsequent laboratory experiments require students to use data, obtained by hands-on use of instrumentation, to solve a problem. Students may be asked to analyze and rationalize the stereo- or regiochemical outcome of a reaction or determine the structure of an unexpected product. Students become independent in acquiring IR, NMR and GC/MS data on research grade instruments and encounter a broad range of ways in which these types of data can be used to investigate molecular structure and reactivity. For example, in almost half of the 22 labs that students do throughout the year, they will acquire NMR data on the department's 500 MHz NMR spectrometer. Although in

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many experiments, analysis of the NMR data involves standard interpretation of a proton spectrum, other experiments use integrations to determine product ratios, or analysis of coupling constant data to assign product stereochemistry or evaluation of a NOESY spectrum to define the regiochemical outcome of a reaction. Multiple exposures to instrumentation provide students with specific skills they can use in a later research experience and develop confidence in their ability to use instrumental tools to investigate scientific questions. The problem solving nature of the experiments enhances students' critical thinking skills, helps them to see science as a dynamic process and often motivates them to seek out formal research opportunities. For example, nearly 60 students, many of them sophomores, attended an evening meeting in February of 2013 in which faculty members described research opportunities for the following summer; 34 students applied.

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Intermediate Level Courses

The 200-level intermediate inorganic course covers descriptive and solid-state inorganic chemistry and is often selected as students' fourth semester of the chemistry curriculum and further encourages student development in experimental design through guided independent work in the laboratory. The course enrolls a range of science majors as well as chemistry majors with an enrollment of about 30 students. Early in the lab program for the semester, students build skills in powder x-ray diffraction, as well as UV-vis, and fluorescence spectrometry through experiments in coordination chemistry, solid-state crystal analysis, and the synthesis and characterization of luminescent complexes Also included are other experiments on thermochromism, light emitting diodes, and inorganic electrochemistry. The last month of lab is turned over to the students for extended individual projects. The students each choose a project in inorganic materials whereby they are provided a basic experimental procedure that can be completed in a traditional three-hour laboratory period. Once they have performed the basic experiment, they are asked to build on the basic synthesis and characterization they carried out by proposing a series of experiments that must include the use of multiple characterization tools to explore in greater depth the synthesis or properties of the materials of their projects. Examples of the projects include the investigation of the synthesis parameters for cadmium selenide quantum dots, the effects of stoichiometry in the synthesis of rare earth iron garnets on their x-ray powder patterns, and the luminescent properties of doped zinc sulfide nanoparticles. Each project topic is chosen so that students can readily use the new methods of characterization they learned earlier in the course, specifically powder x-ray diffraction and fluorescence spectroscopy, in proposing their own experiments.

Students embrace these projects with enthusiasm and a sense of ownership that is evident when they ask for extra hours in the lab and from their presentations to the class in the final week of the semester. This makes the logistical hurdles of running 12–15 individual projects simultaneously well worth the effort. In the initial years (2006–2007), we were able to build up the basic chemicals and supplies for a wide range of projects. Each year since, we have added one or two new topics to the project list and we replace materials and supplies as needed. Students with more experience in the lab (for example those who had a summer research experience after their first year) need less direct guidance, but all students find that the good experimental design that must be accomplished in a few weeks is challenging. Through these projects they learn how to limit the scope of their experimental questions and design a project that provides an interesting story to present to their classmates in their 15-minute conference-style oral presentations. Some of the projects overlap in theme (e.g., properties of nanoparticles of CdS and CdSe) and so present the opportunity for students to propose parallel studies. We intentionally allow maximum flexibility in what students can propose and so often there are several new approaches to the topics every year.

The 300-level biophysical chemistry course was recently designed to be an alternative for Biochemistry and Molecular Biology (BMB) majors to the physical chemistry class required for the concentration. While BMB courses are taught by both Biology and Chemistry professors, the biophysical chemistry course is well suited for instruction by a chemist. Enrollment in this new course has ranged from six to eleven students. The course builds up three interrelated units, thermodynamics, kinetics, and quantum mechanics that lead to spectroscopy, and includes applications featuring the physical basis of biochemical properties. While the course has no laboratory component, it incorporates discovery-based learning and project design, fosters critical thinking and problem-solving skills, and teaches biophysical methods, all of which provide a strong foundation for research. Every week, students read, discuss, and present peer-reviewed research and review articles about important advanced concepts in the field.

The most research formative component of biophysical chemistry is the "mini-comprehensive" project, an in-depth study of the research publications of an important scholar in the field. Specifically, students explore physical chemistry concepts and methods in the context of the work of a distinguished professor as a common thread. During the first month, students become familiar with the professor's work and meet the professor during a video conference. Next, they work alone or in pairs to prepare a research proposal that is based on the material discussed in class as it relates to the scholar's work. They then deliver a detailed presentation of their proposed research approach and methodology to the professor who has been invited to visit Hamilton for two days. During the visit, the professor gives a seminar, meets with the students, and listens to and provides feedback on their oral presentations. This term assignment presents some challenges, including the discipline that students need to develop to work consistently on the project well in advanced of the distinguished professor's visit and the intensity of the activities during that visit. But the benefits are well worth it. The assignment requires students to digest the content of peer-reviewed articles, discuss the limitations of the methods and techniques, and understand a specific area of research in enough depth that that they can propose novel research in that area. This is learning in its highest and best form: students transfer and apply knowledge to a new area, enhancing their capacity to utilize critical thinking and analysis tools to a wide variety of situations. This helps them to acquire intellectual toughness and develop a rigorous chemistry background so they are well-positioned for advanced research.

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Superlab

The course that has been most influential on research in chemistry is “Research Methods in Chemistry” taken in the junior year and familiarly known as “Superlab.” The course was originally started in the late ’80s as a way of disconnecting the laboratories for the advanced courses and physical chemistry from their classroom counterparts. Because of the kinds of demands on instruction, the course was, and continues to be, taught by two instructors. In the early iteration this was a two semester course involving two labs a week plus one hour of class. In it students performed all of the physical chemistry laboratories, explored both organic and inorganic synthesis, and did a little analytical chemistry in experiments that ran for one to several lab periods. In the classroom, advanced topics, such as separation theory, ligand field chemistry, and instrumentation were touched on. In addition, attention was given to scientific writing and ethics.

In the late ’90s the course was reduced to one semester, and the physical chemistry experiments were re-associated with the physical chemistry lecture courses, partly to make it easier for chemistry majors to spend a semester abroad. The course still met twice a week with one classroom period, but the laboratory experience was now built around a unifying theme with students carrying out a semester long project focused on the chemistry of metal complexes of tripodal amine ligands. Ideally, in this project students would synthesize one or two tripodal amine ligands, prepare iron and/or copper complexes of their ligands and study the properties of the complexes in the context of their ability to mimic metalloenzyme systems (*8*). Through this work, students would gain experience in the synthesis and characterization of organic and inorganic compounds, following procedures from the primary literature, and have an opportunity to explore the physical properties of the complexes. This version of Superlab, though highly successful in motivating students to carry out chemistry research, morphed into a course that placed too much emphasis on the organic synthesis of the tripodal amine ligands. Students and faculty aimed more at unknown tripodal amine ligands that promised to have different effects on the central metal ion’s electronic structure and catalytic activity, and the emphasis on the complex properties and reactivity was diminished. This prompted us to find a new general research area for the course that would allow students to experience a better mix of chemical subdisciplines.

The present focus of Superlab is a semester-long exploration of the preparation, characterization and catalytic function of a group of coordination complexes using porphyrins as ligands. The course consists of three different sections. In the first, students synthesize porphyrin ligands and use these to prepare a wide variety of metal complexes. They then characterize their complexes by using different spectroscopic and physical techniques, including IR, NMR, UV-vis, Raman, magnetic susceptibility and mass spectrometry. In the middle third, working in twos or threes, the students propose and carry out a project to study an aspect of the electrochemical, ligand binding, and/or catalytic properties of the metalloporphyrin complexes. In the final phase of the semester students individually design, formally propose, and carry out an independent project.

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The course begins with all students preparing tetraphenylporphyrin. Beyond that students have control over the direction of their work with expectations of increased intellectual independence as the semester progresses. Once they have synthesized the tetraphenylporphyrin, students decide which metal ion to use to make a complex and must find a literature procedure for its preparation. For the second section of the course, students are given general guidance on what type of study to design and are provided with some seminal papers to provide background. Projects usually repeat some aspect of a published study then try to extend the study by looking at changes in solvent, substrate structure, catalyst structure, etc. Throughout these first two sections of the course, students are exploring the literature on porphyrin chemistry and begin to get a sense of the breadth of the subject. From this reading, they are expected to develop an idea for their final projects. These final projects will usually repeat and build upon some aspect of work reported in the literature but the students have the freedom to explore whatever they like. As is typical in research, some of what the students attempt works but much does not and rarely does a student accomplish all of the goals outlined for the project. One of the biggest challenges, and best opportunities for student learning, lies in the process of analyzing what is causing experiments to fail and thinking through alternative approaches, something that is difficult to teach in any way other than through a research-based experience.

The course retains a strong emphasis on working to improve student writing skills. The goal is for students to transform their writing from constructing a good lab report to producing a professional quality, journal-style manuscript. Early in the semester, the students read papers from the primary literature to see and evaluate different models of writing within the discipline. Then, on writing assignments, students get feedback through several different mechanisms including peer review, writing conferences, comments on graded first drafts and final drafts. For each section of the course, students complete a written report in journal style, the first two in the form of a note; for the last they use the style of a full paper, including an introduction with a significant literature search. They also write two proposals that describe the objectives and outlines significant background literature for their projects and present two oral reports.

In the course, scientific ethics are discussed in the context of reading Carl Djerassi's "*Cantor's Dilemma*," a novel which explores issues of scientific misconduct, politics in the academy and the difficulties women face in science, among others (*9*). Students find the novel interesting as well as a bit of a break from the intensity of some of the writing and experimentation. During the class discussion of the novel students often make trenchant and perceptive comments about both the story and the writing. These discussions often lead to extended conversations about graduate school and career options.

Superlab is challenging and sometimes discouraging for students, as they try to repeat some of the complicated syntheses and physical experiments they propose. In spite of the difficulty and attendant frustration, students find the experience stimulating and can see the progress that they make in their capabilities, often commenting on their own growth in the course evaluations. The course is also instructor intensive, which it must be, since it is like supervising eight to ten beginning research students all working on different problems. Students often encounter lab techniques with which they have little or no experience (working in inert atmospheres, separating compounds with column chromatography, etc.). Also, most students are unfamiliar with some of the instrumentation, like the LC/MS, and teaching them how to use the instruments properly can take a good bit of time. Working with students to troubleshoot problems and brainstorm solutions is also time consuming and can be as challenging for the faculty as it is for the students. In the end, however, the investment is well worth it. Students are enthusiastic about research and they bring to their Senior Projects and other research ventures the kind of training and background that enables their projects to move forward at a pace that can lead to publication or presentation of a poster at a national meeting.

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Credit for Supervising Research

One additional recent curricular change has enabled additional research opportunities and helped to build continuity between faculty's academic year and summer research efforts. Five years ago, we instituted a new formalized course for underclass students to participate in research during the academic year. This allows them to continue research they have begun during the summer, to engage in a first research experience to see if research is something they would like to pursue further, or to get a bit of a head start on a summer project that they are planning to pursue. Students may elect to take the class for one credit, one-half credit or one-quarter credit; this is determined by agreement between the research supervisor and the student, and depends mainly upon how much time the student can afford to spend during the normal course of their semester. All faculty members in the department have worked with students through this course and an average of nine students per semester have elected to enroll.

Building Infrastructure and Capacity

Our research-focused curriculum requires two necessary and obvious components: strong research programs headed by individual faculty and high levels of student interest and participation. These programs provide upper-level students access to meaningful senior thesis projects and give underclassmen easy access to introductory projects that they can grow with. Active faculty/student research also directly adds to our curricular offerings. Keeping rigorous research programs active takes considerable effort, but an oft-repeated piece of advice is to attempt to sustain research momentum. That is, always keeping a baseline level of research productivity even at a faculty member's busiest times allows for maximal efficiency at a time when a faculty member can focus more intently on their science. By working extensively with students during the academic semesters in senior theses and independent studies, we can maintain this individual research momentum even as we have full teaching loads. In addition to this *individual* research momentum, however, our department has also recognized the usefulness of a *departmental* and even *institutional* research momentum. Individual research activity and success not only has direct benefits for the individual faculty, but indirect benefits throughout the department, often reaching across the campus through departmental boundaries.

A striking example of this kind of activity is the development of our college-wide, shared-use High Performance Computing (HPC) facility. To our knowledge, it is currently one of the nation's largest and most well-equipped facilities at a primarily undergraduate institution: it includes a 480-core Infiniband-connected Beowulf style computing cluster for efficient parallel processing with several large memory nodes for memory intensive calculations (e.g., *ab initio* calculations), 72 TB of redundant storage capacity, backup systems for duplication of data, and most recently, the addition of seven GPU processors to take advantage of new coding developments leveraging this powerful technology. All of these resources are available on a priority-based queuing system from student and faculty accounts mounted across a network share. This hardware and software infrastructure and the support and policies put in place to manage the resource have grown over the past decade, each advance being assisted by the previous contributions. In particular, the momentum created by past efforts has helped in securing both internal support from college administrators and external support from granting agencies.

The first contribution to the Hamilton college HPC resource was the result of a multi-investigator, intercollegiate NSF-MRI grant in 2001 that created the **M**olecular **E**ducation and **R**esearch **C**onsortium in **U**ndergraduate computational chemist**RY** (MERCURY). Significant NSF and internal funding established a shared facility made up primarily of shared memory machines useful for *ab initio* calculations. Importantly, this grant included initial funding for a full-time system administrator, a position that Hamilton agreed to continue after the NSF funding ended. This position continues to be of paramount importance as it provides the necessary linux/unix support, alleviating the technical burden on faculty since small colleges' information technology departments rarely contain this expertise. The initial success led to a second MRI grant in 2005 to expand MERCURY resources to include a Beowulf style cluster. This second MRI had a much smaller budget because the existing infrastructure enabled efficient integration of the new resources, which was probably a positive factor in reviews. An NSF-RUI grant in 2005 included an update of the shared memory computers.

Although there were personnel changes toward the end of the decade, computational chemistry remained in the department and at the College. Basic software and hardware infrastructure was in place, a dedicated HPC server room with appropriate cooling and power had been constructed, and an experienced system administrator was in place. However, perhaps even more important than these tangible advances, was the direct evidence that computational chemistry could be valuable and successful in the Hamilton College environment. This demonstration is not just important to outside grant reviewers, but to internal administrators and colleagues as well. The past success of this type of research suggests, or at least gives hope, that future successes are possible, allowing internal discussions to start at "how" to achieve certain goals, rather than "why" or even "what" those goals might be.

Successfully building computational infrastructure and integrating these techniques into the classroom and laboratories led to unforeseen institutional benefits. The analogy of all ships rise with a rising tide is applicable to this

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situation. The anthropology, biology, and physics departments each separately hired faculty with computational needs. The college recognized the broadening of this need and moved to find a viable support model. First, the HPC system administrator position, which had previously been housed within the Chemistry Department, was moved into the general information technologies structure, now serving the whole campus. Secondly, the College realized that hosting computational facilities in each lab needing such resources would result in redundant duplication of services and be an inefficient use of space, time, and money. Therefore the College committed to a shared-use, College-wide computational facility to combine services general to all groups, e.g., data storage and backup, queuing and authentication, etc. To organize these various computational groups, the administration created an *ad hoc* committee, called the "HPC Governance Group," to manage the resources and set policies concerning their use. At first, the Chemistry Department was hesitant to agree to these changes. The system administrator position and the facilities themselves, previously under the department's direct control, would now be managed at the College level. However, the positive effects soon became obvious. The research momentum created by the success of computational chemistry had helped the administration recognize the value of the activity, and more importantly, the need to support it. The system administrator had the scope of his activities increased to support faculty outside of the sciences, most notably a burgeoning Digital Humanities Initiative (DHI), but his main focus still lies with HPC. And now that HPC is viewed as a campus-wide activity, rather than the focus of a single investigator, the administration has been more willing to commit significant resources to it. The Information Technology department committed two computational nodes to a new computational chemist's startup in addition to the normal Dean of Faculty support, it added 96 (20% of our current total) modern computational cores in exchange for shutting off older machines that operated with much higher power consumption, and, when our data storage reached its capacity, it added 20TB of additional disk space for the HPC users.

While the legacy of Hamilton College computational chemistry certainly helped our administration understand the possible payoffs of investment in this type of activity, current active and productive research programs are critical to ongoing support. The new chemistry faculty hire primarily utilizes classical molecular simulations that require efficient parallel computation but requires very little memory, different from the demand on the original cluster. To add the type of hardware necessary, faculty from chemistry, anthropology, biology, and physics applied for and were awarded an NSF-MRI with the title: "Acquisition of a High Performance Computing cluster with a fast interconnect to enable shared-use, college-wide computational investigations at Hamilton College." The title makes clear the evolution in support models at Hamilton. One of the proposal's main arguments was the efficiency with which it could utilize NSF's investment given the expertise and infrastructure already existing on campus. This grant funded 288 of our 480 total cores. An additional individual Research Corporation Cottrell College Scholar Award funded an additional 96 cores.

The College's commitment to a shared-use model has continued throughout each of these contributions. Although a principal investigator has priority access

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to the equipment, any Hamilton College faculty member or student can gain access to use the HPC facility. This is important to continuing the momentum that computational research activities have enjoyed at Hamilton College. Because of the open access to our HPC facility, faculty from Africana studies (through the DHI), anthropology, biology, chemistry, economics, geosciences, mathematics, psychology, and physics have used the HPC facility or its expertise. While only a few of the investigators have directly contributed resources to the facility, the larger and more diverse number of users strengthens the argument both internally and externally for supporting HPC activities. Much as efforts at the beginning of the millennium helped enable our successes at the end of its first decade, we hope our efforts will sustain the institutional momentum for computational research at Hamilton College for the foreseeable future.

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Building on Success

There is significant collateral good that can come from a robust undergraduate research program. Three programs in particular are described in this section that benefited directly from the research environment that exists in our department during the summer include: 1) Pre-matriculant Research Experiences, 2) Hamilton College-Paris VI Exchange Program, and 3) Hamilton College - Oneida Nation Summer Research Program. Each of these is built on the premise that once our individual research programs are up and running in the summer, we can bring others into the program for shorter research experiences. The students benefited directly from the research momentum and camaraderie within the department.

Pre-Matriculant Research Experiences (*10*)

This program was originally designed to attract students to Hamilton and the sciences by inviting all students accepted for admission to Hamilton to apply for the program that would allow them to spend five weeks during the summer prior to matriculation working on a research project with a faculty member. Selected students joined research groups in mid-summer following their graduation from high school. Evidence suggests that some students not selected to participate in the program ultimately chose Hamilton because they knew they would have other opportunities to do this sort of research. The program was funded with grants from the NSF-Science Talent Expansion Program (NSF-STEP) and the Camille and Henry Dreyfus Foundation's Special Grant Program in the Chemical Sciences with the explicit goals of attracting more majors to the sciences and improving retention. Funds were used to pay students a $350 per week stipend (equivalent, at that time, to the stipends paid to other summer research students) and students were housed together on campus using a learning community model. In addition to their pre-matriculation summer experience, the College funded a 10-week summer research stipend for all students who participated in the program to return to campus during a subsequent summer. By all measures, this program was an overwhelming success. During the four year grant period, 75% of the

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participants majored in a science discipline with greater retention and graduation rates than the non-participants.

Hamilton College – Paris VI Exchange Program (*11*)

Hamilton has had a very successful study abroad program in Paris for many years. Mostly for logistical reasons, the program had trouble attracting science students. Students participating in the program could ostensibly take science courses at University Pierre et Marie Curie (University Paris VI), but there was no formal mechanism for the program to compensate Paris VI for the spot these students would be taking away from French students. An exchange program was created in which Hamilton College would accept Paris VI students for a summer research experience and students in the Hamilton Paris Program would be able to take courses at Paris VI.

The program is an excellent cultural exchange experience for the French visitors to our labs and for our students and faculty members. The Paris VI students are academically very well prepared, having completed coursework comparable to Masters level work, so they possess a rich understanding of the background science underlying the projects they work on in collaboration with Hamilton faculty members. However, many have never had research experience nor been exposed to open-ended, inquiry-based pedagogy and so have much to learn in the laboratory. By contrast, the Hamilton students are very comfortable navigating within the research laboratory with a mature sense of experimental design. They can design and execute the experiments but, with less formal training and the language barrier, the breadth and depth of their understanding is not as advanced. It has been truly a rich collaborative effort in which all participants bring different strengths to the experience.

Hamilton College – Oneida Nation Summer Research Program

Hamilton College has had a long relationship with its neighboring Oneida Indian Nation. In fact, the College was originally founded to serve the children of Oneida Nation families and white settlers and was named the Hamilton-Oneida Academy. This relationship lay fallow for many years. With a small grant, we began to provide two-week summer research opportunities to Oneida Nation high school students. The program was coordinated with the Oneida Nation Education Department who helped to select participants. The goals for the program were modest. We simply sought to provide an opportunity for these students to spend time on a college campus. Native Americans remain the most underrepresented of all ethnicities in higher education. With little community tradition and few role models, these high school graduates approach college with great trepidation. Our goal was to show them that there is a place for them on a college campus.

We designed the program such that Oneida students would work on projects as teams with a faculty mentor. Following the research experience, Hamilton hosted the students and their families for a tour of the science building to see and hear about their students' research projects. The students also presented their projects to the Nation Council, where they were enthusiastically received.

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ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

We were thrilled when two of the program participants matriculated at Hamilton. One graduated as a neuroscience major and was awarded a Fulbright Teaching Assistantship upon graduation from Hamilton.

Concluding Remarks

Undergraduate research has blossomed at Hamilton College in the past 25 years. The model now includes disciplines in the social sciences, the humanities and the arts, as well as the sciences. The broad success of the model confirms the assertion that research is a powerful teaching tool. But as this chapter implies, the development of the focus on research through the departmental curriculum and the dedication to having students in our labs year-round have far-reaching implications. By having a common purpose, the department can work more effectively together. As a consequence, the administration is more willing to provide support and outside granting agencies take note. Other departments see the appeal of the program and find ways of incorporating ideas from it into their own departments in a manner that suits their philosophy. The department itself garners increased respect both from within and without the college. Ultimately, however, it is the students who gain the most. The skills that they develop through a challenging curriculum and through collaborative research experiences make them highly sought after by graduate and professional schools and more competitive for national awards. Providing an effective education and helping to open up opportunities for our students is, after all, our primary goal.

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Chapter 3

Development of Undergraduate Research Projects That Also Incorporate the Service-Learning Experience

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Undergraduate research in academia can be funded and executed by a number of traditional means. This chapter concentrates its interest on the use of Academic Service-Learning (AS-L) as a venue to staff, execute, complete, and possibly fund undergraduate research projects. Some current definitions of AS-L are offered for the reader's consideration; the definition used by the authors involves 1) meeting an identified community need, 2) helping students meet course objectives, and 3) incorporating a reflection into the students' coursework. Suggestions concerning replacing standard "cookbook" laboratory experiments with actual research protocols, data, results, and laboratory reports, while still preserving the original learning outcomes, are also discussed. Recent research completed at The University of Findlay in this manner by the authors is presented herein to model the execution of undergraduate research using AS-L.

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Introduction: The Intersection of Undergraduate Research and Academic Service-Learning

Many fine institutions, ranging from the smallest of community colleges to the largest of universities, facilitate undergraduate research efforts in a number of ways. Some institutions still do it the "traditional" way, where faculty members pursue grants or other sources of funding to sponsor projects, and then hire undergraduate assistants using some of that project funding to accomplish those projects. Other faculty will instead solicit interested volunteers fueled by their own ambition, career aspirations, and/or curiosity to help execute those projects. Still others will hire students from pools of student employees funded by their institution's financial assistance programs (such as Federal Work Study, or other similar programs, depending on the source of the financial aid). The number and combination of ways to conduct undergraduate research can vary as widely as the number of existing higher learning institutions, as well as with their own resources and creativity. This chapter will not be as concerned with surveying this vast array of methods, but instead it will be focusing on one of the newer routes being taken to facilitate undergraduate research — Academic Service-Learning. Academic Service-Learning evolved during the 20th Century, taking its current form in the 1980s as its use spread from the workforce to higher education, according to the National Service-Learning Clearinghouse (*1*). The practice is used to foster events ranging from charitable service projects to cooperative learning experiences. This chapter will focus on the application of Academic Service-Learning to the area of Undergraduate Research.

What Is Academic Service-Learning (AS-L)?

The definition and application of service learning varies somewhat with the institution employing it. Some randomly chosen examples of the different sources and definitions follow. There are plenty of similarities and just as many differences, but a common theme is evident.

Minnesota State University at Mankato uses Bringle and Hatcher's definition of service-learning (*2*):

> ***Service-Learning*** is "a credit-bearing educational experience in which students participate in an organized service activity that meets identified community needs and reflect on the service activity in such a way as to gain further understanding of the course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility. Unlike extracurricular voluntary service, service-learning is a course-based service experience that produces the best outcomes when meaningful service activities are related to the course material through reflection activities such as directed writings, small group discussions, and class presentations. Unlike practica and internships, the experiential activity in a service learning course is not necessarily skill-based within the context of professional education."

Colorado State University uses a definition based on principles stipulated by Furco (*3*) and Jeavons (*4*): Service-learning practitioners emphasize the following elements in formulating a definition of service-learning:

- Service-learning involves students in community service activities and applies the experience to personal and academic development.
- Service-learning occurs when there is "a balance between learning goals and service outcomes" (*3*). Service-learning differs from internship experience or volunteer work in its "intention to equally benefit the provider and the recipient of the service as well as to ensure equal focus on both the service being provided and the learning that is occurring" (*3*).
- Service-learning course objectives are linked to real community needs that are designed in cooperation with community partners and service recipients.
- In service-learning, course materials inform student service and service informs academic dialogue and comprehension.

Service-learning engages students in a three-part process: classroom preparation through explanation and analysis of theories and ideas; service activity that emerges from and informs classroom context; and structured reflection tying service experience back to specific learning goals (*4*).

The National Service-Learning Clearinghouse (*1*) defines it this way: “Service-Learning is a teaching and learning strategy that integrates meaningful community service with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities.”

At The University of Findlay (UF), we define academic service-learning as “a form of experiential education in which students participate in meaningful service to their communities while engaging in some form of reflection related to the service and integrated into the curriculum.” This definition is intentionally different than The University’s definitions of both volunteerism and co-curricular service-learning. The University’s Campus Compact website (*5*) contains all three current definitions. In addition, we require that three statements must be true about the project in order for it to be qualified as academic service-learning:

1) The service must ***meet an identified community need*** of one of The University of Findlay’s community partners. Community partners are identified as religious organizations, educational institutions, and non-profit agencies.
2) The service must ***help the students meet course objectives*** identified by the professor.
3) The professor of the course involved needs ***to incorporate a reflection into the coursework*** — this reflection allows students to intentionally identify how their service helped them learn their course objectives

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The Anatomy of an Undergraduate Research-Based Service-Learning Project

It is rhetorical but very safe to say that not all undergraduate research (UR) projects involve service-learning; and that not all service-learning projects involve undergraduate research. So what does an effective undergraduate research-based AS-L project look like? An undergraduate research project in the natural and/or physical sciences is a known commodity to most readers of this work, so the remaining mystery then, is how do we take such a project and add the service-learning component successfully?

One effective starting point to uniting the undergraduate research and service-learning aspects under one common project would be to seek out the relevant overlap at compatible points of the project. By way of example, Table I below shows one way in which the three AS-L goals we stated in the UF definition above can overlap with what could be stipulated as a commonly used outline of a "typical" undergraduate physical science lab experiment.

Table I. Suggested overlap of components of a typical physical science lab with an AS-L/UR project.

Traditional Physical Science Lab Experiment Component	*AS-L/UR Project Outcome Using UF Definition*
Purpose	How does it meet an identified community need?
Procedure Data / Observations Calculations	How do these help students meet course objectives?
Results Statement / Conclusion Discussion / Error Analysis	How do these incorporate reflection on the relevant coursework (and, in so doing, fulfill learning objectives?)

The first and probably easiest comparison between the two models is to assess whether the purpose of the lab experiment (or at least one purpose, if it has multiple purposes) meets an identified community need. The course or lab instructor who is pondering whether to use a given lab as an AS-L project might do well to ask him/herself, "Does the experiment have a practical application that meets an imminent, real, identifiable, relevant need of (someone, some organization, some agency, etc.) right now, that goes beyond the classroom or lab and the students who are in it?"

Secondly, once a suitable topic has been chosen that fulfills the purpose of the undergraduate lab, as well as identifies the community need of the AS-L project, a suitable experimental plan must be developed that meets both the course objectives and the needs of the agency receiving the service simultaneously. The project

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advisor thus must manage the cost, timeline and scope of the project to keep it within the range of applicability to the coursework for which it is being used. This may mean that a larger project that involves, say, several sampling events over a period of months, may be too large to apply in its entirety to a single course. The instructor then might consider applying only one or two sampling events toward the course, and completing the other events during the next offering of the course, or by other means outside of the course with other assistance. Consistency between work done via the course by the students particularly working on the AS-L project, and work done by others outside the course for the same research project but not necessarily as part of the AS-L is easily established and/or tracked with the application of proper quality control measures.

The third component, reflection, is actually mandatory in many models of service-learning. That is, some programs go so far as to say that if reflection is not a part of the process, then the project is not considered a service-learning project. During most traditional laboratory exercises requiring a formal report, reflection is already part of the process. Depending on the nature of the project, and the perspective of the instructor's and/or the course's expectations of components like the conclusion, the discussion, or even the error analysis, students are actually reflecting on how well the given experiment went and what concepts they learned from it. The task at hand in this section for the AS-L project is to collect similar reflections from the students on how their project met the identified need and how meeting that need fulfilled their learning objectives for one or more aspects of the course. In other words, how did the students' service help them learn? The National Science Foundation's on-line tool, Student Assessment of (Their) Learning Gains (or SALG), is one tool (*6*) that instructors can use to begin the process of evaluating course content in order to answer these questions.

University Involvement in Managing Service-Learning Aspects of AS-L/UR Projects

Another consideration about the design of the service-learning project is to manage students' expectations. For example, at The University of Findlay, the instructor facilitates this step by providing the intended learning goals or objectives that the work is meant to fulfill, perhaps by working those goals into the purpose of the experiment at the outset. Instructors include the academic service-learning assignment alongside all other assignments in the course syllabus. Since our university has an office of service and learning (namely, the Campus Compact Center), the Director of this office visits classes at the beginning of the semester. She discusses the difference between volunteerism and academic service-learning before elaborating on any details of the service component. Also, to further demonstrate the tie between the service and the class, specific course objectives outlined in the syllabus are highlighted during this discussion. These discussions should be facilitated by either the instructor, the service-learning professional, or, ideally, both.

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Table II. Successful overlap of a typical physical science lab with an AS-L project.

Traditional Lab Component	*AS-L Project Outcome*	*Fulfilling Benchmarks*
Purpose: Determine dissolved phosphorus via Ascorbic Acid Method	Meets Identified Community Need: Determines if dissolved phosphorus levels are excessive / conducive to HAB events	Employs Ascorbic Acid Method (Visible Spectrometry) to determine phosphorus levels
Precautions Procedure Data / Observations / Calculations	Helps Students Meet Course Objectives: Procedure – standard protocols from literature Data/Observations – measurements collected in field, lab; assessed (QA/QC)	Reads literature Follows procedure. Applies theory to practice. Measures samples. Identifies and quantifies parameters Obtains good QA/QC
Results Statement / Conclusion	Incorporates Reflection into the Relevant Coursework: Results & relationship between measured values and HAB risk (need)	Reports findings appropriately; P levels in samples. Report to community partner. Report / Presentation to professional community

When designing an academic service-learning project, it is often beneficial for the faculty and service-learning professional to collaborate. Faculty can teach the service-learning professional about the course, subject, and project ideas. The service-learning professional can assist faculty with identifying community needs and connections with a community partner, project design, and reflection design, as well as with examples of how faculty in other disciplines incorporate academic service-learning. Both on-campus and off-campus entities benefit from these conversations, as they enable the university to present a unified effort as various departments partner with varied community constituencies.

The Director of The University of Findlay's Campus Compact Center has worked extensively to educate community partners about the variety of service offerings available through the University. This education is mainly done through on-site community partner visits, where UF Campus Compact staff member(s) visit a non-profit organization, educational institution, or religious institution. During this visit, various service definitions are discussed, concrete examples of partnerships are explored, and tangible subsequent partnership ideas are generated. This education piece is essential to the success of an academic service-learning project, as the University students have specific course goals to complete while serving at each community partner. This is a service model with which some non-profit organizations are unfamiliar. That unfamiliarity is a primary reason for the site visits. The ultimate goal of an academic service-learning project is to mutually benefit both students and the community through the combination of learning in the classroom and service in the community, both with the intent of focusing on a common goal. We recognize that some universities do not have a service-learning center, so we have outlined the role of that center's personnel in order for the faculty member to consider taking these steps in the absence of a service-learning professional.

How the Physical Science Course and the Academic Service-Learning Project Overlap

An overview of overlap assessment between a physical science lab and its use as an AS-L project is shown in Table II.

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Consideration of Scopes and Outcomes Appropriate for an Undergraduate Course Setting

Research projects of all types, including those mentioned earlier, have certain common goals. Most faculty would like to see results from any sort of research project presented either orally or as a poster at an appropriate venue. However, we also suggest that in order to satisfy short-term and course-related requirements, sometimes a paper in an international journal may not seem within immediate reach. After all, we said earlier that undergraduate research programs needed to be properly managed; that projects are best served with the right combination of short and (or) long term goals that could be processed, presented and then graded within a reasonable time period to be compatible with an undergraduate course schedule. Consideration as to whether the project is suitable for short or long-term service-learning endeavors is also warranted. Both approaches are feasible when properly executed. Particularly, these goals are very achievable if scope and segmentation of research work is planned and monitored effectively. For example, if there are many individual experiments being carried out within the scope of this project, but they are easily segmented or divided into sub-projects, it becomes manageable to only use one segment of the project — one sample set out of the larger scheme, or one set of parameters varied out of all those intended — for the undergraduate research assignment. In due time, the principal investigator can still gather sufficient data to qualify for that national-caliber paper over several sections of the same course, or several semesters, or with supplemental student effort outside of class. The precise solution to this long-term dilemma depends mainly on a combination of the size of the institution, the size of the program (i.e., how many sections of the course are offered over what timespan), and of course the ambition of the principal investigator (PI).

For the undergraduate researcher, there are additional advantages to shorter-term projects, even those that are part of a longer-term project. Depending on the rigor of the program that the undergraduate researcher selects, he or she may have less time to devote outside the laboratory to assembling a poster, preparing a talk, or even coming in after hours to conduct the next round of experiments. A shorter-term project that still has quality outcomes worthy of presentation can provide the student in this predicament

(1) a similar sense of accomplishment and
(2) a positive mentor/mentee experience.

Gratification for both undergraduate researchers and advisors can still come from short-term projects that are presented at state and regional venues, or even local events (symposia, etc.) that occur on campus or at a nearby venue, but are still “outside” the classroom. Encouraging students to present at an American Chemical Society regional meeting, for example, can provide this kind of “happy medium” between a presentation at a similar national event and no presentation at all. If the PI’s sampling and analysis procedure (SAP) plan, and Quality Assurance/Quality Control (QA/QC) plan for a given long-term project are appropriate, the long-term project can be executed and presented by one or more undergraduate researchers as a series of smaller short-term projects, the sum of whose results is then molded into that national paper or presentation. The PI can indeed achieve the identified long-term results.

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A Model Undergraduate Research Project that Simultaneously and Successfully Served as an Academic Service-Learning Project

In the interests of those reading this text who may be budding researchers, new faculty members, or other academicians who are interested in this sort of effort, we will present here a recent example of some work conducted at The University of Findlay. Our purpose for this example includes the following:

(a) We present the background and availability of an area of research that is relatively straightforward, easy to grasp, and locally relevant.
(b) We show how this work was found to meet the requirements for an Academic Service-Learning project within the University guidelines.
(c) We describe how collaborative efforts involving several overlapping research projects, being overseen by University of Findlay faculty from multiple departments, were applied to a number of undergraduate classes. This was accomplished by directly inserting some of the project-oriented work into the class curriculum where academically appropriate (similar in scope, purpose, etc.).
(d) We show how and where opportunities for results and reflections composed by the students were then presented at local, regional, and national venues appropriate to the subject.

Basics of the Academic Setting at the University of Findlay

We recognize that service-learning projects will look vastly different according to campus size and resources, as well as to availability and scope of community partnerships. Therefore, it is important to establish the setting for our example to provide a complete picture. The University of Findlay offers nearly sixty areas of undergraduate study, nine Master's degrees, and two Doctoral degrees. Total enrollment for 2012-2013 was nearly 3600, with undergraduate students accounting for more than 2600 of that number. The student/faculty ratio is 15:1 (*7*).

The University has an ongoing relationship with the Blanchard River Watershed Partnership. In line with this relationship, a number of UF departments (Biology, Chemistry, Environmental Safety & Occupational Health, and others) regularly take samples from at least nine to 11 different sites along the Blanchard River and its local tributaries throughout Hancock County (*8*). Field and laboratory analyses are performed on these samples, including dissolved phosphorus, ammonia nitrogen, pH, dissolved or suspended solids, and others. Measurements at the site, such as Secchi depth, temperature, stream flow rate, dissolved oxygen, alkalinity, conductivity, ORP, GPS position, and others, are also carried out. Sampling trips like these also provide excellent exercises in proper sample collection, handling, chain of custody, storage, and quality control.

One of the parameters of particular interest during these sampling studies that our students regularly monitor is dissolved phosphorus. The reason for the particular interest in phosphorus arises from the fate of the water in the Blanchard River; it will eventually feed into Lake Erie. Water bodies all over the northeastern United States have been plagued in recent years by Harmful Algal Blooms (HAB events). Many species of cyanobacteria (or blue-green algae) under adverse environmental conditions will overpopulate ("bloom") a water body, with several harmful consequences ranging from fish kills to toxic effects on users (people, animals). This phenomenon has been known to shut down local economies and to render water bodies unusable even on a mere recreational level. One of the chemical parameters that have been positively linked to HAB events is elevated phosphorus levels. The source of phosphorus encountered during these studies is not likely geological. It most likely arises from application of fertilizers to local corn and soy farms situated throughout the county, many of which are along the Blanchard River or have creeks or other waterways that empty into the river.

Dissolved phosphorus is a chemical parameter that is relatively easily measured in an undergraduate teaching laboratory with equipment usually easily accessible at the collegiate level. It is quantitatively measured using the Ascorbic Acid Method, which forms a blue solution in the presence of dissolved phosphorus down to ppb levels. The intensity of the blue color correlates directly with the phosphorus concentration in Beer's Law fashion over appropriate concentration ranges. The reagents needed to perform the analysis are easily accessible and relatively inexpensive. Any computer with spreadsheet software (i.e., Microsoft Excel) can be employed to process the data with minimal effort.

Thus far, we have described

(1) the ease of access and availability of environments and samples that might provide an undergraduate research opportunity,

(2) relevant, important, but reasonably simple issues that would potentially be within the grasp and interest of a typical undergraduate science class, and

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(3) an example of a specific parameter and appropriate analytical procedure that would also be within grasp of a typical undergraduate science class. The potential for an achievable undergraduate research project is now in sight. However, can this project be approached from a service-learning perspective?

We will now show, using the University of Findlay's own guidelines, that for UF, it most certainly can (and in fact has been). We will achieve this by showing that this project can comply with all three of the University's requirements for an AS-L project. First, the project must be shown to meet an identified community need. That need can be stated clearly, as follows:

Identifying the Need:

- The Blanchard River and its tributaries are facing the challenge of elevated phosphorus levels which may be connected to or correlated with Harmful Algal Blooms in local waterways.
- These elevated phosphorus levels can adversely affect water quality and can have other consequences that can and do affect local area governments, regulatory issues, utilities, farms, recreational areas, private citizens, etc. Therefore, we need to communicate current phosphate levels to these agencies and people.

The scope and magnitude of that need, particularly from the viewpoint of the local media, can be summarized by the following two examples of excerpts from the Columbus Dispatch in recent years as the state was learning of the degree of importance that algal blooms would place on the condition of their water sources:

> Toxic algae, a threat to humans and animals alike, has been found in Grand Lake St. Marys, already one of Ohio's most polluted lakes. Warnings have been posted, but state parks officials say they won't keep people out of the water on the busy holiday weekend (*9*).

> Fed by phosphorus in manure that rainstorms washed off nearby farms, the algae grew so thick in the lake last summer that the state warned people not to touch the water, take boats onto the lake or eat fish they caught there (*10*).

Similar tracking of this issue as it grew in importance was found in the summer of 2012, in the Toledo Blade (*11*), another local newspaper.

- At a recent University of Toledo College of Law workshop, speakers implored Michigan and Ohio residents to see the emerging parallels between western Lake Erie's record algae outbreaks in 2010 and 2011 and Cleveland's 1969 Cuyahoga River fire.
- Public outrage over algae is finally getting through to the right people, but meaningful action has been a long time coming. The degree of

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commitment has yet to be seen, especially as the two states [Michigan and Ohio] attempt to promote a more business-friendly atmosphere.
- Western Lake Erie needs to become a stronger focal point of fertilizer runoff control, just as Cleveland was the focal point for better sewage treatment after the Cuyahoga caught fire. Cleveland lived with the embarrassment of being called the "mistake on the lake" for years.

The need is now adequately identified.

The proposed project must then be capable of meeting that need. This particular issue, that of monitoring phosphorus in fresh water sources, needs a visible spectrometer, appropriate chemical reagents and glassware, and a means to manage the data (computer, etc.). For the purpose of example, we will assume that a four-year college looking into this project has these amenities. A typical visible spectrometer (such as a Spec-20) is usually purchasable for about \$1500-3000 from an academic vendor. Many undergraduate laboratories already own and maintain several of these for instructional purposes, specifically for spectroscopy labs that are taught within the existing scope of their General Chemistry laboratory curricula. Sample collection bottles (plastic, 1L) are also necessary.

Meeting the Identified Need:

- Students can participate in identifying those waterways which are affected by elevated phosphorus levels.
- Students can participate in public awareness and education efforts to inform the public through participation in public forums and presenting at scientific venues directed at examining environmental issues.

Once the materials and methods are determined to be available and feasible, the instructor must determine how compatible the method is within the current course structure. As one example to illustrate how this compatibility might be determined, we cite commonly-used experiments involving formation of iron (III) thiocyanate complexes or any number of organic dyes. Students dilute a stock solution of a selected colored compound to known concentrations (i.e., prepare working standards). Then they measure the absorbance of these diluted standard solutions at a known fixed wavelength. A plot is then prepared of the absorbance at this known wavelength for each of the diluted samples versus the respective concentrations of those samples. The result should yield a straight line, demonstrating that it complies with Beer's Law, $A = abc$, where

A is the absorbance at a known wavelength,
a is the absorption coefficient,
b is the path length of the measuring cell of th spectrometer, and
c is the wavelength in nm.

Using the mathematical expression then, for that curve of known concentrations and their respective absorbances, a solution of unknown concentration within the range of this curve can be determined by measuring

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its absorbance when treated in the same fashion as the diluted standards. As we implied earlier, there are many current undergraduate curricula that employ experiments that conduct this kind of analysis for their own sake. That is, the experiment is carried out, the calculations are done, the graphs are drawn, and the experiment is written up in the proper format. Beyond submission for a grade, nothing ever comes of the experiment or the report generated from it. In contrast, in a "real world" applicable project like the one we propose here, the same procedure based on the same concepts (Beer's Law) are carried out under the same conditions with the same instruments, with the added benefit of an authentic application of that theory, which will then actually affect the community or a subset of it in a positive fashion beyond the scope of the class itself. In the phosphorus example at hand, we can say that the results do more than just work with synthetic samples that have no real purpose beyond teaching the concept itself. Rather, determination of the phosphorus levels in real water samples taken from the affected community where the identified need applies, will properly inform that community to some extent whether they have a phosphorus issue that might require further study or immediate action.

Ability to operate with real-world samples to address real-world concerns is one thing, but does this ability affect the compliance of the lab course with the academic requirements of the University, its curriculum, or its course syllabus? An ideal AS-L/UR project will replace an "artificial" or "theoretical" one, issue by issue. It should cover the same learning objectives, yet it should add a dimension of application to the real world that goes beyond the classroom or lab, and in so doing, meets the need that was previously identified. It also created "real-life" experiences for our students. These experiences are what create opportunities for publication or presentation in peer-reviewed venues, as well as valid professional experience.

The phosphorus project alluded to previously was used at The University of Findlay as part of its Analytical Chemistry course "Environmental Analysis" (ESOH 316), as taught within the Environmental Science and Occupational Health program. Three learning objectives of this course are shown below.

- Chemical analysis will be used to determine concentrations of analytes based upon accurate and precise analytical techniques and proper instrumentation calibration (i.e., good quality control practices).
- Techniques used in wet chemistry and analytical chemistry will provide experience and care to ensure valid results through use of chain-of-custody documents and procedures for all samples.
- This course seeks to study the methods employed by laboratories which provide valid and defensible data in the Environmental Science and Health fields.

The first goal is met by training the students to construct standard curves by appropriate dilution of a commercial phosphate external standard. The students then use Beer's Law to determine the phosphate concentrations of freshly collected river water samples thought to contain questionably high phosphate levels. Proper quality control is carried out by appropriate spike, duplicate, and blank analyses.

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The second goal is covered by the measurement of other parameters we mentioned earlier in the project description. Briefly, phosphate analysis consists of wet techniques (dilution) and analytical chemistry (spectrometry). The quality control aspects (spiking, duplicating, and blanks) assure valid results in compliance with the second goal. Other wet techniques also employed during the same course relevant to this same project are total solids, and total suspended solids, which use a gravimetric method (wet technique). Other parameters like pH and dissolved oxygen use analytical techniques involving electrometric devices. The third goal is covered by the proper selection of methods that were used to achieve the first two goals. All methods used in this project were taken from the 20th Edition of *Standard Methods for Examination of Water and Wastewater* (*12*). This manual is an industry standard for drinking water, natural water, and wastewater analysis that is widely depended upon in the environmental disciplines. These methods also have corresponding EPA references, further establishing their authority and ubiquitous use.

Incorporation of Reflection into Coursework

At this point, we have successfully shown that the proposed phosphorus project:

(1) meets an identified community need, and
(2) meets the requirements of the course curriculum.

The last requirement expected of an undergraduate research project at The University of Findlay in order for it to be considered an Academic Service-Learning project is for the instructor to incorporate reflection into the coursework in order to present how their service-learning work helped the students to achieve their course objectives. The reflection requirement can be fulfilled at various stages of the project. For example, statement of the conclusion and discussion of the results, the implications, the errors made, and similar aspects might qualify as reflection as long as they incorporate or refer to the service aspect of the project. A more direct fulfillment might also be to ask the students directly to include a paragraph or two as part of their Discussion section that covers this service aspect and how it fulfilled the course requirements. Examples of this sort of student reflection from previous "runs" of our phosphorus lab in this context are shown as follows:

- "I was able to combine the knowledge I used in my studies of the wetland water quality to my work analyzing samples for [this project] for which I was also testing water samples for phosphate levels."
- "Working with [this project] helped me to see beyond the scope of my research and how this information could be applied to real life situations. I was able to look at the data and see spikes in the phosphate levels which is concerning because such spikes trigger algae blooms such as those that have been increasing in Lake Erie."

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- “These algae blooms are dangerous for both people and animals especially those that live in the water. As a pre-veterinary student it was very interesting learning the effects of exposure to blue green algae on dogs that might be exposed to it when swimming.”

For larger scale projects with wider implications, the instructor might consider inviting (or requiring) the student to incorporate this information in a formal presentation at a symposium or conference. The University of Findlay hosts a Symposium for Scholarship and Creativity every spring, which provides a local, free venue for this type of presentation of, and reflection on, coursework with a research-based outcome. Our students have also taken results and reflections from AS-L/UR projects (such as the phosphorus project discussed above) to regional and even national American Chemical Society meetings in both poster and oral presentation form. By presenting their research to the people living in the local community, students can gather feedback as to the community’s response to the research. This feedback can further the students’ learning by giving them the opportunity to field questions and to accept both affirmation and constructive criticism. Local authorities have also been presented with this information. For example, data relevant to the model project herein was presented to the Blanchard River Watershed Partnership (BRWP) at their annual meeting held in November 2011 at The University of Findlay. Ongoing results have been regularly communicated to the BRWP through regular e-mail communication and direct involvement with the BRWP (as Dr. Homsher is a member of the BRWP himself). Additionally, this feedback can be a valuable resource to faculty, as future service-learning projects can be generated through these reflection forums.

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Conclusion

We hope that this information is useful to those faculty who would choose to incorporate undergraduate research together with academic service-learning into their curriculum. The combination of these various teaching and learning methods can benefit students, the community, and the research field. Academic Service-Learning has the potential to serve the needs of projects and institutions of a wide range of size, budget, and focus.

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Chapter 4

Mentoring Undergraduate Research: Opportunities and Challenges

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The philosophy of my research mentorship is to empower students through "hands-on self discovery" in which I design specific projects, set specific goals, teach the synthetic techniques, and motivate students to take control of their respective projects. Undergraduate research poses challenges and opportunities that are different from the classroom experience. Undergraduate research is rewarding; the caveat is that it may involve substantial commitment of energy and time from the student and faculty. Despite the numerous challenges involved in mentoring undergraduate research, the many opportunities of this mentorship are so great that they should be explored. The opportunities and challenges in undergraduate research mentorship, based on my experience in a public University, are presented.

Introduction

Students will not be able to take advantage of the numerous benefits of undergraduate research if faculty members do not give students the opportunity to work collaboratively on research projects. Undergraduate students require extensive hands-on mentorship. In mentoring undergraduates, it is essential that the mentors set clearly defined goals and expectations about the research

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project. My mentoring philosophy is based on some core tenets, which reflect my personality and experience.

First, I view my undergraduate research students as coworkers in the laboratory; we have the same common goal of contributing to science and sharing our work with the rest of the world. By embracing my undergraduate research students as coworkers in the lab, my goal is to reiterate that by working together as colleagues and as a team, important discoveries can be made which might not be possible if we work on our own. This is important because working in teams or collaboratively is a fundamental aspect of the science discipline, which is also very important in the "real world." A quote from the feedback of one of my former research students follows:

"Before I started doing research I had no laboratory experience and had a lot of challenges getting comfortable and understanding how to work in a laboratory. I also had some challenges working with other people. When you are working in the same area as another individual, you need to make sure that they respect what you are doing and that you respect what they are doing. I also made some mistakes. Nobody can be perfect and sometimes mistakes happen, you just have to pay attention and be focused to be successful. You also have to be able to ask questions to make sure you know what you are doing or if you need help. Due to all the responsibilities I had outside of the lab, I was forced to learn time management and be able to get everything including research done on time and done correctly."

Second, I encourage my undergraduate coworkers to feel free to candidly express their opinions on the direction of our research projects. In other words, I encourage them to freely explore new avenues in their respective research projects. This encourages them to try new things and take risks when necessary. I also remind them that in research, any result, positive or negative, is a result as long as we can justify the result or hypothesize the outcome of such a result. This promotes an excellent intellectual environment in which the students know that mistakes can be made and what is important is not that a mistake was made but how it can be corrected. This kind of attitude circumvents a situation in which a coworker may falsify a set of data points in order not to look stupid if a mistake was made. Creating an environment in which everyone is challenged stimulates innovation in research. A quote from the feedback of one of my research students follows:

"Researching gave me confidence, presentation skills and scientific writing opportunities (I presented at an ACS conference, Student Scholarship Day at GVSU, and wrote semester reports on my research progress). Some challenges were discipline and steadfastness – Any beginning science student dreads long three-hour lab sessions that accompany the lecture class. Research with Dr. Ngassa did more for my character as a developing scientist than any other experience in my undergraduate career. The experience of 'owning' a project changed the lab experience. I wanted my experiments to work and was excited to analyze my purified products; this brought a new meaning to the lab experience."

Third, I am always accessible to my undergraduate research coworkers. I work with them directly in the lab, setting up my experiments alongside theirs. We have weekly research group meetings on Friday afternoons in which we review work accomplished for the week and plan for the following week. Through our weekly meetings, I emphasize the need to maintain personal and professional integrity in the research process. I also require each coworker to read journal articles from the literature about his/her project and to give a summary presentation of a journal article every other week. A quote from the feedback of one of my research students follows:

"My research experience at Grand Valley presented me with so many opportunities. First off, I was able to attend my first professional conference. This is something that I am going to have to do yearly, at least, and it was amazing that I got to experience this as an undergraduate (junior year!). I also got so much experience writing professionally. I had not had much experience writing scientific papers and now it is something that I am able to do almost without thinking. We were able to get published in a peer-reviewed journal and that was an amazing addition to my resume. Being able to do these things as an undergraduate made me an excellent candidate for graduate study. Another experience that helped me out greatly was Journal Club in which we were required to present our research in front of peers and professors. This is very similar to what I have to do with my Thesis Proposal. When publishing scientific papers, you need to be able to present, explain, and defend your work. All of these opportunities made me into a more professional person and have led to my current success."

Fourth, I train my undergraduate coworkers to assume leadership roles in the group. Usually, the most senior coworker in the group is the group leader who helps junior colleagues. This gives the senior coworkers the opportunity to lead and teach, and the junior coworkers the opportunity to learn from a source other than me. I have seen that this method has worked very well for my students over the years. By exercising leadership, students are able to build their confidence level as well. A quote from the feedback of one of my research students follows:

"During my research time at Grand Valley, I was able to gain a large amount of laboratory experience and this prepared me for being able to run a laboratory environment very effectively. I am a biological anthropologist and this covers a wide variety of areas such as genetics, human osteology, primatology, etc. Due to the fact that I worked on nucleosides in the laboratory setting, as well as had experience in other areas of biological anthropology, I was selected over all other biological anthropology masters students to teach the biological anthropology lab. Without my laboratory experience at Grand Valley, I would not be able to be currently teaching my own lab."

Fifth, working with students helps to keep me humble; it is a thrill knowing what it is like to do something where one does not know the answer. Also gratifying is being able to see the spark of interest in research bloom in students who have never yet been exposed to the opportunity to carry out experiments that do not have a known answer. A quote from the feedback of one of my students follows:

"Research gave me many opportunities to work with others, run specific reactions under certain conditions, learn how to time manage, be a part of a publication in a renowned journal, and Dr. Ngassa has been a fundamental part in how I have matured as a student and a person. I also had the opportunity to meet many outstanding people in the chemistry department and to learn in the lab hands-on rather than from a textbook."

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Once my students graduate, I continue to stay in touch with them. Most of my students have been motivated to continue their studies and research after graduating from GVSU.

For each faculty member, the experience in supervising undergraduate research may depend on the following factors: 1) How many students are supervised? 2) How much time is spent between the undergraduate researchers and faculty? 3) What is the nature of the research collaboration? 4) How many tangible products (presentations, publications, etc.) result from research collaborations? 5) How supportive is the administration toward research? The goal of this paper is to reflect on my experiences as a mentor of undergraduate researchers vis-à-vis the culture of research at Grand Valley State University. Feedback from some past research students has been incorporated to put into perspective some of the challenges and opportunities in undergraduate research mentorship. This paper is organized into the following sections: An Overview of Undergraduate Research in Teaching and Learning; Undergraduate Research at Grand Valley State University; Challenges of Undergraduate Research mentorship; Opportunities of Undergraduate Research Mentorship; and Feedback from Past Undergraduate Research Collaborators.

An Overview of Undergraduate Research in Teaching and Learning

Research has shown that undergraduate research has many educational and personal benefits for students, as well as opportunities and challenges for faculty mentors (*1–14*). Faculty mentors are important in assuring that students get the best out of the undergraduate research experience. Undergraduate research mentorship is different from graduate research mentorship; an important difference is the experience and level of maturity of the students. Undergraduate research experience is critical for the career development process and faculty mentors can facilitate this process through effective mentor-student interaction (*1*).

Undergraduate research, whether in a college or university, offers a student the opportunity for direct contact and interaction with a faculty mentor (*1–3*). This results in a relationship between the faculty mentor and the student in which the faculty mentor gets to know each student as an individual. Thus the faculty mentor is able to understand the student's strengths and weaknesses as the student is trained in the research process (*1*, *7*, *9*). The student, on the other hand, is able to establish a sense of respect for intellectual curiosity and develop a strong will to appreciate science and discovery. This is possible especially when the student sees the faculty mentor as a contributor to the growth of science rather than as an interpreter of science (*1*).

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Mentoring undergraduate research requires a substantial amount of time spent working with the undergraduate coworkers (*5*, *13*). Through this mentoring relationship, the faculty mentor and students have a common interest. A good mentoring relationship is one in which the faculty mentor spends quality time with the students working on a research project and in which the time spent is very productive (*4*, *5*). Some characteristics of a good and comfortable mentor-student relationship include: mutual trust, respect, honesty, openness, and collaboration (*7*). Given that it is the quality of time spent and not necessarily the quantity of time spent with mentors that is critical for successful undergraduate research mentorship, it is therefore important to make sure that the time spent between students and mentors is productive (*4*, *7*, *14*). Productivity can sometimes be measured by the presentation of research results at conferences and publication in peer-reviewed journals. The ACS defines undergraduate research as "self-directed work under the guidance and supervision of a faculty mentor or advisor." The undergraduate student researcher is expected to be more independent over time as he or she gains confidence in the research project (*2*). Students will naturally gravitate toward a faculty mentor who is working on a research project that is of interest to the student researcher. There are many benefits to the undergraduate research experience such as; an opportunity for "hands-on" learning, an opportunity to use "highly sophisticated" and "modern" instruments that would not be possible otherwise, an opportunity to experience the excitement of discovery, and getting an excellent foundation in preparation for future career endeavors (*2*).

Many institutions are finding creative ways to give faculty mentors credit for the time spent working with undergraduate researchers. To maintain active research programs with undergraduates, colleges and universities need to address the issues of time and money in relation to the need for one-on-one research experiences required by undergraduate researchers (*3*). One possible solution to account for the substantial amount of time faculty mentors need to spend working one-on-one with undergraduate researchers is to credit the "research time" as teaching time.

A new era of undergraduate research started in October of 2010 when the Council on Undergraduate Research (CUR) and the National Conference on Undergraduate Research (NCUR) joined forces (*4*). The new organization, known as the Council on Undergraduate Research (CUR), is the leading voice in advocating for support from external constituencies to fund undergraduate research (*4*).

In laboratory courses, students usually conduct experiments in which there is a certain outcome. Sometimes most of the experiments follow a "cook-book" kind of format in which students just follow the steps as outlined in their laboratory manual. Some have argued that this format of learning in the undergraduate chemistry laboratory does not offer students the opportunity to conduct investigation (*5*). By properly designing experiments that incorporate inquiry rather than the routine "cook-book" style of laboratory design, meaningful learning can be achieved in the undergraduate chemistry laboratory (*14*). Through undergraduate research, students usually get the first opportunity to conduct an investigation with an uncertain outcome (*5*).

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Undergraduate Research at Grand Valley State University

"At GVSU, research, scholarship, and creative activity are essential components of the university's mission as an institution of higher learning. Excellence in teaching at the University level depends upon active scholarship by faculty members. GVSU has a center, the Center for Scholarly and Creative Excellence (CSCE), that oversees the research and scholarship pursuit of faculty and students. The mission of the CSCE is to encourage, facilitate, and support the Grand Valley community in its scholarly pursuits. The Office of Undergraduate Research and Scholarships (OURS) offers a variety of opportunities for undergraduates to pursue research and scholarship in various disciplines under the direction of a faculty mentor. Some of the hallmark programs of OURS include, the Academic Conference Fund (ACF), the Academic and Professional Enrichment Fund (APEF), the Student Summer Scholars Program (SSS), and Student Scholars Day (SSD)."

Challenges of Undergraduate Research Mentorship

There are many challenges involved in undergraduate research mentorship. Some of these challenges are:

Time: One of the major constraints in working with undergraduate students is the commitment of time. Many undergraduates are taking several courses at the same time; this breaks up the day and makes it difficult to find a continuous block of time to devote to research. In the beginning students need orientation to the project and have to acquire the requisite skills as well. Taking into consideration the time students will be tied up with exams and term papers in their classes, one semester is not enough time to be meaningfully involved in a research project. Even in cases in which students are available for an academic year, the numerous breaks from semester to semester make consistency difficult. The demands of teaching can sometimes be too much for faculty mentors and may make it difficult for the faculty mentors to devote a reasonable amount of time to research. Also depending on the institutional culture, other committee duties and institutional commitments may put a huge premium on the time that may be available for research. Ultimately, there is the challenge of finding a proper balance of time between teaching and research.

Motivation: For some students, the idea of undergraduate research is daunting and tedious. Some see research as something they "have to do" to get a good letter of recommendation, and not something they "like to do" to learn and contribute to science. If the former is true, then you may find students who try to cut corners on a research project when they encounter hurdles. For faculty mentors, there is the constant challenge of balancing criticism with positive reinforcement. Although there may be an urge to lay greater emphasis on a

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student's initial results, it may sometimes be more important to reward a student's persistence and enthusiasm over some initial results of his or her work. There is also the challenge of motivating students who do not realize the opportunity they have and thus do not give it their best effort.

Project Design: There is the challenge of developing a project that is suitable to the time commitment the student has. It is equally challenging maintaining an ongoing project as students move in and out of the research group. Another challenge is how to tailor a project to fit students at different levels of independence. As we are at a PUI and have limited time, the faculty has to attempt to work in a field that can provide more concise projects with definable outcomes (projects that can reasonably be completed within a maximum of two years). The projects can still be cutting-edge, but we need to provide opportunities in which students can learn and make progress with less time input. For example, I changed fields to provide my students more definable projects.

Mentoring Relationship: Developing the mentoring relationship takes more than a semester but students often start late in their careers and there may not be enough time to develop the relationship. While being fair to all students, each student needs a slightly different approach to work on their weaknesses (which seem to vary from student to student). Identify how to best approach each student: every student is unique—some need a boost to their confidence, some have too much confidence, some need micro-managing, some need independence, etc.

Professionalism: Faculty mentors face the challenge of dealing with relatively young, inexperienced, and often unprofessional undergraduates. This is not surprising since most undergraduate students are young, and are still learning how to act professionally. The undergraduate students, for their part, are under the increased pressure of adjusting to the responsibilities of adult life and are struggling with how to deal with their new college life.

Research Space: Finding research space to accommodate more student researchers is a problem. Most undergraduate institutions don't have the luxury of space that may be available in more research-oriented institutions. This lack of research space may serve as a deterrent for faculty mentors who are motivated to pursue research working with undergraduate students. Sometimes with very limited space for research, there may be congestion in the research lab; this congestion may result in safety issues. A faculty mentor is thus confronted with the problem of making use of limited space and finding creative ways of making sure safety is not a concern.

Funding: Finding external funding for undergraduate research may sometimes be difficult, especially when one has to show preliminary results to back up one's hypothesis. The challenging part is carving out enough time to write any grant proposals. Sometimes a mentor may have a great idea but this idea may be deemed lofty by funding agencies that determine the work cannot be accomplished by undergraduates. With funding agencies under increasing pressure to cut or conserve funding, undergraduate institutions with limited resources find it hard to compete with large institutions (research-focused institutions) that have more resources. In the face of this competition for funding, undergraduate institutions have a better chance focusing on their core competency of providing one-on-one mentoring as a great tool for teaching and learning.

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Some Solutions to Challenges in Undergraduate Research Mentorship

Some of the challenges in mentoring can be circumvented by smart design and good strategy:

- Design research projects in which the skills required must be those undergraduates possess or can easily acquire with appropriate training.
- Design research projects in which the amount of time required to complete the project must be realistic in terms of resources available and student availability.
- Design projects with clearly defined goals and expectations on the part of the student researcher.
- Design projects that the undergraduate researcher can conduct with limited or no undue burdens in terms of safety considerations.
- Design projects that provide opportunity for reflection and that can take students to a new level of understanding. This is important because even if the project turns out to be unsuccessful, the students can still come out having learned something in the process.
- Take advantage of research space during the summer when teaching laboratories become available for faculty mentors to use for research.
- For reasons of efficiency and safety, faculty mentors and their students can take advantage of shared research space. By using shared research space, faculty mentors can assure that their students can keep close tabs of each other in the research laboratory.
- For safety reasons, faculty mentors should encourage a “buddy system” to ensure that students don’t work alone while in the research laboratory. Such a system also encourages collaboration and communication among undergraduate research coworkers.
- The administration should have a culture that values research as an integral part of the teaching and learning process. Such a culture will make it easier for faculty mentors to find time for research, as their teaching load will take into consideration the time spent working with undergraduate researchers as part of a teaching load.

Opportunities of Undergraduate Research Mentorship

Despite the many challenges in undergraduate research mentorship, the inherent excitement and valuable experience that the mentor-student relationship offers is great and the opportunities are endless. Some of these opportunities are:

Teaching and Learning: Undergraduate research mentorship offers a great opportunity to teach and advise students. The students truly learn a lot in such an intense one-on-one setting. The faculty mentor also has a great opportunity to learn new things about his or her research.

Contribution of New Knowledge: The mentorship experience offers the opportunity to contribute new knowledge in the field. Through collaboration with student coworkers, their contribution can improve the mentor’s work, thus allowing the possibility of a new perspective in the mentor’s research.

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Gratification and Humility: The mentorship experience provides the opportunity for the mentors to influence students in a deeply personal manner; the mentors have the privilege of effecting the scientific development and the personal character development of the students. This offers gratification for the mentors as a result of a sense of accomplishment from helping undergraduate coworkers.

New Directions: The mentorship experience can offer the opportunity for new direction in the faculty mentor's research. After training undergraduates in the research-appropriate techniques, a faculty mentor can leverage his or her own skills and approaches to a particular problem in a much more extensive way. For example, through collaborations with undergraduate research coworkers, more investigations, more data, and more progress can be made in the mentor's research than could have been without the contribution of the undergraduate coworkers.

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Feedback from Past Undergraduate Research Collaborators

As faculty research mentors, we are particularly happy to see our former students and research coworkers graduate and go on to "big things" as they pursue their career. It has been a joy for me the last 10 years working with more than 20 undergraduate research coworkers. As I prepared my presentation after winning a "Distinguished Undergraduate Mentoring Award," I started to think about possible questions I could ask my former students that would give them the opportunity to share the value of their GVSU research experience post-graduation. Herein are the questions that were asked and following are answers from some of my former research students:

1. *What have been your accomplishments post-Grand Valley State University?*
2. *How can you link your accomplishments to your GVSU research experience?*
3. *What opportunities did your GVSU research experience present to you?*
4. *What challenges did your GVSU research experience present to you?*
5. *What would you say is the overall impact of your GVSU research experience to your education at GVSU?*
6. *What would you say if you had to advise current students on the benefits or lack of any benefits of research?*

Response from Student # 1: *Jamie Gomez is a Graduate Student in Anthropology at Western Michigan University.*

"Due to my achievements at Grand Valley, I was accepted to the Anthropology Master's Program at Western Michigan University. I was also awarded a graduate teaching assistantship that covers six graduate credits per semester. Currently I am teaching my own biological anthropology lab in which I have two sections and a total of 50 students. I was elected to be the faculty member of the Anthropology

Graduate Collective and plan to run for President next year. Also, I am up for consideration for a graduate research position for two consecutive summers in the Wyoming Great Basin in which we will be using a predictive model to find fossils and determining life histories from what we find (mostly teeth).

"My research experience completely changed my life and the way that I operated. I was required to work hard and learn all the skills I needed to be successful in the lab as well as in school. When my research time was done, I was very well-prepared for a professional future. I attended a professional conference and got published in a peer-reviewed journal. Doing these things as an undergraduate made me an amazing candidate for graduate study and makes me a great leader. All of my accomplishments in some way can be attributed to all the laboratory and life-style lessons that I learned during my research experience.

"There were very high standards in the lab and those translated to my general studies at Grand Valley and life in general. I worked hard in the lab and worked hard in the classroom and was able to graduate Grand Valley with a great education. I graduated Magna Cum Laude and received the Biomedical Sciences Outstanding Student Award from the faculty my senior year. My hard work in the lab led to hard work in the class and I was extremely successful at GV as a result.

"Research is the best decision I ever made. While you have to put a lot in, you get so much more out of it and learn so much. No matter what the student's plan in life is, research is something great to have on a resume. With technology and advancements in medical knowledge, laboratory work in many forms is a growing industry. Laboratory experience is a great thing to have and who knows, it could change your life, like it did for me."

Response from Student # 2: *Gillian Kupakuwana graduated with her Ph.D. in Biochemistry from Syracuse University and is currently a Second Year Medical Student at Columbia University, N.Y.*

"I earned a Ph.D. in Structural Biology, Biochemistry and Biophysics at Syracuse University, and am currently a medical student at Columbia University, N.Y. Research sparked a sense of direction and career goals development. Any student can be good at class work but I discovered through research with Dr. Ngassa that discipline, direction, field exposure, and mentorship is what students require in addition to the classroom experience to build and achieve their dreams. Through the application of knowledge learned in the classroom, research made it clear why organic chemistry mattered. Also, research sparked a scientific curiosity that has driven me to this point in my career.

"The overall impact of the research experience is that it provided a glimpse into the bigger picture of why it all matters, and why chemistry is an exciting field. The research experience as an undergraduate student, especially with a principal investigator such as Dr. Ngassa, who is accessible and invested in his students, is invaluable. More than anything, it challenges the student to think outside the classroom, apply what they are learning, while investigating new phenomena."

Response from Student # 3: *Kyle DeKorver graduated with his Ph.D. in Organic Chemistry from the University of Wisconsin in Madison and is currently employed with DOW Agrosciences in Indiana.*

"I received my Ph.D. in Organic Chemistry from the University of Wisconsin-Madison in May of 2012. I have thus far published nine peer-reviewed

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papers, six of which I am first author on. In 2010, I was awarded the American Chemical Society Division of Medicinal Chemistry Predoctoral Fellowship. In June, I started at Dow Agrosciences.

"GVSU prepared me very well for the coursework in graduate school, as well as gave me an excellent start on how to conduct scientific research and how to convey results to the scientific community through publication. I remember struggling through writing the first draft of an Organic Letters manuscript and all of the subsequent revisions. At the time, I didn't realize how valuable (and rare as an undergraduate) that experience was. Above all else, research with Dr. Ngassa, as an undergraduate was the most important factor in succeeding in graduate school. GVSU is unique in that it is an undergraduate university (for chemistry, anyway) so undergraduates "lead the charge" on research, yet it is large enough to provide excellent resources. As far as whether or not to do undergraduate research, the answer is simple…. Yes! ALL chemistry undergraduates should work in a research lab and should start as early as possible!"

Response from Student # 4: *Jared Hector is a Dental Student at the University of Michigan.*

"After graduating from Grand Valley State University I applied for dental school and was accepted into three programs. My final decision was to attend the University of Michigan's dental program and that is where I am now. At every interview the interviewers would ask me to elaborate on my research experience. It seemed to stick out on the application and when I answered about the many opportunities and experiences it seemed to interest them.

"One of the challenges in organic research is that I did not have as strong of a chemistry background as I would have liked. This forced me to learn many of the techniques, compounds, and procedures that I would have never experienced if it weren't for this experience. My research experience helped me become a better student. It made me realize the amount of time and effort that was needed to accomplish something well. Within a few months of starting research my GPA drastically increased and I was able to gain knowledge in the chemistry field. I would tell current students that if you can put forth enough time and effort into a research project, do it. There may be very stressful times where low yields, incorrect compounds, and human error occur but those are the times that help build character. Whether you plan on doing this as a career or are trying to gain experience in the vast research field, I would highly recommend at least one semester of research before graduating (especially with Dr. Ngassa)."

Summary

The challenges and opportunities in undergraduate research mentorship are based on my experience and the experience of some of my undergraduate coworkers at Grand Valley State University over many years. These challenges and opportunities may also be the collective experience shared by my colleagues who have engaged undergraduate students in research, scholarly, and creative activities over the years. As a research mentor, I strive to instill in my students the confidence to explore their full potential in research through the development of critical thinking and problem-solving skills. Although my research students work on their individual projects, the ability to work independently does not deter them from interacting with other group members in team projects. I have seen first-hand how my mentoring experience has helped to change the lives of many undergraduate research students. Many former students have written e-mails saying how their experience in my research lab was a life-changing experience and helped them in choosing a career path; indeed I have been pleased and humbled by feedback from past students. In summary, the philosophy of my research mentorship is guided by the belief that my undergraduate research coworkers and I have a joint responsibility to make a contribution in the science discipline through the pursuit of knowledge and discovery. Once knowledge is pursued and important discoveries are made, the goal is to ultimately disseminate the knowledge gleaned through presentations at regional and national meetings, as well as peer-reviewed publications.

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Chapter 5

Keys To Building and Maintaining a Successful Undergraduate Research Program: Designing Research Projects for an Undergraduate Research Lab

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Undergraduate research is limited by time available for research and research experience; of which time is probably the most important. Successful undergraduate research advisors can compensate for these limitations through setting realistic goals, matching research projects to the level of experience of their students, directly assisting in the lab, practicing good data management, and dividing projects over a large research group.

Introduction

New faculty, with multiple years as graduate students and post docs, have plenty of experience in a research lab, and may even have experience supervising undergraduates; so how is an undergraduate research program different? Research in a group that is majority undergraduate is limited by the experience of the students, and also the time that they can contribute to the endeavor. These limitations mean that taking what might be called a traditional approach with a group of undergraduates is likely to be frustrating at best, for both faculty and students, and the resulting research will be a poor stepchild of a "proper" research group. But undergraduate research can be a lot more, if as an advisor you understand what these limitations are and play to the strengths of the students.

I have been a research active faculty member for 16 years at three, predominantly undergraduate, institutions. My research, mostly in the area of properties and coordination chemistry of stable free radicals, has been conducted

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largely by undergraduates, and has been funded by the Petroleum Research Fund and the National Science Foundation. This success has come from some trial and a lot of error. Some of my insights in undergraduate research are summarized below; while I think they are relatively general, the caveat "your mileage may vary" applies.

Understanding the Limitations

At first glance, the biggest limitation of undergraduate research seems to be lack of experience; however, I have found time to be a more serious issue. Graduate students may start with little more laboratory experience than an undergraduate researcher, but with a lighter course load and an expectation of significant lab time, they have time to make mistakes and learn from them. Undergraduates cannot waste time in the same way if they are to make any research progress. Unlike graduate students, undergraduates have many other commitments, including a high course load and the possibility of athletics or employment commitments. Finding undergraduates willing to commit 9-10 hours per week for research is challenging and frequently I have had to make do with less. Unfortunately research, in part because of its uncertain nature, is a very time-intensive exercise. Especially in areas like synthetic organic chemistry, many experiments simply don’t work the first time, and need to be repeated several times before success, but for an undergraduate that is only in lab once a week, this means that completing only one step in a synthesis may take a whole semester. Making matters worse, delays beget delays. Experiments don’t always fit into a three- or four-hour window, and if the student is not available to complete a workup, products can decay and little progress is made even considering the time available. New researchers are typically unprepared for the frequency of failure in synthesis and several times I have had students, in a display of rash optimism, commit "the world’s supply” of an intermediate to an experiment, only to have the reaction fail. For a graduate student this might mean that the next week or so is spent making more of the starting material; for an undergraduate this might mean that the rest of the semester is spent re-making material rather than making progress. With time being such a big issue, I have found a more traditional model of students in the lab and research advisor providing direction rarely works for undergraduates, and a far more hands-on approach is more fruitful. The challenge is getting the balance right between contribution of students and faculty.

Set Realistic Goals

Even with the limitations of time and experience, there is no reason why undergraduates cannot produce high quality, significant research. However, it’s going to happen slowly. Tackling competitive research areas where several other groups are working to the same goal is unlikely to be a successful approach. Conversely, because the “overhead” on undergraduate research is relatively low (salaries are low, or students often just work for course credit during the semester) undergraduate research groups are well suited to explore areas that

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currently do not receive much funding. My own research in the field of stable verdazyl free radicals had the advantage that very few groups were studying these molecules when I started. However, it took three years before I received any kind of external funding and 14 years before I was directly funded by the NSF (*1*). In the meantime we were still generating results on a low budget, but eventually managed to publish enough to demonstrate that the research area was worthwhile.

Match Projects to Experience

Undergraduates arrive in the research lab with a great range of experience; from almost nothing, to having completed project based teaching labs. While it is common to apply a class prerequisite to incoming researchers, in my experience it is helpful to keep limitations as low as possible. Getting students involved early in research gets them experience sooner, and hopefully they will become competent researchers before they graduate. Time rears its ugly head again here, because in most cases undergraduates will graduate and leave your lab whether their research project was successful or not. The sooner you get them started, the more likely they are to successfully contribute to a project. Of course the question is, what research can you do with a sophomore with only a year's lab experience. The answer is quite a lot. After a year of chemistry, students are familiar with concepts such as pKa, equilibrium constants, oxidation potentials and reaction rates, and setting out to measure such physical quantities can be a great introduction to the research lab. If the system is well behaved, these experiments have a high likelihood of success and can motivate students to delve deeper into research. One of my recent publications (*2*) began as the measurement of the pKa of a verdazyl phenol, which then led to the question "How does the pKa vary with structure?" and eventually turned into an interesting paper.

Measurement projects also have the advantage that they can be relatively discrete—even if a student leaves after one semester (which has happened all too often) you are likely to be left with a useful result that can be combined with others in a publication. On a slightly more synthetic direction, coordination chemistry can be a very useful entry into research; synthetically the concepts are pretty accessible ("ligand binds metal") and at least with transition metals the experiments frequently have aesthetic appeal. Many of my publications with undergraduates (*3–12*) have involved coordination chemistry for those reasons; for the first of these (*3*, *4*) the student approached me before Christmas about research, and I asked her to combine a ligand with several metal salts and see what happens. She duly made the requested mixtures and left for Christmas vacation, upon returning several of the samples had crystallized and gave satisfactory crystal structures. Admittedly, a good part of this was luck, and further work was required before publication, but the seeds of an interest in research had been planted.

Ideally, the research project should grow and match the laboratory experience of the student; in the projects above, students went on to synthesize new ligands as their synthetic laboratory skills developed. I have found that it can actually be quite fruitful to have students start synthetic research projects as they are

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beginning the organic laboratory sequence (typically their first exposure to synthetic chemistry) rather than after they complete it. Running lab experiments and synthetic research in parallel reinforces students understanding of the techniques involved, improving their learning experience in the lab class, while giving them a head start on completing synthetic projects. In an ideal case, the synthetic efforts of a senior undergraduate provide new ligands that can be investigated by the incoming students. Even so, synthesis in an undergraduate lab can be exceedingly challenging. If the project can be divided up into several discrete, independent, semester (or year) long sub-projects, (e.g., investigating the scope of a reaction using multiple commercially available substrates) a “divide and conquer” approach with many undergraduates can lead to very satisfying results. For example our synthesis of diisopropyl verdazyls has been applied to numerous different targets with different goals but the same simple methodology (*2*, *9*, *10*, *13*). However multi-step syntheses can be hard to complete even with experienced undergraduates. Our diisopropyl verdazyl syntheses were only possible after the completion of the synthesis of the starting material, a 2,4-diisopropylcarbonohydrazide, that though a relatively simple four steps, took almost four years to develop. For multi-step syntheses, typically I have found that the project seems to be making good progress until the first student leaves. At this point a large amount of accumulated experience is lost and the next student frequently spends most of their time just getting back up to where the first student was; progress slows to a painful crawl. A partial solution to this is to have overlap between outgoing and incoming students so that one can help train the next, but this is not always possible; schedules can easily conflict, or there may not be a suitable student to take over. It is illuminating to me that of the papers we have published involving novel organic syntheses, not one of them has had a single student that initiated the project and saw it to completion, and I as a faculty member, have had to make a significant contribution in lab work in order to keep the project progressing.

Expect To Get Involved

Neither my Ph.D. advisor nor my postdoctoral advisors spent a significant amount of time in the lab. Their role was largely managerial, which is not an unusual situation in a Ph.D. granting institution. However, as a PI in a largely undergraduate research group you can expect to spend a significant amount of time in your laboratory. As I have already noted, undergraduates don’t have the time to learn from failure to the same extent that graduate students do; failure is important to increasing understanding, but without some successes, undergraduates can easily quit in disgust. Having an experienced researcher directly involved in the lab can greatly improve outcomes and prevent this from happening. Sometimes this can involve mundane tasks such as turning things off and on that can help students get more out of their limited laboratory time. In other cases faculty involvement is important for safety reasons, for example in teaching new and/or hazardous procedures. But faculty experience in making and interpreting observations can make the difference in turning a failed experiment into a success the next time around. Students learn by example as to what observations are likely to be important and what is less so.

In some cases getting involved can be as much as testing an initial run of a reaction to see if it is feasible, or even completing one or more steps of a synthesis. In our synthesis of 1,5-dipyridyl-6-oxoverdazyls (*10*), I made the initial attempt at the one-pot reaction that formed a mixed bis(hydrazide). The reaction seemed a little far fetched at the time and I didn't want to give a student a project that was doomed to failure from the start. Undergraduates then went on to refine the reaction and purification techniques and to take the intermediate on to a verdazyl. In other cases I have also found myself getting heavily involved in syntheses when there are no undergraduates with sufficient experience to complete the experiment, or the synthesis is particularly challenging, but students will be available to follow up with characterization or metal coordination studies. Such was the case with my first publication with undergraduates; for the first experiment I had already made the ligand, and the new student only needed to combine ligand and metal ion. A similar challenge was the synthesis of the isopropylpyridyl verdazyl we reported in 2010 (*9*); while I had undergraduates begin the synthesis, the number of steps and the techniques involved ultimately made the synthesis too challenging for an undergraduate lab and I stepped in to complete it.

With graduate students it is a reasonable expectation that the student collects all the data necessary to complete a project and drafts and writes the publication. While this is also a worthy goal for undergraduates, it is far less commonly achieved. Because of the limited time available, most publications in an undergraduate lab result from the contributions of several students and, despite my best efforts (*vide infra)* it is still a frustratingly common experience to have some mundane piece of characterization data missing when it comes time to publish. The challenge is, in an undergraduate lab, the student responsible may well have graduated at this point. It might be possible for another student to remake the materials needed and fill in the gap, but it is not a quality research experience. I would prefer to have my students experiencing the thrill of new discovery rather than correcting others mistakes; meanwhile, by collecting the necessary data, I have an opportunity to check the accuracy of the earlier students work.

Work on Good Data Management

Again, because undergraduate research projects are often the product of several students, not always working concurrently, it falls upon the research advisor to marshal the data and bring it all together for publication. A traditional approach to this is for students to each write a report before they leave the research group. This is certainly good practice for them, but with modern instrumentation, a written report is not necessarily the best way to archive the data. In order to publish, spectra may need to be overlaid, graphs re-plotted and data re-analyzed, all of which is facilitated by having digital copies of data in other formats (spreadsheets, digital copies of spectra etc.) How you organize and maintain this collection of data is a non-trivial challenge. Students can keep and archive

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data from their own research, but it becomes harder to organize when combining data into files to compare results from different students. To help with this problem, I have developed a filing system on my main lab computer that works reasonably well. The essence of this is that each new compound we make gets a folder that contains digital copies of all spectra and other characterization data. Non-synthetic experiments also get their own folder; importantly the definition of experiment includes purely data analysis and comparison operations. This provides a place to put all the spreadsheets where we overlaid a set of spectra from different students for comparison purposes. It is also good practice for students (and faculty!) to get into the habit of thoroughly annotating data analyses and spreadsheets—what were you doing with the data? And why? Annotation, along with using shortcuts/aliases to point to one dataset rather than making multiple copies, goes a long way to avoiding the problem of having multiple similar copies of the same data analysis, but not knowing which is the “correct” one.

Co-Opt Laboratory Classes

Project based laboratory classes have been a useful way to support development of undergraduate research. In such a class in organic chemistry students are responsible for developing and implementing a "mini-research project” providing an introduction to research and also playing a role as recruiting tool. Project based classes vary in that in some cases students are provided with synthetic targets and only have to develop the synthesis while in others they are responsible for developing the project idea as well from the ground up. The latter gives them more overall “ownership” of the project; however when I have been teaching such classes, I have, in a self interested manner, given synthetic targets that are of interest to my own research. While shortchanging the “ownership” aspect, this does mean that projects are more likely to actually turn into publications; our contribution to a collaborative publication on self assembling grids actually began as a project in an undergraduate teaching lab.

Don’t Be Afraid of a Large Research Group

When it comes to undergraduates inquiring about research opportunities, I find it hard to say “no.” When I was at the University of Detroit Mercy, this was not a huge consequence, since the overall student population was low and my research group was never very large. At San Jose State University however, the larger student population has made for a much larger research group; at times as big as 15 or 16 undergraduates. Initially, there was an aspect of shock to this; a "What have I done?!" moment but I admit I have been pleasantly surprised that it actually worked quite well. A larger research group means that students can benefit from a social work environment and a safer work environment; they are less likely to be working in isolation and can and do frequently learn from each other, rather than constantly asking me. My workload does not actually scale linearly with the number of students in the lab, and with more students around I find I actually spend less time explaining how to use the rotary evaporator or the

GC. The challenge with so many students is actually making sure they all have something to do. Some projects lend themselves to multiple researchers; running numerous different variations of a new reaction for instance. In other cases, having students work together as lab partners on a project can be effective, provided they can work collaboratively and communicate effectively. In ideal circumstances, this can significantly increase the time available to work on a project, especially if they can arrange schedules so that they are not always in lab at the same time.

Collaborate

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A good collaborative relationship can benefit any research program, but is not always easy to develop. At primarily undergraduate institutions, research collaborations are typically necessitated by a lack of resources. A large fraction of my publications with undergraduates have used a collaboration with faculty in other institutions in order to access resources such as high field NMR (*4*), computational facilities (*4*), crystal structure determination (*3*, *4*, *9–11*), and magnetometry (*3*, *6*, *9*, *10*). Students can benefit enormously from collaboration; besides the obvious benefit of higher quality and more complete publications, collaboration provides opportunities to explore and learn about other techniques. My students have learned the basics of crystallography and magnetometry through analysis of data collected elsewhere. Furthermore, collaboration provides connections to graduate programs that can help with future career development. Collaboration can also help alleviate competition with larger, better funded research groups, i.e., "If you can’t beat them, join them." In 2003, when I realized that Lehn’s group had just published the core part what some of my undergraduates were working on in terms of self-assembling hydrazones (*14*), my initial instinct was to abandon the project. However, a careful reading of Lehn’s publication revealed that we may have some insight that had eluded the larger research group. (Curiously this may be because our NMR was a lower field instrument!). Rather than trying to compete further, I chose to offer to share our data, resulting in a stronger publication and for my students to author a paper with a Nobel Prize winner (*7*).

Unfortunately collaboration can also have its downside. When undergraduate research groups are the recipients of collaborative data and not the providers, collaborators at larger institutions may not be as motivated to collect data in a timely fashion. It can be frustrating to see projects languish while waiting for data from collaborators. Collaboration is not always beneficial to the PI’s career either. Early in my faculty career I collaborated with one of my postdoctoral advisors in order to collect NMR data. Though the research ideas in the subsequent publications were my own, the co-authorship resulted in proposal reviewers commenting that I had not done enough independent work as faculty. Ultimately, though, the benefits outweigh the problems and collaboration provides undergraduate research groups access to needed instrumentation, it facilitates publication in a timely manner, and can provide the connections to help students further their own careers.

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Final Thoughts

I hope I have illustrated some of the things I find make a successful undergraduate research lab. Above all though, I have found working with a largely undergraduate research lab is, more than anything, fun! I love being in the lab (it is why I am in this job, after all!) and by working with undergraduates I can (I am even expected to) spend more time in the lab and share the excitement of chemical discovery.

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Chapter 6

Developing and Sustaining a Research Program at a Traditionally Undergraduate Liberal Arts College

Research, it's our thing! Experiences in establishing a research culture at Augustana College, Sioux Falls, SD

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In the past 10-15 years, Augustana College has experienced a quantum leap in undergraduate Chemistry research because of a fortunate set of circumstances which converged at roughly the same time. Several factors were instrumental for establishing this research culture but the essential ingredients are a very organized and hard-working faculty dedicated to making a research culture a reality and students who are excited about research and willing to work to make it happen. Creative use of available facilities and efforts to secure financial support from a variety of sources is essential for maintaining and growing this research culture, where success breeds success in obtaining support.

The decades long effort at Augustana was sustained at a moderate level until about 10 years ago. At that time several larger collaborations fueled growth, but participation in an NSF-URC entitled the Northern Plains Undergraduate Research Center (NPURC) provided the biggest boost. In a very real way, the impact of NPURC is still being perpetuated in the department. The intentional manner each program fed students into summer research as well as the funding support for students,

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ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

faculty, instruments, and travel to meetings over the extended period of time effected a change in student expectations to one of entitlement.

The details of these circumstances will be examined to see what effect they have had on the recognition, honors and placement of students in and after graduating from this department and its research program. The necessary elements of a successful research program will be discussed.

Background

Undergraduate research in Chemistry at Augustana College has undergone a quantum leap in the last 10 to 15 years. It was not established by faculty members just sitting together to decide it should happen. It has happened because a variety of circumstances converged at this time, and most of these elements required a great deal of faculty time and effort. Some ingredients were:

- ***Recognized need***: Decades ago, a research experience was considered a plus for a graduate school but was not required for acceptance. Medical or other health science graduate schools did not require research and didn't give such experience much weight in an applicant's package at all. Today, that has totally changed. Graduate schools expect multiple research experiences and perhaps one publication, and health professional schools expect applicants to have a research experience.
- ***Motivated students***: The most important ingredient is a student who has the desire to try research. While admissions and the Natural Science Division ramped up efforts to attract high aptitude students about 15 years ago, for research, a high aptitude is a plus but not an absolute requirement.
- ***Faculty***: There have been several Chemistry faculty retirements in the last few years. New faculty members were hired with the expectation that they would initiate research with undergraduates and would also obtain outside funding. The faculty must pursue projects appropriate for the level of sophistication these undergraduate researchers possess and, perhaps most importantly, must be *willing to "teach" research*.
- ***Financial support*:** External grants to individuals plus collaborative grants with other institutions as well as through on-campus support have allowed the research culture to bloom.
- ***Administrative support***: including financial. This is essential. As our research culture grew, the faculty needed to teach the administration what scientific research is and what is appropriate support.
- ***Laboratory space*** and appropriate ***instrumentation:*** The creative use of available lab space and access to appropriate instrumentation is a must. Through collaboration with other institutions, their instrumentation also becomes available.

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- ***Disseminate research results:*** Opportunities to communicate results were through venues such as student presentations at regional and national meetings, publication in appropriate journals, etc.

These will be examined in depth after we introduce Augustana College.

Historical

Augustana College is a selective, private, residential, comprehensive (liberal arts and professional) college of the Evangelical Lutheran Church in America located in Sioux Falls, SD, with 1750 full time students. About 40% of the students are in the Natural Science Division, of whom about 80 are Chemistry or Biochemistry majors. The Chemistry/Biochemistry majors' average ACT score in math is 29. In the last 85 years, more than 200 graduates of the department completed a Ph.D. in some area of chemistry and another 175 became MDs. Over the last 20 years, the Chemistry Department has had an average of 10 graduates per year (range 3 to 15). During that time, 50% of the graduates have gone on to graduate school in Chemistry and Biochemistry and another 25% have pursued a variety of health professions (medicine, pharmacy, dentistry, optometry, etc). The remaining 25% attended graduate school in areas outside chemistry, took industrial positions, became forensic chemists or entered secondary education. At least five attended law school, most to pursue patent law.

Rise of Research Culture

The Chemistry Department has a long tradition of undergraduate research. For well over 50 years, Augustana Chemistry faculty members have occasionally procured funding for a handful of students, most always junior and senior students. Some examples of support came from Research Corporation, NSF-REU and the Bush Foundation.

During the years without external funding, a creative method was used to conduct at least a limited amount of summer research: two or three regular courses were offered during the summer school term. Often freshman chemistry (we have only a one-semester freshman course) and first semester organic were taught. In an arrangement with the administration, at least one undergraduate student was hired as a lab assistant for each summer course. Realizing the student would be preparing lab setups, making solutions, grading lab reports and assisting the professor in the lab, the student still had at least half a day free from lab duties. They were then pressed into half-time summer research with one of the faculty, being paid for a full-time summer job. Usually about three students were involved in this research which was justified as training for academic year assisting. About 10 years ago, we discontinued summer classes and devoted our laboratory space and staff to full-time summer research. Since then we have been able to secure at least one, sometimes more, departmental assistants whose responsibilities have included updating the inventory and other summer maintenance jobs, but they then spent half-time on research.

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A Bush Faculty Development grant in the 1980s allowed us to establish the Student Mentor Program, which provided a small stipend for two or three students to participate in faculty sponsored research projects. Part of the six years of Bush support included a commitment by Augustana to expand its Augustana Research and Artists Fund (ARAF), which was already in existence for some years, to include student-faculty research. This year that program was further extended by separately funding a program specifically for student research called the Augustana Undergraduate Research and Artist Fellowship Awards. One Chemistry student was supported in 2013.

During the employment interview of one of us (Dr. Earl) in 1993, the Natural Science Division chairperson made it abundantly clear it was expected that new faculty would obtain outside funding and establish a viable research program in addition to excellent teaching. Allowed a bit of release time during the first J-term to prepare a research proposal, an NSF individual research grant resulted. This, itself, supported three students each summer for three years. This grant allowed the development of a research program rather than just very short studies conducted by a single student. A substantial publication resulted (*1*). (In these Augustana-originated papers, boldface names reflect undergraduate student authors.)

Later, one or two students were supported each year from the NIH-**BRIN** (Biomedical Research Infrastructure Network) grant obtained through the collaboration of Sanford Research and Augustana Biology and Chemistry departments. (Sanford Research is a component of Sanford Health, a large urban comprehensive hospital system having numerous locations throughout Minnesota, North Dakota and South Dakota. The hub location is just four blocks from the Augustana campus.)

NPURC and its dictated activities: The key in developing a research culture for us at Augustana was participation in a $2.9 million NSF-URC (Undergraduate Research Center) grant (NSF CHE-0532242) in 2005. Named “The Northern Plains Undergraduate Research Center” (NPURC), the University of South Dakota was the lead institution. It was joined by seven regional colleges with diverse missions and student populations (*2*). *The goal of NPURC was to effect a regional transformation of the role of undergraduate research in chemical education into an integral part of the entire four years of the undergraduate curriculum.* A number of activities were dictated by the NSF proposal that were used to develop a regional undergraduate research capacity and culture as much as was possible at each of the eight participating schools:

> ***Summer Research*:** The structure and activities of NPURC were based on the philosophy that the most effective way to develop a sustainable research culture at each school was for faculty to develop programs and practices by directing their own research students at their home institutions.
>
> ***Freshman Research Experience*** or Integrating Authentic Research into the Honors Freshman Chemistry Lab: From the proposal, the goals of this curricular revision were to revise laboratory courses in the first-year curriculum so that first-year students were immediately engaged in research experiences that enhanced their abilities to a).

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create new knowledge through experimentation, b). design appropriate methodologies for experimentation, c). synthesize prior knowledge and apply it to new problems and d). use collaborative relationships to achieve a scientific goal. Emphasis was placed on critical analysis of results, communication and teamwork.

Workshops**:** The one-week workshop model was a way to introduce students to the methods and thinking of science worked especially well at the tribal colleges because their students tend to have less background or exposure to science. (Both Sinte Gleska University [SD] and Fort Berthold Community College [ND] were established on the Indian Reservations to make higher education more accessible to the Native American students from their respective reservation. Some Native American students enroll in the state colleges and universities but often do not stay more than a few weeks or a semester since the needed level of cultural support is not available. Sinte Gleska has only one chemistry professor and Fort Berthold has one science professor, so access to chemistry courses is very limited.) With so few faculty to provide opportunities for summer research as well as students unwilling to spend the entire summer away at the tribal college, a 10-week research experience is not an option.

Instrumentation**:** New instruments were purchased at each institution and USD also acted as a multi-user facility for providing access to the major instrumentation that may not have been available at the smaller schools.

Expertise and training**:** NPURC provided a half-time technician at USD to lend technical expertise and training to all the NPURC participating schools for setting up and using modern scientific equipment and methods.

Advanced Opportunities for students**:** NPURC included three non-academic partners: a government laboratory (Pacific Northwest National Laboratory), a corporate laboratory (Battelle Science and Technology International), and an industrial partner (CIMA Labs, Inc.). These non-academic partners provided internship opportunities for advanced undergraduates to extend the reach of undergraduate research experiences from first and second-year students into professional development for advanced students and recent graduates.

Augustana Experience with NPURC (The Jump Start)

The above list of activities dictated by the NSF-NPURC proposal were carried out in different ways and degrees by the eight participating schools, often constrained by faculty and staff limitations. The following is a description of how Augustana College's Chemistry Department carried out these dictated activities.

The major effect of NPURC at Augustana was to get four chemistry and one physics faculty involved every summer in student research. Each NPURC award provided research support for a faculty member and two freshman or sophomore students for a 10-week summer research experience. In addition to the research stipends, funding for research supplies and student travel to a professional meeting were included. Over the six-year life of the grant (some funding remained after the five year grant cycle which was distributed during the sixth year) it allowed Augustana to support a total of 39 students for a 10-week summer research session. Here was concrete sustained support for conducting research.

The success of the research experience was fueled by the **Freshman Research Experience**. It was decided that this would be started the first year at USD, Mt. Marty College and Sinte Gleska University with Augustana as the lead institution. The other schools would start the second semester with their freshman course. USD also had a second semester Honors section as well. At Augustana this effort was initiated in the Intro to Chemistry Honors section, taught the first semester. (Freshman chemistry is taught as a one-semester course.) This one-semester general chemistry course is populated each year by 20 to 25 students who earned a AB@ or better in two semesters of high school chemistry and attained at least a 28 composite on the ACT. We expected these students would have the concept skills and perhaps even the research interest to make this a >go= for the first time around for we knew the first effort needed to be a successful one. (Just because the student qualifies for the Honors section does not mean he/she will actually enroll. That obviously depends on student advising, grade fears, etc.)

The students' assignment was to characterize and look for potentially useful properties in a set of new quaternary ammonium ionic liquids which had been prepared by an Augustana research group during the previous summer and which had not been fully characterized (a faculty research project). To help the students develop a research mentality, the project was initiated early in the semester with a one hour lecture that contained a short background on the chemistry of these compounds, a discussion of green chemistry, green reagents and processing as well as green solvents, and broad areas of inquiry such as viscosity, surface tension, solubility, melting point, etc. Examples of specific projects include: "Determination of the melting point of tributylmethyl ammonium methyl carbonate." This was a tricky concept because the ionic liquid had a freezing point. Another would be "The Determination of Solubility of quaternary ammonium methyl carbonate in organic and hydroxylic solvents," etc.

They were instructed in the use of the chemical literature and search engines, including SciFinder Scholar. Using the literature, each group of four students developed a research proposal which was further refined through consultation with the instructor to fit the equipment and materials available, and sometimes to make it more "reasonable": for example, the suggestion of animal testing was eliminated from one proposal. The research was conducted in the regular lab periods during four weeks toward the end of the semester. During the last lab period (two hours) of the semester, each student group gave a 10 minute oral report, using PowerPoint presentations to convey their research plan, experimental data, and evaluation of that data with conclusions. Their written report on the project was due the same day as the oral report. Directly from this experience, each student became aware of what authentic research entails and of available research opportunities. Most had the expectation to participate in research, perhaps as soon as the summer after their

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freshman year. Each year of the NPURC grant students from this course provided nearly all of first-year students who participated in the 10-week summer research experience.

A reason for describing the schedule of events for these students is to emphasize the time commitment for the faculty in charge. To have a successful experience, students must have a timely response to each group's research proposal. In order for the research experience to be a good one, there must be two or preferably three lab assistants per lab section of 20. With four to six student groups working independently, they need materials preparation, guidance inside and outside the lab, instrument training, safety discussions, data analysis/interpretation, etc. So the function of the assistant becomes one of encouraging the researchers, being a "cheerleader" of sorts, and often times a participant teaching how the apparatus should work, guiding safe setup, even becoming the teaching expert on the equipment/instrument. The assistants need prior experience and training. Trying to implement a research project without assistants or with just one lab assistant will make for a difficult time for everyone and is not recommended.

Dr. Moore taught Chem 120H for the first three years. When Dr. Eichler inherited the course, he retained much of the template for the research segment in the lab but put his own imprint on the course for the next three years. He incorporated a variety of new techniques, including Karl Fischer titration for water analysis, rheometry (for viscosity), NMR, X-ray crystallography, conductivity, recrystallization and IR spectroscopy. Here quaternary ammonium compounds with several different anions were compared. Examples of projects included "Determination of hydrophilicity of tributylmethyl ammonium salts with various anions" or "Synthesis and crystallization of tributylmethyl ammonium trifluoroborate and its structure as determined by X-Ray Defractometer. ".

The written report construction became a two-step process: a rough draft of the paper was due two weeks after the experimentation was completed, and the final paper in journal format was due the last week of the lab. One group used the X-Ray Defractometer at USD. Road trips are good!

Dr. Earl (summer research mentor and NPURC Managerial Board member) presented a summary of our experiences after the first three years of Chem 120H research at the 2007 National ACS meeting in Chicago (*3*) and Dr. Eichler presented an update after the conclusion of NPURC at the 2013 National ACS meeting in New Orleans (*4*). Both talks disseminated how the integration of authentic research into the freshman honors chemistry lab actually works! The research component in Chemistry 120 H has been so successful that of course we have continued it. Most recently Dr. Dey taught Chem 120H and brought his own research ideas to the project. This Fall Duffy-Matzner is teaching the course and centering the research project on aspects of her organic synthesis research.

Three **NPURC Workshops** rst two during year one and two of the NPURC grant focused on ionic liquids and gave 12 students a hands-on experience in the laboratory with synthesis methods, instrumental analysis of the products, keeping a laboratory notebook and writing research reports. Thus each student was given an opportunity to see the components of research and assess his/her interest and enthusiasm for that type of work. Nearly all those students accepted a 10-week

In Developing and Maintaining a Successful Undergraduate Research Program; Chapp, T., et al.; ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

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research commitment after this experience, some that same summer. However because offering the workshop was an extra load on research mentors and recruiting students for the workshop had become more difficult, we discontinued offering these workshops at Augustana.

The third workshop took advantage of our experience with the Freshman Research Experience and focused on helping consortium faculty to implement a research experience in their undergraduate curriculum. In addition to the schools that piloted the research experience, Briar Cliff University and Dort College added a research component to at least one course the following fall.

Two Augustana students took advantage of **NPURC's Additional Opportunities** conducting research at PNNL. Several others engaged in similar "extension" activities: one finished a MS degree in Norway, several worked in industrial research, and several others took advantage of REU programs at a variety of research universities including Michigan State University, Purdue University, Vanderbilt University, Kansas University, and Syracuse University, among others.

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Continuing Development of the Research Model

The NPURC model for bringing authentic research into the freshman lab was so successful that it has been expanded beyond the NPURC proposal into other courses.

Organic Chemistry II: After the exciting results in Chemistry 120 H, a four-week research experience was integrated into Organic II by Dr. Earl. The project was somewhat similar to that of Chem 120H but tailored for Organic lab, and students worked in pairs. The authentication lab for the Diels-Alder reaction was expanded into a solvent study comparing ether (flammable, low boiling and thus usually lost), a eutectic ionic liquid reported by Abbott (*5*, *6*) as a solvent for the Diels-Alder reaction, and the ionic liquid used in Chem 120H tributylmethyammoinium methyl carbonate (TBQ). Students discovered that the TBQ anion decomposed during the reaction, but had they read the literature, they would have realized this was expected (*7*). This was a great lesson on the value of using the chemical literature. In subsequent semesters, Dr. Duffy-Matzner was included as an instructor. Ionic liquid solvents were explored for the Diels-Alder reaction by varying the anion and quaternary cation and the Mannich reaction was tested in these ionic liquids with the aim of improving on the work of Kendrew (*8*).

Some of the Organic students had the research experience in Chem 120H under their belts, and that fact was obvious from the vigor with which those students approached the research segment. As a result of the enthusiasm generated by the research segment, students spent considerable time preparing presentations. This, coupled with expertise shared from the Chem 120H veterans, resulted in excellent PowerPoint presentations. Student comments indicate most felt this

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research experience was preferable to regular authentication labs and expressed a wish to do summer research. New ACS Guidelines resulted in converting the Organic II into an Introduction to Biochemistry Foundation Course, so the research segment in that course has been discontinued.

In ***Analysis*** (Quant) Dr. Weisshaar introduced a major four-week lab project where he asked groups of three to four students to validate some aspect of an experimental method used in this class previously. Each group wrote a proposal describing what they were going to test and how they would proceed. They then carried out their proposal, analyzed their data and submitted a formal written report. An oral report (PowerPoint) was also presented to the class. As part of their project, students were required to compile a safety report, identify handling precautions and disposal for all reagents the group used.

Students really enjoyed the project but it was clear that they were in the initial stages of learning the process of research even if they had had a summer of research previously. More time and attention to the basics are required. The students need to learn realistic expectations and pay attention to details like checking for and requesting needed materials rather than assuming reagents will be available. The importance of literature searching cannot be overemphasized. It is our experience that it is hard to get the students to seek out what others have done and decide to build on that. They are eager to work in the lab and often spend time reinventing the wheel. The professor is still working on strategies to get them to do more with the literature.

In Dr. Weisshaar's ***Advanced Analysis*** (Instrumental) the whole lab program is based on method development. In the 26 lab periods (two per week) two research projects are assigned. Each requires a proposal, a written report on the project as well as an oral report. The students are provided a list of potential projects that are of some interest to the department (how to incorporate instruments into lower level courses, to develop methods for newly acquired instruments or attack a research problem of interest to the department's faculty) as suggestions, but groups (usually pairs) may develop their own proposals. Students are encouraged to focus on those instruments where they have had less experience (broaden their expertise).

In ***Advanced Inorganic*** Dr. Eichler has also instituted a four-week research experience as the last four lab periods of the course. He provides them a detailed template for the research report. These students have been involved in a cooperative effort with Dr. Hoffelmeyer at USD to prepare titanium nanorods.

***Others*:** The research component has been incorporated into other advanced courses as well with a similar format.

Several other factors contributed to the growth and maintenance of a research culture at Augustana. An ***NSF-EPSCoR grant*** centered at South Dakota State University but involving several Augustana faculty has provided funds for 34 research students over the past five years. (There was a two-year overlap with NPURC and EPSCoR.) A primary goal of the EPSCoR grant is to build research infrastructure at institutions within the state, and primarily undergraduate institutions have intentionally been included. A result of this grant has been expanded collaborations of scientists across the state of South Dakota.

The ***BRIN grant*** has been renewed several times and provided support for 31 chemistry students since 2005. The relatively new ***SPUR*** (Sanford Program for

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Undergraduate Research) program taps the NIH-BRIN consortium for the faculty mentors and supports several Augustana faculty and students every summer, among them two or three chemistry students.

Augustana's Biology department has just been awarded an ***NSF-REU grant*** in cooperation with Sanford Research. This grant is designed to foster interest in science and in research among minority, low-income and first-generation university students. Although primarily for Biology students, those majoring in Biochemistry can also be supported. For summer of 2013, one biochemistry student was supported by the new REU grant.

Several ***endowed fellowships*** have been established by alumni:

Viste Research Fellowship supports one chemistry research student each summer.

Jane and Charles Zaloudek Faculty Research Fellowship.

Ralph and Susie Wagoner Student-Faculty Research Endowment Fund.

The ***Roland Wright Chemistry Endowment***, established to "keep Chemistry on the cutting edge," has enabled purchase of instrumentation and software. The proceeds from this endowment is $15,000-$20,000 each year. Our Dean's office has allowed us to borrow against the endowment proceeds so we can purchase instruments costing more than $20 thousand.

There were several other **unexpected opportunities**: A summer research stipend for two students was awarded by ***Evonik Chemical Corporation*** (Connecticut) in 2008. Recently (2011) our alumnus who is an Abbott Labs employee won an award which was accompanied by a $10,000 research stipend from ***Abbott Labs*** to his alma mater. Two students were supported for a summer's research effort.

***Funding to purchase equipment*:** Funding has been liberal for instrument purchase during the past 20 years. An early NSF-ILI grant allowed the purchase of a new GC-MS system. Another NSF-ILI grant supported a new GPC with Light-Scattering detector. Augustana took advantage of the NPURC grant to purchase two instruments, a Karl Fisher Titrator for water analysis and a cone and plate rheometer. A special advantage of EPSCoR for Augustana College has been the funds available for instrumentation: A new 400 MHz NMR, a fluorometer, a new GPC and two rotary evaporators have been added to the departmental repertoire. BRIN has also contributed to the department's instrument collection with a refurbished 300 MHz NMR (before EPSCoR), a UV-VIS spectrometer and later an autosampler for the new 400 MHz NMR. The Wright Endowment recently provided funds for a new GC-MS. These instruments unfortunately come with the additional requirement of an appreciable maintenance budget. We also have had to be very creative to find space for these new instruments in a building designed for only a few instruments.

How We Made It Work, the Nuts and Bolts of the Process

***Application Process*:** Applications for summer research, including student ranking of mentor preference are due in the department by March 1 of each year.

The faculty members have the chance to choose students with whom they wish to work, often based on previous research experience and the desire to spend another 10 weeks together in order to finish up details on a publication. Then by March 15, students are notified with whom they will be working. With at least one faculty member in each of the five classical areas of chemistry, students at Augustana have the opportunity to do research on a variety of topics in all areas of chemistry.

***During research*:** Not only do the individual faculty have suggestions for a research project but they spend a great deal of time in the lab with their students, teaching them the essential techniques and use of instrumentation appropriate to their particular project. The faculty has realized that research IS ALSO TEACHING! For them it is a very time and energy-consuming process. During the first two or three days of the summer research session, the students have a half-day safety workshop and formal training/review in using the basic instruments. We mimic graduate school research groups: the senior members of the research groups help train the inexperienced first-year researchers in use of specific equipment (Schlenk lines, Parr high pressure reactors or whatever is unique to the particular research group). Every Monday, all groups gather for a brown-bag lunch and a research seminar where research students learn how to communicate the essence of their projects. In the early years each student presented each week. Now with larger groups a rotation is established so each student presents at least twice during the 10 weeks. After a 10-minute presentation, the student is then questioned by his/her peers and faculty. Often experienced undergraduate researchers give positive feedback or make suggestions about how problems experienced might be overcome.

***Administrative support is not just $*:** There have been several instances where the Administration has been supportive or encouraging without spending a lot of money. A number of years ago, the Academic Dean's office made sure the faculty knew that research and resultant publications were very important to decisions on rank and tenure. Research proposals are expected and occasionally faculty members are given a bit of release time to prepare them, a good example is giving new faculty the J-term off in order to prepare and submit a research proposal. There is even a support staff in the Dean's office to assist in proposal preparation. That office also allowed the NSF-EPSCoR indirect costs to be used for supplies to support research since the EPSCoR grant has no such funding and then the Dean provided an extra $20,000 for faculty summer support.

***Creative use of space and instrument access*:** For summer research, our teaching labs are converted into research labs. Schlenk lines and hot oil baths populate nearly every hood, while dry boxes, high pressure reactors and balances live on bench tops as well. At the end of summer research many of these items must be packed away in storage until next summer. Finding space for sustaining a research effort during the academic year is an on-going problem.

***Instrument Experience*:** In order for students to be of any value as a researcher, they must begin the research experience with a good bit of knowledge about at least the rudimentary instruments. We attempt to give our students every opportunity to build expertise with every instrument we own. This is not just lip service. There is a plan to make it happen and that begins first-semester freshman year.

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***Instrument Proficiency Courses*:** These courses are designed with an independent study format so a paucity of faculty time is required. Enrollments (typically less than 10) are restricted to upper level students (Organic II or Analysis pre-requisites). The Analytical Chemistry by Open Learning Series (*9*) and a variety of computer-based training modules and online sources have been used. Typically one proficiency course is offered each semester focusing on one instrument or two related instruments (e.g., FTIR and Raman), with instructors rotated among the staff to match instrument with expertise. This one credit hour course allows students to develop a foundation in the theoretical aspects and operating principles and to gain hands-on proficiency in the operation of the featured instrument and interpretation of the data or spectra. Students are expected to spend two-three hours per week in lab working with the instrument and additional time outside lab reading background material and writing reports. A paper describing our experiences with these courses and example syllabi are has been published (*10*). In recent years increased faculty load to meet increased enrollments in courses has prevented us from continuing to offer the proficiency courses. We are trying to remedy the situation and offer these courses again.

***SMACS involvement*:** Another option for instrument proficiency comes each semester when the Student Members of the ACS (SMACS) have a pizza party followed by instrument training on several major instruments. Students can choose to join a group working with a particular instrument in which they have an interest. Obviously the depth of this instrument training is nowhere near to that of the Instrument Proficiency courses and is meant more for encouraging freshmen to join the SMACS chapter.

***Trustees' Fellowship in Chemistry*:** For a number of years we have invited freshman chemistry majors who have won a selective “Distinguished Scholars” scholarship to enroll in a one credit hour class which meets one hour per week for two semesters. In the Fall Semester we discuss career option topics such as graduate school, what is expected from applicants and how to prepare themselves for it; medical school and what is expected and how to plan to be a successful applicant; chemical engineering; forensic chemistry; dentistry; teaching chemistry; optometry; the scientific method; ethics; how to be a lab assistant and research opportunities. During the second semester, students in this course are allowed to be “junior assistants”. They receive no pay, but spend at least two hours per week observing/helping an assistant in the laboratory, learning stockroom organization and helping prepare solutions for their lab. As part of their lab duties they also receive training on one or more of the instruments.

Often students tell me they had not thought of a particular profession as an option for them, but now they are more aware and can perhaps one day do an internship that will allow them to be sure which profession to enter. At the very least, they quickly realize their academic record is being established day-one of their freshman year, not the last two or three semesters of their undergraduate careers, and they are the ones in charge of assembling the grades and experiences that will help secure acceptance to their programs of choice.In a very real sense, the freshman students who have taken advantage of theTrustees' Fellowship, and the SMACS instrument training have then prepared themselves for summer research right after the freshman year.

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Dissemination of the Research Results

The dissemination process has to begin with ***preparation***. Posters are most common for undergraduate research, so about the 8th week of the 10 week research experience each student begins preparing their research poster and poster abstract. Preparation is the iterative process to teach students the typical process for science presentations. This is another intense time for research mentors as they teach students poster fundamentals: to "tell a story," poster organization, use of pictures, equations, diagrams, spectra and graphs, readable at a distance, etc.

Again creativity is essential for generating opportunities for students to present their research results. Presentation at professional meetings is a good option but with a little effort one can manufacture other venues as well. We have regularly used the following opportunities: a number of years ago we decided to devote a significant portion of our weekly ***Departmental Seminars*** to student presentations. Students who have done research during the summer are required to make an oral presentation (PowerPoint) on their research to give them experience in this form of science communication. Again mentors work with the students to prepare good seminars with appropriate use of PowerPoint. It is good to start the seminar series each year with an experienced researcher who can "hit it out of the park" and set the bar high for all later speakers. Early on faculty met with presenters after the seminar to provide constructive feedback on the presentation. More recently schedules have become so harried that we haven't been meeting with presenters, but we a planning to return to that model.

The ***ACS Sioux Valley Section*** holds an ***Undergraduate Poster Competition*** in September of each year. The inception of this competition was the brain child of an Augustana Chemistry faculty person who worked with the Section to make it happen. Judges probe the students to determine who really knows what they have done, why they have done it and what the significance of their progress is. The winner of the competition is rewarded with funding to present his/her poster at the Spring National ACS meeting. Second and third places receive funding for presenting their posters at the Regional ACS meeting.

In the 11 years of this competition, 25 of our students' posters placed in the top three with seven taking first place. Four students have also won top places in the undergraduate poster competition at the ACS Midwest Regional meeting , interestingly not the ones who won the local competition.

Augustana Research Symposium**:** Another opportunity occurs annually in April at the Augustana Research Symposium. It is a day-long showcase of campus-wide student research. At that occasion, those who have presented posters at previous meetings are encouraged to give an oral presentation which, of course, requires them to prepare a PowerPoint presentation.

Professional meetings when possible**:** We strive to provide opportunity for all of our research students to present their work in at least one professional venue. Lab manuals for several courses have been developed and published in-house. Proceeds from the sales go to a restricted Travel Account that is used to help students get to professional meetings. Of course, grant funds are leveraged for this purpose as well.

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In recent years our primary meeting has been the *ACS Midwest Regional Meeting*. A few students each year, when results warrant, also present at the *National ACS Meeting*. Some of our colleagues also encourage students to present their work at *Council for Undergraduate Research Meetings*. Augustana Chemistry faculty have decided to focus our efforts on the ACS meetings.

BRIN students are required to present posters at the *South Dakota Academy of Science Meeting* and the BRIN grant covers travel expenses. We encourage the other research students to also present at this meeting when it is close enough to minimize travel expenses. Those who have presented their posters several times are encouraged to give oral presentations.

Publications: Of course it is hoped that the student's work will end up as a publication in an appropriate journal. We have published with student authors in a variety of journals (*1*, *11–21*), but The Journal of Undergraduate Chemistry Research has been targeted most often. Thus when they begin to apply for graduate or professional school admission, they have publications as an additional factor to be considered.

Assessment and Evaluation of the NPURC Experience

The student's knowledge about research, their motivation for participation in it and their level of awareness for opportunity to do so were evaluated before and after the research experience at all participating NPURC institutions. (Most of this comparison data came from USD, Mt. Marty College, Dordt College, Briar Cliff University as well as Augustana College.)The average response for motivation to do research from the Chem 120H students, about 6 on a scale of 1-10, was unchanged after the research experience. With regard to motivation for a career in science, the average response remained constant at 7. When the students were questioned about their change in motivation for careers in science, 37% indicated an increase, 50% remained the same and 5% reported their motivation had actually decreased.

Across all NPURC participants, students also showed an increased level of awareness for opportunities (about a 6 on a scale of 1-10) available to them for undergraduate research. On average, students felt they had learned more from the research-oriented laboratories, but the percentage that felt that way varied somewhat from year to year. The preference for a research lab was strongest in smaller sections and Honors sections. Compared with other colleges, Augustana students were quite receptive to the research oriented lab experience. About 90% of Chem 120H students had an increased motivation to do research and 78% preferred research oriented labs over the traditional authentication labs.

From these data as well as the oral reports given by the student researchers, the freshman lab experience was deemed a resounding success.

Augustana Experience

The most obvious indicator of the research culture we have established is the extent of student involvement in research and the variety of resources that has supported this endeavor. In the early 1990s, the majority of our student who participated in summer research did so at other universities as part of an NSF-REU grant. That has now made a complete turnaround where most of our students who do research will be on our campus supported by the many sources already discussed. A summary of selected data from 1991 to 2013 is presented in Table 1.

Table 1. Augustana Student Involvement in Summer Research, Selected years[a]

Year	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*Sum*
1991											6	6
1992											6	6
1993											2	2
1994											2	2
1995								4			2	6
1996								5				5
1997								6				6
1998								6				6
2005			5	1				3		1	0	10
2006	9		3	2				3			5	22
2007	6		2	3		1		3			0	16
2008	6		2	1		1	2	3			6	21
2009	6	1	0	5		1		3			8	24
2010	5	0	0	6	2	1		4			6	24
2011	6	9	0	4	5	1		2	2		5	34
2012	0	13	1	4	3	0		3			3	27
2013	0	11	1	5	2	0		3			3	25
	39	34	14	31	12	5	2	48	2	1	36	242

[a] A=NPURC, B=EPSCoR, C=ARAF, D=BRIN, E=Spur, F=Viste, G=Evonik, H=Assistant, I=Abbott, J=NASA, K=Other (this includes NSF-REU at other universities)

Another indicator of the positive impact our research culture has had on students is their increased participation in professional meetings and their success in poster competitions. Before NPURC student participation (even attendance) at professional meetings was sporadic and dependent on availability of grant funds. Since NPURC we have taken 15-25 students to the ACS Midwest Regional Meeting each year and 5-10 to the ACS National Meeting. Attendees who visit with our students about their posters are often quite surprised to learn they are undergraduates, not graduate students. A related indicator came in 2011 when

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two of our juniors were selected for the prestigious ACS SCI Scholars Summer Internship Program. These two students were among only 32 participants selected nationwide.

Continued inclusion in state-wide collaborations like EPSCoR and BRIN also indicates a respect for the quality of the research culture we have established. In-state institutions are increasingly asking us to encourage our students to attend their institutions for graduate school.

Each year the Sioux Valley Section of the ACS honors Outstanding Chemistry Seniors with awards at two levels. The top award of Outstanding Senior requires at least a 3.5 GPA; a major that includes a year of Physical Chemistry, Analytical Chemistry, Physics, and Calculus; a plan to attend graduate school in chemistry; a research experience; and service. Nominees not selected for the Outstanding award or who don't meet all the criteria (like plans for a health profession career) are given the Distinguished Graduates award. In the early years all qualified graduates were honored and the distinction between the two awards was primarily career plans. From 2005-2009, 14 Augustana seniors received the Outstanding Award and another 17 received the Distinguished award. Starting in 2010 the Section has awarded a limited number of Outstanding awards (typically four each year). Since that time seven Augustana Seniors received the Outstanding award and 11 have received the Distinguished award.

Augustana has followed the national trend with increased enrollments in science courses, but the increase in chemistry majors has been significantly greater. The number of chemistry majors since 2009 has jumped 51% from the previous five year average. Comments we hear from students tell us our research program is attracting them – they want to be involved in research.

The quality of the students we are attracting and their mastery level in Chemistry is reflected by our chemistry majors' results on the ACS Diagnostic Undergraduate Chemistry Knowledge (DUCK). In 2011, (first year we used the exam) the eight seniors who took the exam had an average percentile of 89.6 (range of 77 to 99). In 2012, the 14 graduates taking the exam averaged in the 52.1 percentile (range 3-94). For the 10 graduates taking the exam in 2013, the class average was the 66th percentile (range 12-99) percentile. One interesting observation was that of the six students who did not have a summer chemistry research experience, four of them scored below the 20th percentile and of the 26 with a summer chemistry research experience, only six scored below the 50th percentile. (Note: these data are for all our chemistry graduates, not just those involved in Honors freshman chemistry. Obviously, we are interested in raising the level of research experience for all our students. Years ago, we required every chemistry graduate to have a course in research, either during the semester or the summer. Now we are trying to encourage students to take advantage of research opportunities because they want to, not because they are required to do so. Obviously, we are not always successful.)

Another indicator is the increase in numbers of Goldwater scholars. Since NPURC we have averaged almost one recipient per year (six over the last seven years). A research experience is required for a competitive application. Our research culture makes it possible for our students to obtain multiple experiences and helps them to get the most out of each experience. Mentoring students through the application process is easier when students have had extensive research experience.

Each year the graduating seniors have individual exit interviews with the Department Chair. Several comments from these exit interviews related to their research experience. One said: “For students in advanced chemistry courses, those who have not had a research experience are at a severe disadvantage in comparison to those who have had research”. Another said: “The fact that we got first-hand experience running all the instruments in the department as well as actual research made me distinctly prepared for my future.” “I appreciate the rigorous emphasis on writing and communication skills. Departmental seminars were wonderful and I think prepared me for my future.” On a 1-5 point scale, 5 being “strongly agree,” the seniors rated at 4.11 the Chemistry Department student research seminars as a “useful experience.”

Of course, the ultimate measure of success is where they go after graduation. Recent data on the last four years shows excellent professional success (Table 2).

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Table 2. Post Augustana graduate destinations

Year	*Students*	*Ph.D.*	*M.D.*	*Pharm.*	*Industry*	*HS teach*	*Gov't*
2009	10	4	2	1	2	1	1
2010	11	7	2	2			
2011	9	7	1	1			
2012	20	9	4	1	4	2	

Summary Comments

Several factors were instrumental for establishing a research culture in Chemistry at Augustana College but NPURC provided the biggest boost. In a very real way, the impact of NPURC is still being perpetuated in the department. The very intentional manner each program fed students into summer research as well as the funding support for students, faculty, instruments, and travel to meetings for the extended period of time effected a change in student expectations for research. Indeed it has almost become a feeling of entitlement. This research culture provides excitement that carries forward to communicating with potential Chemistry or Biochemistry majors during the recruitment process.

It is indeed unplanned and almost surprising that so many components came together to establish a research culture in the chemistry department at Augustana College. Certainly that culture could have been established without ALL of these components, but absolutely essential is the excitement projected by a very organized and hard-working faculty. Also essential are students who are excited about research and work very hard to make it happen. Definitely an attitude helps the culture. Continued financial support from national and local grants is absolutely essential, and as we know, the success in obtaining support seems to be based on past successes. Administrators are excited about external grants

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because it means financial support for their faculty and students. Perhaps more importantly, they see indirect funds as a source of discretionary support.

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Notes

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Chapter 7

Introducing Chemical Research to Undergraduates: A Survey Course for Sophomores and Juniors

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The practice of chemistry research often differs considerably from the laboratory and lecture experience of lower division students. This chapter describes the successful implementation of a redesigned Introduction to Chemistry Research seminar course, deployed at Austin Peay State University, a regional primarily undergraduate institution with an ACS certified program. Using innovative and engaging activities, this course aimed to increase interest in undergraduate chemistry research and prepare students to begin a faculty mentored research project the following semester. Details regarding course content and structure, notes on implementation, and student feedback are presented.

1. Introduction

As a well-known high-impact practice, undergraduate research has been established as a powerful and valuable experience for students (*1*, *2*). However, chemical research often differs considerably from the lecture and laboratory experience of lower division students. Passive lectures and cookbook style experiments do not prepare students for the creative and logistical requirements of the research lab. As a young tenure-track faculty member at Austin Peay State University, I saw this disparity at first hand. My research students needed considerable guidance to be successful in very simple tasks like keeping a lab notebook and reading journal articles. Consulting with my colleagues showed

In Developing and Maintaining a Successful Undergraduate Research Program; Chapp, T., et al.;
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me this was not an uncommon occurrence. Some problems cited by my peers at APSU and other universities include:

- Students are unfamiliar with the research process.
- Students are not prepared to enter a research lab and work on an independent project.
- Students don't know how to access and read current literature.
- Teaching an independent study course is too time consuming.

These concerns significantly inhibited faculty interest and kept the number of students involved in research low.

In an effort to alleviate these concerns of my peer faculty and better prepare students, I retooled an existing independent study course into a seminar format designed to equip interested students with the skills needed to be successful in the chemistry research laboratory. The literature on these courses is scant. Evan T. Williams and Fitzgerald B. Bramwell from Brooklyn College published about a similar course in 1989 (*3*), and many of their goals and ideas were adopted in my redesign process. Lauren Denofrio and colleagues at the University of Illinois designed a course to help connect undergraduates to their large network of research opportunities in biology and chemistry (*4*). This Introduction to Research course adds to these initial ideas by explicitly identifying the learning outcomes, including modern literature search methods and discussion of ethics, and modeling the research process with a group project and dissemination.

In this chapter, I will describe the course design and activities, and provide some student feedback as assessment of the course's value.

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2. Course Design

Entitled "Introduction to research," Chemistry 2940 was taught as an independent study course at APSU. Faculty received a small fraction of the course credit hours as teaching load, which was very little compensation for the considerable time required to personally mentor an undergraduate. I approached my department chair in Spring 2010, with the idea of offering the class as a workshop style course with a group of students. If ten students agreed to take it, I could receive one teaching load credit. My chair agreed and the course was advertised in the Spring for a Fall section.

The student learning outcomes (Table 1) were written to appeal to a large population of students, even those not majoring in chemistry. The course catalogue description "Experiment design including methods, techniques, and information resources in a specialized area" (*5*) wasn't abandoned, but it was certainly expanded with these new outcomes.

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Table 1. Student Learning Outcomes for Introduction to Research Course

Upon successful completion of this course, students will be able to …
• Appreciate the nature and challenges of chemical research
• Understand the relationship between a research mentor and student researcher
• Search for references using SciFinder (*6*) and other library databases
• Identify reliable references and access, read, and utilize primary literature
• Obtain, read, and apply MSDS sheets for safe chemical handling
• Understand the basic requirements regarding data handling, including keeping accurate records in a lab notebook
• Appreciate the ethical and professional requirements for scientists
• Identify conflicts of interest and research misconduct
• Design and propose a research experiment related to general chemistry and/or chemical education
• Effectively communicate a research idea via written and oral presentations

These outcomes were used directly in a recruiting flyer, which was posted around the department in the Spring. Students were recruited from the General Chemistry and organic classes. Personal invitations from my peer faculty and myself were very helpful at securing a full section for Fall 2010, with 14 students enrolled. After a successful term, it was offered again in Fall 2011 for 20 students. Last taught in Fall 2012, by a different instructor, the course had 7 students.

Coordinating with the department, I chose to offer the class during the lunch hour (12:20-1:15 p.m.) on Mondays. Students were welcome to eat in class as long as they were not disruptive. As the later schedule will show, there were a variety of class activities that were facilitated by being in a classroom with moveable seating.

The grading for the one-credit hour course is summarized in Table 2. Attendance was recorded each day, but one free absence was allowed. Students were given one overall participation grade. Written assignments described in more detail below were primarily for reflection and primarily graded for completion. Due at the beginning of the next class period, only the ten scores were counted toward the final grade.

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Table 2. Grading Scheme from Syllabus

Method	*Number*	*Value*	*Total*
Assignments	11	30	300
Group Project Presentation	1	50	50
Group Project Written Summary	1	50	50
Attendance	15	3	45
Participation	1	55	55
TOTAL			**500**

3. Classroom Activities

The redesigned course includes lecture, discussion, a group project, and student presentations. In this section, I present a description of each activity, the corresponding assignments, and the suggestions for implementation. Table 3 shows the Course Schedule from the Syllabus.

Table 3. Course Schedule

Class	*Activity*	*Written Assignment*
1	Syllabus and introductions	✍ What is research?
2	The Making of a Scientist, Pt.1	✍
3	The Making of a Scientist, Pt.2	✍
4	Working with a mentor	✍
5	Primary Literature and SciFinder	Reading *Science*
6	Lab Logistics (Data, Safety, and more)	✍ MSDS assignment
7	Ethics and Professionalism	✍
8	Communication and Dissemination	✍ Find an REU
9	Group Project - Work Day 1	
10	Group Project - Work Day 2	
11	Group Presentations	✍ Summary of group project
12	Chemistry faculty presentations	✍
13	Future problems in chemistry and final discussion	✍

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3.1. What Is Research?

Undergraduates rarely have a firm grasp on the scholarly process. This first day activity aimed to stimulate discussion and reveal the complexity of being a researcher. Students were each give a quote about research printed on a half sheet of card stock. Each quote was repeated three times in the class and the students were instructed to find the others who had the same quote. Examples of the quotes used include:

> *"Research is what I'm doing when I don't know what I'm doing." - Wernher Von Braun (German-American rocket scientist, 1912–1977)* (*7*)

> *"Paintings are but research and experiment. I never do a painting as a work of art. All of them are researches. I search constantly and there is a logical sequence in all this research." - Pablo Picasso (Spanish painter, co-founder of the Cubist movement, 1881–1973)* (*8*)

> *"How wonderful that we have met with a paradox. Now we have some hope of making progress." - Niels Bohr (Danish physicist, 1922 Nobel Prize in Physics, 1885–1962)* (*9*)

Serving as both an icebreaker and a conversation-starter, the groups discussed the quotes, then shared with the class on how they related to the question "What is research?" This activity is very interesting and gets students talking. Many were surprised by how broad and uncertain the research process can be. The class concluded by assigning a one-page paper in which each student was asked to answer the question "What is research?"

3.2. The Making of a Scientist

In the second and third classes of the semester, the PBS Video production *Naturally Obsessed: The Making of a Scientist* was shown (*10*). Directed by Richard Rifkind and Carole Rifkind, this short documentary tells the story of three graduate students working in Lawrence Shapiro's molecular biology lab at Columbia University. I showed the film over two days to allow for discussion, pausing after there is a significant set-back in the experiments. I asked the students to write what they think will happen and how they would feel about the disappointment they witnessed. In the third class, we watched the conclusion of the film and then divided into groups for discussion. I provided prompts for this last discussion.

Each time I have shown this video, the students had a range of responses. Some were excited by the ideas and the possibility of discovering something new. Many were sympathetic with the students who are struggling. Each semester, at least one was immediately turned off by the reality that there is no guaranteed success in research; failure is always an option. This video shows that reality in a very real and personal way, from a student's perspective. The third class

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concluded with another writing assignment, in which the students wrote about what new perspectives they learned from the film.

3.3. Working with a Mentor

After spending two weeks watching students interact with Professor Shapiro in *Naturally Obsessed*, the next class period began with asking the class to define the term mentor and identify characteristics of a good mentor. Then I presented a lecture presentation in which the relationship between a mentor and student is given some framework. Students often assumed they should relate to the mentor in the same way they would to a professor they have for a class. Ideally, the mentor-mentee relationship is on a more even level than the teacher-student relationship. In this class, I provided some insight into what a mentor will expect and what students will be asked to do, including a lot of independent work. I also shared with them the importance of open and clear communication. Research is a frustrating process and I challenged them to be honest with their mentors when they are struggling. Finally, I shared the positive stories of how I have built lasting connections with my mentors and mentees over the years. As an aside, the Council on Undergraduate Research has printed a great handbook for new faculty "*How to mentor undergraduate researchers"* on this subject (*11*). I used it as a resource when developing the material for this class.

3.4. Primary Literature and SciFinder

Chemical literature can be very intimidating for undergraduates, so the purpose of this class was to expose students to journal articles and teach them how to use scientific databases, such as SciFinder (*6*). In preparation for this class, I had previously distributed a print copy of *Science* to each student with instructions to find one article about which they were curious in preparation for this class. We met in a library computer lab with a reference librarian; the class was given a short presentation on searching for articles, and then began an assignment in class. They used the databases to find five articles referenced in their *Science* issue and then wrote brief synopses of how the referenced papers related to the article.

3.5. Lab Logistics

This class period covered basics such as using Material Safety Data Sheets (MSDS), hazardous waste disposal, and keeping a lab notebook. I also presented departmental policies regarding work in research labs. A short worksheet was distributed as homework; each student was given a random compound and asked to look up a MSDS and complete a series of questions. Many students had never before used an MSDS and did not know about personal protective equipment beyond the goggles required for General Chemistry.

3.6. Ethics and Professionalism

Faculty mentors expect student researchers will behave in an ethical fashion. Becoming a researcher in a faculty member's lab is a professional pursuit and should be respected as such. In this class, I presented The Chemical Professional's Code of Conduct (*12*) established by the American Chemical Society and discuss how it relates to students conducting undergraduate researcher.

We also discussed the general concept of ethical problem solving. The students formed groups and were given one of four case studies to read, discuss, and propose a solution. The class concluded with each group reporting to their peers about the solution they devised.

3.7. Communication and Dissemination

Oral and written communication are important components of scientific research. This class presented the types of dissemination common to chemists, including posters, talks, and written articles. I discussed the pros and cons of each type of presentation as well as how they are differently valued.

This class ended with a brief discussion of summer research opportunities, such as those funded by NSF-REU. I recall the class being surprised that they could travel and be paid to do research somewhere for the summer. For their homework, the students were tasked with finding a summer research opportunity to which they were interested in applying.

3.8. Group Project and Presentations

The final project of this class was designed to mimic the actual research process. The students worked in pairs; they were allowed two working weeks in class and the third week they gave a presentation of their project. From the syllabus:

> *A presentation will be developed as a group project by the members of this class. You may use any multimedia device available during your group presentation. One purpose of the presentation is to give you more experience with public speaking and oral communication skills. Each member of the group will be evaluated by the other members of the group, the members of the audience and by the instructor.*

The groups were given a list of General or Organic Chemistry experiments and asked to design a follow-up question and design an experiment to answer it. They could also chose a topic from one of their classes which did not have a specific laboratory experiment connected to it. The teams presented their proposal for the project in a 10-minute oral presentation and submitted a short paper.

For example, one group used a freezing point depression experiment to ask how other salts might change the temperature. Rather than just studying sucrose and sodium chloride as in the existing experiment, the students suggested using calcium chloride and aluminum chloride, which each have different van't Hoff

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factors. The students proposed a series of experiments that would use the technique they previously learned to study the effects of these other salts on the colligative property. Another example project came from two juniors who had struggled to understand optical isomers in organic chemistry. They designed an in-class activity using a modeling application to explore R vs. S isomers.

While not truly original research in the strictest sense, the idea behind this group project was to encourage students to ask questions and strategically think about how they would go about reaching an answer. In each example, the students took the role of the principle investigator. They were evaluated on their good-faith effort to propose a reasonable plan and their oral and written communication skills. Each member of the pair received the same grade for the project.

3.9. Chemistry Faculty Presentations, Future Problems in Chemistry, Final Discussion

In the final class periods, I invited my peer faculty to present a few of their research interests to the class. This was a direct recruiting opportunity and some productive partnerships resulted. I also encouraged the students to get involved with the student chapter of ACS and be curious about current and future problems in chemistry. I shared my own enthusiasm for research and communicated that, though frustrating at times, it is worth the effort!

4. Student Perspectives

The student response to this course was quite positive. Table 4 shows select student evaluation data from the first time the course was taught in Fall 2010. Rated on a Likert scale, the average ratings were all over 5, where 6 was the maximum.

Table 4. Select student evaluation data (n=12) from Fall 2010 using a 6-point Likert scale, ranging from Excellent (6) to Very Poor (1).

Evaluation Item	*Average Rating*	*Standard Deviation*
The course as a whole was:	5.5	0.9
The course content was:	5.4	0.8
The instructor's contribution was:	5.8	0.5
Relevance and usefulness of course content are:	5.4	0.9
Reasonableness of assigned work was:	5.5	0.8
Clarity of student responsibilities and requirements was:	5.6	0.7

In addition, the students' written comments were also very encouraging regarding the value of the course. Sample comments included:

- *"This is an excellent class for those thinking about doing research."*
- *"Very well-organized and well-thought course with lots of different material that appeals to many disciplines in chemistry."*
- *"I wasn't sure what to expect with this course but I found it incredibly relevant & educational. I am applying to a handful of REU's for summer & writing a PRS all because this course introduced & prepared me for research."*
- *"This class was a great taste of what research is… I leave it with the desire of more."*

A junior in the first iteration of the course, Ms. Kathryn White, is now pursuing a Ph.D. at George Washington University. When I contacted her in 2012, she provided this valuable perspective two years after taking the course:

> *"The intro to chemistry research course truly opened my eyes to the world of research. I was able to see that research is not only a practice but a sort of philosophy. Before, research seemed like a lofty ambition. Now look! It will be my life for at least the next five years!"*

While only a fraction of students chose to pursue undergraduate research (approximately 50% each time), these written comments and student evaluations are indicative of a successful implementation and the course's perceived value.

5. Conclusions

This revised course provides an introduction to chemical research and creates a helpful bridge for students at APSU from classroom to scholarly activity. This course benefits faculty by producing students more prepared for independent research. Teaching the material as a seminar created a low-pressure environment and the content humanized the research process. Depending upon the needs of the department and the student population, the course can be easily customized.

Future implementation of this research course would benefit by including preliminary and post surveys of the student participants. These instruments may assess the course's impact on student perception of and interest in research. Also, it would be helpful to track the number of students who do indeed pursue an independently mentored research experience with a faculty member after completing the course. Longitudinally, connections to career path and post-graduation plans could be studied with an accessible alumni population. Assessment of this course and its impact will help justify the investment of time and energy required for implementation.

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Chapter 8

Just-in-Time Approach to Undergraduate Biochemistry Research

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Experimental science follows convoluted pathways that depend on extensive dialogue with the scientific community. For an undergraduate, navigating the entry into and successful completion of a research project is often daunting and seemingly intractable. The integration of inquiry-based courses and laboratories has facilitated the transition from the classroom to the research group. These experiences have numerous benefits yet suffer from many complications in the case of interdisciplinary projects. Specifically, a large portion of an interdisciplinary preparation centers on introductory courses. Thus, idea integration occurs toward the end of a student's education. The long-term gains of experimental science are lost if a student or mentor waits for a successful introduction into each contributing discipline. This chapter proposes a three-stage model that integrates comprehensive mentoring and Just-in-Time teaching to manage the challenges of undergraduate interdisciplinary projects.

Introduction

The process of science follows a non-linear and repetitive pathway (*1*, *2*). This process can be broken down into five essential components: hypothesis development, experimentation, interpretation, engaging the scientific community, and production of research outcomes (*1*, *3*). Most scientists learn how to successfully navigate the intricacies of research by actively participating in laboratory inquiries for many years (*4*–*6*). However, an undergraduate student's

In Developing and Maintaining a Successful Undergraduate Research Program; Chapp, T., et al.;
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first authentic experience is often daunting and typical obstacles may be perceived to be insurmountable. The incorporation of inquiry-based courses and early involvement in undergraduate research allows students to “bridge the gap between the textbook and the ever changing scientific process” (*7*). These curricular adjustments have noteworthy academic and personal advantages yet have encountered several obstacles for interdisciplinary programs (*3*, *5*, *8–16*). Fluency in multiple disciplines or sub-disciplines is an increasing requirement in the job market as well as for granting agencies (*13*, *17*, *18*). For example, biochemistry research merges general chemistry, organic chemistry, physics, and biology fundamental principles to increase our knowledge of living systems and the metabolic pathways associated with them. The long-term benefits of research are lost if a student or mentor waits for the achievement of basic knowledge in all four disciplines mentioned above. This chapter proposes an adaptable model for managing the challenges of biochemistry research at the undergraduate level. This model is a result of several years of personal observations and discussions with biochemistry colleagues.

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The Benefits of Incorporating Both Inquiry-Based Courses and Research in Undergraduate Curriculums

The Misconceptions and Realities of Practicing Science

The underlying goal of any science course, whether it is biology, psychology, physics, or chemistry, is to give students a glimpse into how scientist perform and think about science (*1*). Instructors typically utilize textbooks as their main source of reference to initially convey and discuss fundamental skills and knowledge (*5*, *7*). For example, all general chemistry or introductory science course books will enthusiastically describe the process of science, in the first chapter, by outlining the main components of scientific thought. The scientific method is defined as a linear, yet dynamic, process with five to eight crucial steps:

Observation→Hypothesis→Results→Revisions→Theory→Prediction Testing

Students are instructed that the process begins with the identification or observation of a phenomenon. A hypothesis is constructed based on our current understanding of various systems as well as our "intuition" (*1*). A scientist will propose a research plan to prove or refine a hypothesis and develop a theory, based on the interpretation of data that explains the original observation. Lastly, further experiments are performed to refine a model or theory. The linear format found in all textbooks and online resources centers on obtaining a finite answer or model for an identified problem. In reality, this linear format of thought is far from the truth (*1*). Scientific research is disordered, lacks consensus, involves countless dialogues, and raises more questions about a phenomenon or system (*2*, *3*, *7*, *10*). Science is not an individual venture, it involves a community of scientists as illustrated by the Wiegant, Scager, and Boonstra course study (*7*). Thus, this oversimplification of the scientific method grossly misrepresents the current state of science to our students.

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The process of experimental science is non-linear and repetitive, as seen in Figure 1 (*1*). Similar to the protein folding funnel (*19*), it has an infinite number of pathways that can be followed in the ultimate pursuit of knowledge and the appreciation of the world around us (Figure 1). A scientist may even return to his or her original query to understand more profoundly a system or occurrence (*1*). Scientific progress can still be broken down into five essential components: hypothesis development, experimentation, interpretation, engaging the scientific community, and production of research outcome. These elements are connected and are in a symbiotic relationship (Figure 1). They can be accessed in different orders and revisited several times (*1*). An authentic analysis of a hypothesis is not solely reliant on making observations and revising an idea but also dependent on the ability to retrieve and critically analyze previous and current research as well as the ability to communicate these ideas to colleagues. It is our community that aids in maintaining the integrity of science and evaluating the validity of developed hypotheses. Colleagues and collaborators also shed new light on problems that can have profound implications on policies and new technologies (*1*). Experimental scientists learn to navigate various possible pathways by taking part in research for many years, as eloquently noted by Chopin (*2*, *4*, *5*, *7*). However, this process is often intimidating and seemingly intractable for a novice student. The publication of the Hackett, Croissant, and Schneider study on the positive effects of undergraduate research has inspired many discussions over the last two decades that center on how to best prepare students for the realities of science (*3*, *5*, *10*, *13–16*, *20*). These dialogues have subsequently fueled an education revolution.

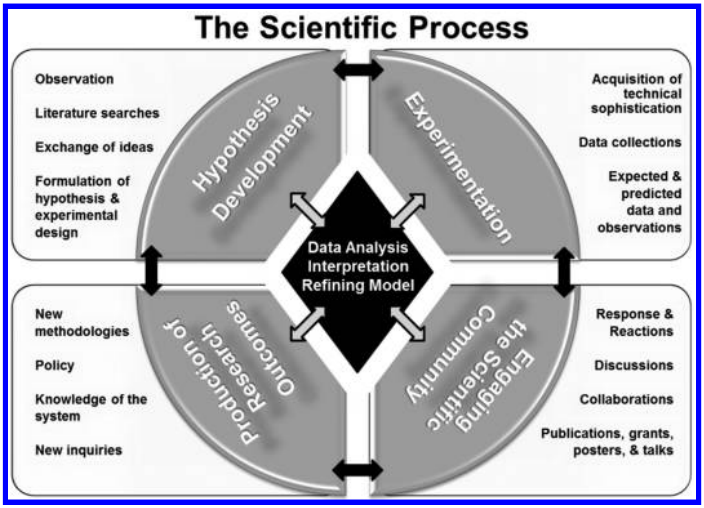

Figure 1. A model of the scientific process. The model has five essential components: hypothesis development, experimentation, interpretation, engaging the scientific community, and production of research outcomes. Data analysis is central to the model since the remaining modules all affect the process of data analysis and interpretation. All five elements are interdependent resulting in a circular model with many possible paths (1).

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The Rejuvenation of Science Instruction in Higher Education

Students' first experience with college science courses normally begins in the classroom (*2*). The traditional classroom is the principal method educators utilize to convey fundamental principles of science. Information is disseminated in neatly organized and easily digestible modules, which summarize models and concepts that represent the consensus of the scientific community (*2*, *7*). Learning assignments and activities are also judiciously designed to follow a predetermined layout set forth by the selected reference textbook (*5*, *21*). The laboratory component of the course often can be classified as students following a "cookbook-style recipe" in which detailed laboratory protocols yield predetermined or expected outcomes (*5*). These experiments do not require modifications or repetitions. As Bligh's examination suggests, classrooms, textbooks, and laboratories have limited yet important roles in education (*21*, *22*). They facilitate the learning of basic academic and technical skills needed in the later stages of a scientific career. As alluded to above, the goal of a well-balanced science curriculum is to give students a glimpse into how science is done and how it connects to the world in which we live. Current research involves the design of protocols, communication, collaborations, debates, and creativity (*1*). The traditional format of a classroom and laboratories cannot mirror the realities of science (*23*, *24*). Since the truest form of learning about the process of science is by participating in an authentic research experience, Boyer (*18*), Bio2010 (*25*), AACU (*26*), the Teagle report from ASBMB (*27*), and CUR (*28*) have uniformly rallied science departments to include inquiry-based courses and research in all undergraduate curriculums (*15*). Inquiry-based courses and undergraduate research allow students to "bridge the gap between the textbook and the scientific process" (*7*). Hmelo-Silver, Dewey, and Kolodner noted that these modifications in education enable movement from passively accepting to critically evaluating the authenticity of information (*5*, *7*, *29–31*).

Inquiry-based courses incorporate student-centered team projects that help develop critical thinking and problem-solving skills by mirroring the scientific process summarized in Figure 1 (*5*, *7*, *11*, *12*, *24*). Successful project development and integration depends on the knowledge-base of students as well as the content and available resources of the course. Over the last several years, two inquiry models that emphasize intense student engagement have gained popularity: problem-based inquiry and research-based inquiry courses (*7*, *11*, *32–35*).

- *Problem-based inquiry:* Projects or courses in which faculty and peer mentors guide a team of students through the scientific process with the goal of obtaining a known outcome (*11*, *32*, *33*, *35*). This model seems most appropriate for introductory science courses where discipline proficiency is limited.
- *Research-based inquiry:* Projects or courses in which faculty and peer mentors guide a team of students through the scientific process with the goal of obtaining an outcome unknown to both mentors and students (*11*, *33*, *34*). This model is better suited for advanced science courses where students have a good grasp of fundamental principles.

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Weaver, Russell, and Wink argue that both inquiry models afford students the opportunity to evaluate and produce ideas (*36*). Specifically, participating students are assigned a project in which they learn to apply their scientific knowledge, critically evaluate current research, mediate debates, and outline strategies to test their model(s) (*5*). Each team, subsequently, writes, presents, and defends their methodologies to other participating groups (*7*). Faculty and peer mentors are considered contributing members of the team. Specifically, they can mediate discussion and provide assistance. Weigant, Scager, and Boonstra have previously described seven self-reported academic and personal gains from a one-semester research-based course (*7*). Students indicated an increase in content comprehension, critical thinking skills, the ability to retrieve and evaluate essential information, understanding of the scientific process, appreciation of experiment complexities, efficient collaborations, and the ability to develop and communicate ideas to peers (*7*). The biggest hurdle students faced in the Weigant, Scager, and Boonstra study was transitioning from reading textbooks to engaging with primary literature (*7*). Studies, such as the Michigan State University research assessment, indicate that a positive and effective student-mentor relationship facilitates the leap into primary research literature (*7*, *12*, *37*, *38*). The Weigant, Scager, and Boonstra course evaluation showed inquiry-based courses and mentored teams are ideally suited to prepare students for undergraduate research as well as to expose a larger number of students to how science is done and how it connects to the world in which we live (*7*). One unfortunate drawback of problem-based or research-based courses is the inherent time restrictions a semester or a quarter places on the scope of the class. As a result, organizations such as ASBMB and CUR suggest the incorporation of both student-centered inquiry course as well as undergraduate research (*27*, *28*).

Many studies and reports have strongly recommended awarding undergraduate students access to authentic scientific investigation (*10*, *18*, *25–28*, *39*). Discussions led by Hunter, Laursen, and Seymour acknowledge that the outcomes of such opportunities are exceedingly reliant on the quality of the faculty mentor's commitment and guidance (*12*, *37*, *40*); nevertheless, Lopatto noted that research can achieve broader goals and impart greater breadth and depth of knowledge than traditional or innovative classroom teaching models similar to those described above (*9*). Specifically, the immersion of students in a laboratory is the only means of experiencing the realities of science plus obtaining the skills needed for a "knowledge-based" field of study (*13*). Models of undergraduate research vary drastically and are highly dependent on discipline, number of majors/minors, and available resources. Various institutions and programs, however, have independently developed similar unifying goals. Advocates such as Project Kaleidoscope have carefully reviewed these objectives and identified common yet important components of successfully implemented and maintained undergraduate scientific investigations (*10*, *12*, *28*, *41–43*):

- Discovering/synthesizing primary literature;
- Enhancing knowledge of science;
- Student-formulated experimental design;
- Independence;

- Production of reliable results; and
- Presentation and defense of results and conclusions.

Surveys and interviews administered during studies or program evaluations from various institutions have thoroughly assessed the effectiveness of the above aims (*2*). Table I summarizes the outcomes of these assessments in the form of self-reported academic and personal benefits. For example, presentation of design and results to peers or at conferences allows students to directly appreciate how the scientific community can affect the subsequent progress of a project (Figure 1) (*41*, *42*, *44*). Mabrouck and Peters noted that 20% of active research students listed attending a scientific conference as most influential (*45*). Several studies have also illustrated that research should not occur just once in a student's undergraduate career (*13*, *38*, *46*). Fechheimer, Webber, and Kleiber reported enhancements of GPAs and academic/personal skills in participants who have completed more than two semesters or summers of research, strongly suggesting that independent investigation should begin early in a student's education (*15*). Experienced students can additionally step into leadership and mentoring roles within a team/group as reinforced by Detweiler-Bedell (*47*, *48*). Student mentors report greater academic and personal gains compared to their research counterparts (*10*, *24*, *49*, *50*). Thus, students afforded the opportunity of partaking early and often in authentic laboratory projects obtain highly sought-after skills that are applicable in other non-science professions (Table I).

Every discipline that depends on the process of scientific thought (outlined in Figure 1) will come upon several complications. Projects can be challenging, fail, or change directions regardless of careful planning and hard work (*3*). These encounters are typically not off-putting to an experienced researcher, while seemingly daunting and insurmountable for an undergraduate student. A brief summary of previously self-reported challenges, confronted by students during their first genuine laboratory experience, can be found in Table II (*3*, *4*, *38*, *46*, *50*). During several studies and program evaluations, students indicated their mentoring relationships, both faculty and peer, affected the degree of academic and personal gain (Table I) as well as aided in overcoming the challenges outlined in Table II (*5*, *12*, *37*, *38*, *56*). These accounts illustrate the importance of a productive student-mentor relationship (*57*). The research mentor is called upon to not only impart his or her intellectual knowledge, but to also relate his or her laboratory experiences, expertise, and wisdom (*14*). A meaningful interaction can and often does involve instruction on the theory and practicality of techniques, feedback on experimental analysis, clarifying research content, maintaining on-task behavior, designing control experiments, and learning the art of troubleshooting a procedure or instrumentation issues. In addition, peer mentors help emphasize laboratory practices and team expectations in addition to serving as role models in demonstrating success in science as noted by Detweiler-Bedell (*10*, *24*, *47–50*). For example, many students in my research team struggle with balancing student life and research. This issue forces mentors to also act in the capacity of a "life coach." I often help students prioritize their responsibilities and come to the realization that their research does not have a

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fixed time slot. Students learn to alter their work schedule around exams or conferences yet still hold themselves accountable for experimental goals. Peer mentors often guide discussions on proper time management, during weekly meetings, to help other student ensure they can meet their academic goals. The task of alleviating the stresses of research, however, does not solely rest on the shoulders of the research advisor or peer mentor. Inquiry-based learning should be incorporated throughout a departmental program to achieve a well-balanced curriculum that continually reinforces fundamental principles and the skills necessary to be successful in research as indicated by ASBMB and CUR (*13*, *27*, *28*, *58*). One such program architecture is reviewed in the subsequent section. However, implementation of both inquiry- and research-based learning within a curriculum varies drastically and is highly dependent on field of study, number of majors/minors, and available resources. Reviews of alternative curriculums and courses are, thus, beyond the scope of this chapter and are thoroughly examined and assessed elsewhere (*59–79*).

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Allegheny College Chemistry Curriculum: A Model for the Incorporation of Student-Centered Inquiry and Undergraduate Research

Allegheny College is a private liberal arts institution founded in 1815 and located two hours north of Pittsburgh, PA. Allegheny ranks in the top 5% of schools whose graduates go on to earn Ph.D.s in all fields, in the top 4% in the science disciplines, and in the top 2% for producing chemistry Ph.D.s (WebCASPAR) (*80–82*). Because of this strong record, we are one of a select group of institutions included in Peterson's Top Colleges for Science (*83*). These achievements in mentoring undergraduates are made possible by Allegheny's research-active faculty who are committed to student collaborative research. As a result, many Allegheny faculty have been awarded PUI-NSF grants on topics ranging from Collisional Magmatism in South-Central Alaska to Photoinduced Gliding of Azo Dye-Doped Nematics on Polymer Surfaces (*84*). Our institution fosters undergraduate research by encouraging freshman and sophomore students to participate in authentic laboratory experiences and by financially supporting on-campus summer internships. Allegheny College is one of only a few liberal arts colleges that require a senior research project and/or original creative work from all graduates. Thus, faculty members work closely with students to conceptualize a project hypothesis as well as to develop appropriate and scientifically significant inquiries. Our students typically produce a thesis and defend it before a diverse panel of professors, similar to the model used in most science graduate schools. As a result of such commitment, students have attended national conferences and served as co-authors in high-impact journals such as *Biochemistry*, *Journal of Physical Chemistry B*, *Journal of the American Chemical Society*, *Journal of Organic Chemistry*, *Nucleic Acids Research*, *Developmental Cell*, *RNA*, *RNA Biology*, and the *Journal of Biological Chemistry* (*85*, *86*).

Table I. A summary of self-reported benefits of undergraduate science research

Benefits and Improvement	
Increased academic skills	*Increased personal skills*
Understanding primary literature	Relationship with faculty and peer mentors
Problem solving	Perception of science community
Communication (presentation/ writing)	Appreciation of the process of science
Critical thinking	Clarifying career goals
Technical expertise	Tolerance for obstacles
Knowledge	Independence/Responsibility
Interpretation of results	Thoroughness
Statistical analysis of data	Confidence/Perseverance
Integration of course material	Patience
Retention of fundamental principles	Leadership
Engagement in field of study	Diversity
Finding collaborations	Managing collaborations
Note: listed outcomes originate from surveys, interviews, and focus groups administered during a study or program evaluation (*2–6*, *8*, *10*, *12*, *13*, *15*, *37–39*, *41*, *42*, *44*, *51–55*).	

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The success of Allegheny's undergraduate research projects centers on the flexibility of each discipline's curriculum. For example, chemistry courses are populated by a diverse set of students. Several chemistry classes are pre-requisites for many core courses in the natural sciences and for entrance to graduate or professional school. Approximately half of the chemistry majors enroll in graduate school, while other students pursue employment or health-related careers (*81*). Several program evaluations were devoted to understanding how to better serve the majority of these students as well as our chemistry majors (*81*). As a result, the chemistry curriculum focuses not only on developing and preparing chemistry students for graduate school but also strives to instill the habit of scientific thought in all students studying chemistry. In order to accomplish such goals, the program has been and continues to be modified to ensure flexibility, adequate coverage of a rapidly expanding knowledge base, incorporation of interdisciplinary requirements, and authentic laboratory experiences. Often science courses disconnect conceptual classroom learning from in-lab experiential learning (*13*). Our program evaluation illustrated that this separation forces students to make their own connections with the material without having the fundamental skills to accomplish the task successfully (*81*). Thus, the curriculum was altered to ensure that all lecture components are heavily tied to the laboratory. Senior-level laboratories were also eliminated to accommodate advanced research-based electives as well as a two-semester senior thesis (*59*). These modifications and alterations allow students to experience the long-term academic and personal gains of research.

The chemistry curriculum begins preparing students to understand the process of science their first year of college and gradually culminates in a year-long senior research experience. In foundation courses, such as Introduction to Chemistry I and II, students participate in weekly experiments that alternate between “cookbook-style recipes” and problem-based inquiry experiments. Instructors utilize detailed experimental procedures to familiarize the students with proper material handling, operation of instrumentation, and data analysis. In the following week, students are expected to apply their knowledge and design an experimental procedure to answer a question posed by the instructor. For example, students learn to handle samples, use volumetric glassware and analytical balances, collect data, make observations, statistically analyze results, and understand characteristic chemical properties of liquids and metals during our instructor-guided density experiment. Laboratory teams are subsequently challenged with a problem-based exercise (see example below) that augments the learned techniques and chemical properties.

> *Example Case Study:* In the plastics industry, many of the material’s properties are dependent on the amount of crystalline (ordered solid) and amorphous (disordered “liquid”) polymer within the sample. It is, therefore, important to know what percentage of the polymer sample is crystalline and what percentage is amorphous to predict the product properties. As one can imagine, the density of amorphous and crystalline portions of a polymer sample are different. Your team has been hired by the Carson Chiruks Toy Company to conduct density tests on a set of common polymer samples to determine the percent of crystallinity. Carson Chiruks Toys is looking to use one of these polymers for a new self-propelled vehicle for toddlers. It is imperative that these measurements are accurate and precise to ensure that the material will have the proper mechanical and optical properties for vehicle safety (*87*).

This query requires the design of an investigation and defense of derived conclusion to a panel. Teams work independently and with a student mentor to propose a detailed experiment addressing assigned case studies. Proposals are discussed and approved, in class, prior to execution. Thus, our general chemistry series models the Center for Authentic Science Practice in Education (CASPiE) modules (*66*, *88*). CASPiE modules encourage students toward scientific careers as well as to join a research team within their first year of college (*66*, *88*, *89*). In addition, the general chemistry lecture component also offers problem-based team activities. Each group is tasked to resolve a multi-concept question or case study using the fundamental knowledge acquired in the course. An illustration of such an inquiry involves the determination of the

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cocaine mass needed to decompose into methylbenzoate to reach the narcotic dog detection limit of 50 ppb. Members of the team discuss their problem-solving strategies and, on certain occasions, defend their findings and strategies to the class. Curriculum core courses (e.g., organic, inorganic, biochemistry, and physical chemistry) also refine and reinforce the fundamental skills needed to navigate the process of science while introducing new sub-disciplines. These classes progressively increase the number of group/team centered case studies and problem-based laboratory inquiries. Specifically, the Organic II laboratory course encompasses multi-week independent projects that follow a three-week introduction to advanced laboratory techniques. The methodologies reviewed include flash column chromatography, micro-scale synthesis, solid phase synthesis, management of air/water sensitive compounds, and recrystallization. Subsequent team projects are less directed and focus on designing an experimental plan to efficiently synthesize oxazolidinone, a moiety found within the anti-fungal Callipeltin A, as well as to improve the chemical synthesis of DNA. The above team projects are designed in a fashion similar to that of the Hollenbeck, Wixson, Geske, Dodge, Tseng, Clauss, and Blackwell organic synthesis laboratory (*77*). Our biochemistry course also strives to instill the habit of scientific thought as well as prepare students for their career aspirations. The laboratory component involves numerous group/team centered case studies and inquiries modeled after the Knutson, Smith, Wallert, and Provost research-based biochemistry laboratory series (*11*, *90*). These projects merge biology, chemistry, physics, and mathematics to increase our knowledge of living systems. Specifically, a team utilizes molecular biology techniques to isolate a target protein that is, subsequently, characterized structurally, kinetically, and thermodynamically to better understand the structure-function relationship. The protein structure and folding inquiry, for example, highlights ligand-mediated conformational changes that activate catalytic amino acids. Through bioinformatics, limited-proteolysis, and thermo-fluor analysis in the presence and absence of various ligands, students can probe various research-based questions that center on substrate specificity and chemical rate enhancements. Thus, the above-mentioned courses continually utilize authentic learning exercises that promote active participation and model the true nature of the scientific process (*30*, *33*, *91*).

Chemistry majors also complete three seminar courses (sophomore seminar, junior seminar, and advanced topics), which afford the opportunity to explore primary literature and advanced laboratory techniques in the context of research-based problems (*7*). These seminars serve to bridge the gap between textbook knowledge and the scientific process by increasing proficiency in current chemical research and facilitating the identification of scientifically relevant questions (*7*). Student are mentored in proposal design and defense similar to the Weigant, Scager, and Boonstra one-semester advanced cell biology course, by contacting appropriate investigators and discussing team objectives in and out of the classroom (*7*). As our majors become more versed in chemical research, they are given the opportunity to experimentally test their inferences and postulations. Students often complete the majority of their fundamental, core, and seminar courses by their junior year, allowing them to focus on their final undergraduate chemistry milestone, a senior thesis. The specific goals for the senior project includes exposing students to scientifically relevant research in chemistry, developing well-defined questions, and engaging in multi-dimensional investigations. Senior projects span two semesters and have the following components:

- *First semester goals:* Independently identify a scientific problem, acquire needed background and technical expertise to address the problem, design a research plan, resolve any data-acquisition problems, and defend proposed project to a diverse scientific panel.
- *Second semester goals:* Collect data, interpret results, present findings to research counterparts, refine hypothesis, refine analysis, and defend conclusions and outcomes to a diverse scientific panel.

Many pivotal studies that gauge the effectiveness of undergraduate research as well as problem- and research-inquiry courses solely rely on student-perceived gains (*2–6*, *8*, *10*, *12*, *13*, *15*, *37–39*, *41*, *42*, *44*, *51–55*). Fechheimer, Webber, and Kleiber, however, argued that quantitative measures are needed to determine the true impact of education-based innovations on academic growth (*15*). Thus, chemistry senior projects are quantitatively assessed based on three criteria: written proposal, panel presentation, and academic maturity (concept integration, contribution to experimental design, and technical sophistication). Each benchmark is evaluated before and after completion of the senior thesis, by a designated scientific panel. A five-point Likert scale ranging from 0 to 4 (poor to excellent) was utilized due to the ease of comparison with a four-point grading scale. An examination of the mean scores prior to thesis completion, from 2003 to 2013, clearly demonstrates that an inquiry-intensive curriculum properly prepares students for an independent senior project ($\text{Mean}_{,\text{before}}$, Table III). Additionally, a 6% increase in conceptual understanding and a 10% increase in experimental design ability were observed upon completion of the senior thesis (Table III). The level of academic maturity observed from our two-semester senior project correlates well with the academic growth measured in the Fechheimer, Webber, and Kleiber study (*15*). In addition, the final assessment determined by our diverse panel of scientists mirrors the student-derived scores, within the Lopatto study, for literature knowledge, laboratory technique, and independence (*10*). The impact of the chemistry senior capstone was also investigated through a Teagle Foundation grant (*92*). Reported Teagle outcomes, for chemistry, mirrors our assessment scores summarized in Table III as well as yielding student-reported benefits similar to those seen in Table I. Furthermore, the incorporation of a flexible and inquiry-intense program has resulted in a 12% increase in retention of majors (*81*). This enhanced retention is analogous to the 12% increase in career affirmation detected in the Seymour, Hunter, Laursen, and DeAntoni study (*41*). These comparisons illustrate that both survey- and quantitative-based studies that monitor the outcomes and impacts of research on education provide converging evidence as to its true benefits. Thus, the realities of the scientific process, outlined in Figure 1, are deeply integrated into the entire chemistry program to prepare majors for the challenges and expectations of an independent research project.

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Table II. A summary of self-reported challenges of undergraduate science research

Research Challenges
Transition between learning about and doing research
Balancing research with academic/social responsibilities
Inherent challenges
Tedious
Encountering failure/demoralization
Longer-than-expected time commitments
Multi-draft models of communication (presentation/written)
Unclear project
A lack of a specific conclusion
Technical experience
Project redirection
Intimidation/reluctance toward research
Approaching faculty mentor daunting
Lack of progress
Data collection barriers
Non-linear process of science
Perception of a finished or complete answer
Note: listed challenges originate from surveys and interviews during a study or program evaluation (*3*, *4*, *38*, *46*, *50*).

The Challenges in Biochemistry Research at the Undergraduate Level

Academic researchers, corporate research and development departments, and funding agencies are recognizing that current scientific progress often involves interfacing two or more disciplines (*13*, *17*, *18*). The ability to communicate in more than one discipline's or sub-discipline's language is becoming a requisite skill. Interdisciplinary investigators are able to work with a diverse group of colleagues and have a deep understanding of their team's strengths and weaknesses (*93*). Merging various fields of expertise opens the door to creative approaches in proposing scientific questions, critically evaluating results, and refining models (see Figure 1) (*94*). The education of an interdisciplinary scientist begins with the parallel teaching of basic foundation skills that culminate in the integration and synthesis of various ideas for a common goal (*94*). Biochemistry programs are the hallmark of an interdisciplinary curriculum that perfectly embraces collaborative progress. For example, biochemistry research or related projects merge molecular biology, genetics, microbiology, general biology, general chemistry, organic chemistry, physics, and fundamental principles from mathematics to increase our knowledge of living systems. An investigator or team typically finds a protein of interest by genetic manipulations and phenotypic responses. The protein(s) can then be isolated utilizing molecular biology techniques and theories. Selected proteins are characterized structurally, kinetically, and thermodynamically in isolation as well as within a biologically relevant complex to elucidate how they function in the cell. To accommodate the growing quantity of information for each contributing division, many pioneering departments have adopted both inquiry-based learning and independent research to reinforce the utilization of various fundamental principles (*10*, *13*).

These curricular adaptations have noteworthy academic and personal advantages, as mentioned and illustrated above, yet have encountered unique obstacles for interdisciplinary fields such as biochemistry. Unfortunately, a large portion of an interdisciplinary student's preparation centers on introductory courses (*14*, *95*). Thus, idea integration occurs toward the end of his or her academic career. Concept integration confusion occurs when just one or two courses are made available to demonstrate the application and merging of various fields. The transition from textbook to primary research literature is also exacerbated when compared that of a traditional chemistry student, due to the explosive increase in available information and required fluency in multiple languages (*3*, *13*). Allegheny College assessments of biochemistry senior projects precisely illustrate these concerns (Table III). Students participating in a biochemistry thesis within the chemistry department score 8% lower in ability to contribute to experimental design and 10% lower in concept integration when compared to their chemistry counterparts, prior to thesis completion (Table III). Additional concerns center on the loss of the long-term benefits of and productivity in research when an authentic laboratory experience is postponed until the achievement of basic knowledge in all biochemistry related disciplines mentioned above. First and second year students have only rudimentary laboratory skills and knowledge of a small subset of required disciplines; thus, an early research experience becomes a greater challenge for both the student and mentor (*2*, *5*, *14*, *38*, *96*). Reports suggest that an "interdisciplinary background is a pre-requisite" for an understanding of and participation in interdisciplinary research (*10*, *95*). The required understanding and experimental skill set in several of the above-mentioned areas can be cultivated by a faculty mentor (*6*). Thus, the level of commitment from both the student and mentor far exceed that of a single field participant. Wenderholm correctly pointed out the impracticality of a research mentor introducing or substituting full course content with individualized instruction (*97*). The hurdles mentioned above have been successfully conquered with the creative utilization of instruction, student accountability, apprenticeship, and peer mentoring (*10*). This chapter proposes a model that incorporates Just-in-Time teaching to effectively manage the challenges of interdisciplinary research such as biochemistry at the undergraduate level. The mentoring style described in subsequent sections resulted from years of personal observations and discussions with biochemistry colleagues.

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Table III. Mean values and significance levels for dependent t-tests on senior thesis (academic maturity) assessment scores before and after completion of research project

Item	*Mean,*$_{before}$	*Mean,*$_{after}$	*t statistic*[1]
chemistry projects (2003–2013)			
Concept Integration	2.98 (SD=0.74)	3.15 (SD=0.89)	-2.9 (n=91)
Contribution to experimental design	2.87 (SD=1.19)	3.17 (SD=0.95)	-3.9 (n=91)
Technical sophistication	3.33 (SD=0.93)	3.37 (SD=0.88)	NA
JiTTER-biochemistry projects (2008–2013)[2]			
Concept Integration	2.53 (SD=0.79)	3.48 (SD=0.92)	-4.4 (n=13)
Contribution to experimental design	2.66 (SD=0.87)	3.60 (SD=0.90)	-3.2 (n=13)
Technical sophistication	3.20 (SD=0.71)	4.00 (SD=0.37)	-3.6 (n=13)
Note: NA: indicates no significant change observed. 1.) $p<0.005$ in every statically relevant evaluation. 2.) Since JiTTER was only implemented in 2008 within my laboratory, the number of chemistry projects exceeds that of biochemistry base projects and, thus, the sample size is small yet significant.			

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Implementation and Assessment of a Three-Stage Model for Undergraduate Research in Biochemistry

The studies mentioned above have clearly shown that students who participate in more than one semester or summer of research are better prepared academically and personally to tackle the realities of their profession. As with all research, students need time to feel comfortable with the research culture, environment, instrumentation, and protocols and to slowly progress into independent experimental design and outcome evaluation, as noted by Merkel and Baker (*2*, *57*). We should never assume, however, that first- and second-year students are not prepared for the challenge (*96*). Unfamiliarity with multiple disciplines, however, results in dramatically longer acclimation times for interdisciplinary fields such as biochemistry. Thus, the important question is not *can* we incorporate the truly novice student, but, *how* do we incorporate the truly novice student in interdisciplinary research without sacrificing other important and required faculty responsibilities? One answer incorporates comprehensive

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multi-approach mentoring and **J**ust-**in**-**T**ime **T**eaching of **E**xperimental **R**esearch (JiTTER) (*56*, *98–100*). Mentoring undergraduates in biochemistry research is a long-term commitment to foster and develop a passion for research as well as to empower them to make meaningful contributions to science (*38*). These opportunities for crucial mentoring or coaching arise during several key components of independent work. For example, weekly group meetings are the perfect forum to practice communicating outcomes, critical reading of primary research papers, relating current discoveries to individual projects, clarifying project goals, and learning experiment design (*5*, *46*). A combination of faculty and peer mentoring can effectively communicate expectations for courses, workload management, and successful navigation of undergraduate research (*10*, *24*, *49*, *50*). Student leadership should be encouraged from the beginning of the laboratory experience by giving novices the opportunity to shadow a more experienced student (*47*, *48*). Detweiler-Bedell argued that this level of peer coaching alleviates the greater time-demand felt by biochemistry faculty and helps develop a sense of community and accountability (*47*, *48*). The development of peer mentoring also foster the exchange of ideas (*47*, *48*). As illustrated in Figure 1, collaborations and community feedback in science are imperative to scientific success. The exchange of ideas and technical expertise leads to an unbiased interpretation of one's work. Thus, we strive to make every effort to instill a sense of community and teamwork in our laboratories. A student who joins a biochemistry research group becomes a member of a team that aims to understand biological macromolecules by utilizing different chemical and physical approaches.

Most students joining my laboratory, however, have no conceptual understanding of or experience with biochemistry concepts and techniques, since they typically enter as freshmen or sophomores. The role of the faculty mentor is to aid and guide students toward an understanding of needed abstract and practical research theory while not replacing a future course (*97*). Guidance should occur during the first semester of research or three weeks of summer research (*15*, *38*). In addition, Merkel and Baker have demonstrated that effective mentors must "accommodate to various levels of preparation, skill, and ability" (*57*). To facilitate the effectiveness of individualized instruction, I utilized **J**ust-**in**-**T**ime **T**eaching of **E**xperimental **R**esearch or JiTTER. **J**ust-**in**-**T**ime **T**eaching is a pedagogical approach, developed by Novak, Patterson, Gavrin, and Christian, that centers on establishing a "feedback loop" with preparatory reading assignments and probative questions (*98*, *101*, *102*). These exercises are constructed to fundamentally affect subsequent discussions on course material (*91*, *101–103*). Specially, students have a wide range of knowledge, experience, misconceptions, and philosophies that demand a personalized education to maintain an engaging atmosphere (*91*, *101–103*). Roschelle and Bransford, Brown, and Cocking have successfully argued that effective learning occurs when prior knowledge and the ability to independently understand concepts are established and integrated in education (*91*, *103*). In the case of JiTTER, the teaching philosophy thus centers on the development of carefully designed out-of-laboratory exercises that build on existing knowledge (*56*, *98–100*). Assignments or primers focus not only on textbook principles but also on experimental research principles of various

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contributing fields. Prior to a discussion session, research mentors receive student responses, comments, and/or questions surrounding targeted fundamental ideas that correlate to their future project (*56*, *98–100*). A student's feedback enables more meaningful weekly discussions (*56*, *98–100*). For example, assignments can introduce and develop Hückel's rules of aromaticity, practical aspects of spectrometers, the need to buffer enzymatic reactions, or the importance of statistically evaluating data sets. The above topics are relevant in a project that, for example, monitors the kinetic progression of enzymatic reactions via light absorption or emission. Responses may bring to light the inability to grasp or to make appropriate connection with basic concepts (*56*, *98–100*). Thus, discussions can be tailored to either revisit topics such as clarifying what makes benzene aromatic or examine why a biological macromolecule might contain aromatic functional groups. While JiTTER identifies and augments the level of conceptual understanding as well as reading-comprehension skills (*99*), peer mentoring maintains an atmosphere in which students are encouraged to refine or confirm conceptual knowledge (*104–106*). Gokhale and Cross reasoned that critical thinking and discussion skills are enhanced in a cooperative learning atmosphere that emphasizes team scholarship (*104–106*). The Detweiler-Bedell study also illustrated that ladder teams (team leader, associate, and assistant) mirror larger research communities and increase the effectiveness of undergraduate research (*47*, *48*). Thus, Mazur and Watkins strongly argued for the combination of Just-in-Time teaching and peer mentoring within multidisciplinary fields (*99*). This study indicated significant growth can be achieved in multi-dimensional research with the utilization of peer leadership, multi-year research exposure, and strong mentoring relationships (*99*). To actualize comprehensive mentoring and effective JiTTER, I currently utilize a flexible three-stage model (see Figure 2) for interdisciplinary experimentation that can be tailored to each student's conceptual confidence:

- Stage 1: JiTTER experience (1st-3rd year students lacking biochemistry)
- Stage 2: Apprenticeship (JiTTERs or biochemistry course registrants)
- Stage 3: Research Fellowship (apprentices or senior-year students)

Stage 1: JiTTER Experience (Joining the Team)

JiTTERs are students who have not taken or successfully completed a biochemistry course. Mentors typically dedicate the majority of a student's first semester of research to aid in the understanding of biochemical research and techniques as well as laboratory safety. Students are invited to group meetings to become familiar with our investigations. Questions and note-taking are strongly encouraged during team meetings. Biochemistry competency for select topics is obtained through the implementation of JiTTER as outlined above (*98–100*). Each primer or lesson contains reading assignments with various single

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answer and open-ended questions, which center solely on the material needed to understand future projects (*98–100*). Single-answer questions cover topics from previously accomplished courses to reinforce fundamental knowledge and identify misconceptions. Open-ended questions gauge a student's ability to apply and connect with previously learned principles (*100*). Examples of both categories of questions are found below:

- *Single-answer examples:* For the following Kas, does the equilibrium favor the products or reactants? What do K_a and K_b represent? Explain the outcome of the equilibrium, if the product is depleted.
- *Open-ended examples:* Explain the order of UV absorption: A > G > U > C; for example, Cytosine absorbs the least UV light while Adenosine absorbs the most. Why do you think that equilibriums are important in nature? Explain why double-strand DNA absorbs less UV light than single stranded molecules.

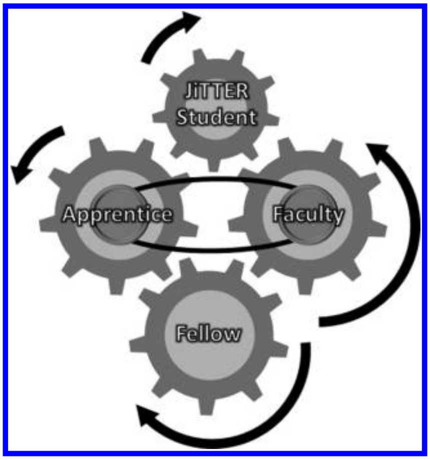

Figure 2. Graphical depiction of a three-stage advising model to incorporate comprehensive mentoring and JiTTER. The flexibility of this model allows academic and personal mentoring to be tailored to a student's level of confidence with project-related concepts. Faculty mentors make themselves available to JiTTER, apprentice, and research fellows. This model also expects more-experienced students to take on leadership roles in research. Apprentices help JiTTER students become accustomed to the laboratory. Fellows guide apprentices in research troubleshooting and design. This model helps student realize that they are part of a team in which all three "gears" or stages must function to successfully navigate the process of science. This model also has the added benefit of lowering faculty time commitment for truly novice students.

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JiTTER students are asked to discuss, refine, or expand their responses with peer mentors. The majority of JiTTER students understand, to varying degrees, fundamental principles such as equilibrium (*100*). Significantly fewer, however, are able to have a scientific discussion regarding the application of these principles to elucidate complex problems in nature (*100*). Thus, positive peer interactions afford the novice students the opportunity to identify misconceptions and learn how to assess their knowledge, similar to the Detweiler-Bedell ladder teams (*47*, *48*). This exercise results in improved confidence and readiness for faculty-led discussions. Intense dialogues between faculty mentor and JiTTER students often yield engaging in-depth analyses of scientific fundamentals and processes, as a result. These sessions, furthermore, facilitate the guidance of cross-discipline connections by initially focusing on textbook concepts and, subsequently, moving toward primary research literature. Thus, JiTTER assignments are designed to bridge the gap between an interdisciplinary textbook and research laboratory (*7*). Examples of literature-based questions include: “Why do you think that mutation “X” decreases ATP hydrolysis, while mutation “Y” increases ATP hydrolysis? And why do you think an alanine scan was a useful tool in this study?”

I must emphasize that the breadth and depth of JiTTER is strictly limited to principles relevant to future projects. JiTTER is not intended to take the place of a semester-long biochemistry course (*97*). The success of the JiTTER experience lies in the recruitment and orientation process. Although several students aggressively search for research opportunities, approximately 50% of first- or second-year students, in the Michigan State University study, participated in research due to a personal invitation or position advertisement (*38*). However, the identification of an “ideal trainee” is exceedingly difficult for interdisciplinary fields since first- or second-year students lack exposure to important introductory course material (*46*, *97*, *107*). Test-taking ability, furthermore, does not always translate into hands-on laboratory success (*97*). Diamonds in the rough sometimes are students who are engaged and perform exceptionally well in other aspects of an introductory course (*38*). In addition, a colleague’s recommendation can describe a student’s ability and work ethic (*38*).

Stage 2: Apprenticeship

Apprentices are students who demonstrate competency in biochemistry concepts through one-on-one instruction (JiTTER) or in a course (*2*). The main goal of this stage is to mentor JiTTER students as well as to develop and refine laboratory skills. Apprentices tutor JiTTER students with out-of-laboratory assignments and on laboratory culture. They are instructed to lend guidance and foster discussions with probative questions during tutoring sessions, instead of simply providing "correct" answers. Apprentices are also responsible for general laboratory preparations. For example, students become familiar with laboratory instrumentation and develop techniques that yield reproducible data by synthesizing, purifying, and testing the activity of target macromolecules (*2*). Training sessions are supervised by the research mentor to ensure technical proficiency. Students are also introduced to our protocol database. Laboratory

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procedures are written to function as comprehensive guides for the novice student. The database contains step-wise justifications, warnings, and suggestions on handling/storing biological and non-biological samples such as:

- Enzymes are stored in -20°C freezer blocks and pipetted gently to prevent degradation or inactivation.
- Dithiothreitol can hydrolyze in aqueous solutions. Thus, keep on ice to decrease the rate of hydrolysis as well as replace monthly.
- Froth can be a sign of protein denaturation and will ultimately cause light scattering affects, which will negatively impact data analysis.
- Fluorescence intensity values of ~50 indicate substantial bleaching of fluorophore at which point a new solution must be prepared.

Students are also provided with the opportunity to shadow a research fellow and, subsequently, participate in a project that mirrors or complements his/her mentor's project. This relationship serves to increase an apprentice's confidence level in scientific research. Weekly group meetings support the development of communication skills as students give short formal presentations reviewing their progress and identifying experimental concerns (*5*, *46*). One-on-one meetings not only give students the opportunity to articulate apprehensions but also allow the mentor to develop a semester timetable to foster time-management skills. In addition, I work very closely with students to develop their scientific writing skills with end-of-semester reports and laboratory notebook critiques. These assignments are designed to introduce scientific creativity that facilitates the transition into a research fellowship.

Stage 3: Research Fellowship

Once students enters the research fellowship stage, they possess the necessary skills to become peer mentors and fully independent researchers (*10*). Fellows typically take on a mentoring role toward research apprentices since their problem-solving and critical thinking skills in experimental design and analysis have greatly improved by this stage. For example, peer shadowing can encompass various matters including management of course-research load, literature discussions, and proper time-management during experiments. Research fellows are encouraged to guide apprentices with procedural or instrumentation challenges in addition to aiding in data interpretation within the context of our field. Weekly group meetings afford a fellow the opportunity to improve communication skills by giving short formal presentations that elucidate research design, experimental outcome, connections to primary literature, and contributions to the scientific community (*5*, *46*). Research teams are encouraged to assist with the improvement and evaluation of research goals and design. One-on-one meetings give students the opportunity to articulate apprehensions and identify experimental problems. I work very closely with these students to develop their scientific writing skills in preparation for their final thesis. Students who are genuinely participating and engaged in the process of science (Figure

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1) typically are very successful in defending their theses to a scientifically diverse committee. An examination of completed biochemistry-based projects clearly confirms the success of the JiTTER/mentor model inspired by the Mazur and Watkins study, as well as the Detweiler-Bedell reports (see Mean,$_{\text{after}}$ in Table III) (*47*, *48*, *99*). Specifically, students' assessment scores increased 38% in concept integration, 35% in the ability to contribute to project design, and 25% in technical sophistication (Table III). The observed level of growth supersedes the growth observed for chemistry-based projects. In addition, the final scores given by a diverse panel of scientist are substantially greater for JiTTER-biochemistry theses (see Mean,$_{\text{after}}$ in Table III). Not surprisingly, former and current fellows have presented posters at local and national conferences. In addition to academic achievement, research fellows are also crucial in fostering a good team environment. They contribute to recruitment by identifying students with interest and potential as well as organizing social excursions for the team. A direct result of this rigorous three-stage model is the ability to confidently use my students' data in posters, publications, and grants while maintaining good student rapport.

Concluding Remarks on JiTTER and Undergraduate Research

Current monumental discoveries in biochemistry are made possible by the cooperation of researchers in various areas of expertise. As this multifaceted branch of science progresses, it is becoming more and more evident that interdisciplinary education is paramount to further our understanding of the biological world (*13*, *17*, *18*, *93*, *94*). The simultaneous instruction of diverse fields of study in combination with convoluted paths of scientific thought brings new apprehensions into transforming education dialogues (*10*). The incorporation of inquiry-based courses allows students to "bridge the gap between" several textbooks and current biochemistry research (*7*). The disadvantage of these courses, whether problem-based or research-based inquiry, is that an "interdisciplinary background is a pre-requisite" (*10*, *95*). These classes as well as an authentic laboratory experience are often postponed until the achievement of basic knowledge in all biochemistry-related disciplines. Thus, the long-term benefits of and productivity in research is lost. Several studies, however, have shown the successful navigation of any field of study is achieved by active and continual participation in laboratory experiments (*2–6*, *8*, *10*, *12*, *13*, *15*, *37–39*, *41*, *42*, *44*, *51–55*). It is imperative that the first authentic interdisciplinary experience should be made available early and not be perceived as insurmountable for first- or second-year students (*39*). The required understanding and experimental skill set for research can be cultivated by creative faculty and peer mentoring in conjunction with JiTTER. JiTTER centers on reading assignments and primers that build on students' fundamental knowledge (*98–100*). Individualized instructions are adjusted to fit the needs of each student as suggested by Mazur and Watkins (*99*). Learning the required principles for a project becomes more dynamic, efficient, and sustainable (*98–100*). The progression through JiTTER allows the student to

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make a meaningful contribution to science as an apprentice and finally as a research fellow (Figure 2). The challenges of biochemistry research and success of JiTTER are clearly demonstrated in three student narratives below, as well as in quantitative assessments administered prior to the completion of a senior thesis (Table III). For example, a rising senior chose to postpone research due to time conflicts and a false perception that basic knowledge in several fields is a prerequisite for research. This student, upon reflection, regrets this decision since realizing that needed skills can be learned early with the aid of a committed advisor. In reading the reflections of the two other students stories, the challenges encountered in biochemistry research as first-year students are confirmed. Both students experienced JiTTER to varying degrees. They mentioned overcoming their knowledge barrier by completing tailored assignment and participating in fruitful conversations with their research faculty and peer mentors (*10*). Additionally, students' self-reported benefits outlined in the stories below, anonymous reflections, Teagle surveys, and curricular evaluations are comparable to those listed in Table I for single discipline research (*81*). These outcomes include, yet are not limited to, independence, increased problem solving, greater understanding of primary literature, self-motivation, increase in critical thinking skills, increase in communication skills, increase in creativity, refinement of scientific interest, and increased confidence in science. Exciting implemention of the above-described three-stage model has yielded greater academic growth during the senior thesis experience (compare $\text{Mean,}_{\text{before}}$ and $\text{Mean,}_{\text{after}}$ in Table III). Thus, the advantage of this model is its inherent flexibility and adaptability, as well as the leadership growth of students. The disadvantage, of course, is the requirement of enthusiastic faculty willing and able to dedicate additional time to promote critical thinking, communication, and resourcefulness in an increasingly multi-disciplinary world. Is this model, or any adaptation of, appropriate for all interdisciplinary undergraduate research? I would like to believe so, yet this experience is still tremendously reliant on the quality and not just the quantity of mentoring faculty.

Biochemistry Student Testimonies of Their Research Experience

Abby's Story

My name is Abby. I just graduated from Allegheny College in May 2013 with a major in biochemistry and a minor in history. I am currently working at Allegheny College as a biochemistry research fellow before starting medical school this fall. I have been working in the same biochemistry lab since the summer of my freshmen year. I was able to start research early because my introductory chemistry professor asked me to join his research group. After my first summer research experience, I continued my project during the subsequent academic school semesters and summers. At the end of August 2013, I will have completed four years of lab work.

My research in the last four years has revolved around predicting the secondary structure of RNA molecules. Much of our research involves "freshman" chemistry concepts such as thermodynamics. Thus, these projects are ideal for an easy transition into research as a younger undergraduate student. However, one of the initial struggles I had when starting as a freshmen was a lack of biology background. Most of the biology concepts used in our lab are covered during the sophomore year at Allegheny College, which made some of our proposed models hard to understand. However, by reading articles and with the help of my research mentor, I was able to learn what was needed.

Working in a laboratory for the past four years, as a student researcher, has provided me with numerous benefits. One problem a lot of students run into, when transitioning from high school to college, is the ability to teach yourself information and solve problems independently. Working in a research laboratory has provided me with these skills. For example, problem-solving becomes natural through the constant reading of research articles. These articles helped me better understand my research project and its impact. Journal articles also helped me go far beyond the material covered in class. Additionally, I learned to find new information independently and be proactive about my learning. My mentor encouraged his student researchers to understand the procedure, analyze data, design experiments, and present our work at conferences. This encouragement forced me to think critically and to understand my project beyond the protocol. By presenting my work at local and national conferences, I have become more familiar with our research and the RNA field in general. In addition, presenting allowed me to develop confidence as a speaker. Another opportunity I received from my research experience at Allegheny was the chance to apply for a Beckman Scholarship. I was awarded the Beckman scholarship during my junior year. I received funding for my research, a stipend for my summer and school-year work, and the opportunity to present my work at the national Beckman Conference in California. This conference was an incredible opportunity to make connections in the science and medical fields.

All in all, the four years of research that I have participated in have been critical in my education. My work has taught me to take initiative, become independent in my education, think critically, and become a confident speaker. Most importantly, it challenged me to go beyond my comfort level by learning and exploring areas of science I once thought were too complex to understand.

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Allie's Story

My name is Allie. I am a chemistry major and have completed my second year at Allegheny College. Coming to college, I thought I wanted to be a biology major. However, after taking a few chemistry courses, I knew that chemistry was right for me. I enjoy learning about the elements and various reactions. I am continually amazed that without these elements and reactions nothing in this world would be possible. Personally, I think it is remarkable that with chemistry, people not only have the opportunity to better understand the world around them, but also find ways to improve both the world and the lives of others.

As a first-year student, I spoke to one of my professors about how I could become involved in research. She referred me to a research-active professor who had a position available. That summer, I began a research project in the

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biochemistry field. As a rising sophomore, I had not yet taken biochemistry. The bench work I performed was easy to follow and the instruments I used were not too difficult to use. Thus, despite just finishing my first year of college, the procedure was not a struggle. Nevertheless, I felt that not taking biochemistry made it challenging for me to fully understand the reaction mechanisms and the significance of my research. Thankfully, my mentor gave me suggested readings to help with my understanding as well as answered any questions I had. However, my mentor was not always available. When my mentor was unable to answer questions or provide guidance, I would talk to two rising seniors who were also working in his lab. As students, they were relatable to me and were great assets to my learning. Nonetheless, they were only able to help me to a certain degree since we had separate projects.

After my first summer of research, I decided to pursue a different topic, but still within the biochemistry field. I began researching DEAD-box proteins in the first semester of my sophomore year and continued this research for an entire academic year and throughout the summer. Once again, the greatest struggle was understanding the basic biochemistry concepts, rather than actually performing the experiments. Nevertheless, my mentor helped me significantly. She was there on a daily basis and was approachable whenever I had questions. She also provided me with several suggested readings to better understand the research and experimental steps.

In August 2013, I will actually be switching labs again. However, this time, I will be participating in organic chemistry research. Although I have enjoyed the biochemistry research I have done, I realized that I have a greater interest in the organic field after taking organic chemistry.

In my opinion, starting research early was very beneficial to me. It gave me an opportunity to learn several experimental techniques not offered in courses as well as the ability to use a variety of instruments useful in both collecting and analyzing data. Research also gave me a sense of how the process of science really works. For example, course-related experiments only take the allotted three hours to complete. However, I now understand that true research experiments are not a one-time deal but, rather, a long, continuous process that takes multiple trials, creative thinking, and patience. Because I started research early, I have had the opportunity to work on different projects and with different professors to find the topic that best fits my interest. Despite jumping into biochemistry research before taking a biochemistry course, I have been able to learn and understand a lot through working closely with professors, asking for help from fellow students, and reading research articles.

Overall, starting biochemistry research as soon as possible is challenging but beneficial in the long run.

Erika's Story

My name is Erika. In August 2013, I will be a senior at Allegheny College. I am originally from Pittsburgh, Pennsylvania where I have lived my entire life. In high school, I was passionate about science and community outreach. The combination of these two interests led me to pursue an education at Allegheny College, where I was offered a Bonner Scholar fellowship. The Bonner Program requires students to participate in 150 hours of community service per semester and 300 hours of community service for two summers. This program, in addition to being a Biochemistry major and Psychology minor, consumed the majority of my schedule.

Many students at Allegheny College find time during their first two summers to join a research groups. This is especially true for students interested in chemistry or biochemistry. However, my first two summers were dedicated to completing my service commitment for the Bonner Program. It is also common for students at Allegheny College to earn credit hours for experimental research during the semesters. I chose not to participate due to my Bonner service at the Meadville Area Free Clinic as well as taking an average of 20 credit hours per semester. However, this summer I decided to join a biochemistry research group within the chemistry department. My mentor uses basic biochemistry methods to study DEAD-box proteins. I found this research very interesting after completing a biochemistry and molecular biology course during my junior year.

As a biochemistry major at Allegheny College, I must first complete two semesters of general chemistry followed by organic chemistry and physics. It is not uncommon for both biochemistry and chemistry majors to take the Introductory to Biochemistry course in their junior year. Thus, I was not exposed to the techniques and concepts that my mentor uses until my junior year. I originally thought that I would need to complete the biochemistry course to understand the concepts and methodologies of biochemistry research. I believed it would have been difficult to do research in a field that requires several introductory courses before taking and understanding the subject(s) that one is passionate for. However, my summer research has made me realize that it is important for students to start research early in their college career and, thus, I wish I had done so. Students can learn about their diverse field of interest long before taking a specific class by participating in research. There are pros and cons to doing research early, but if one has the time they can always benefit from research.

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Chapter 9

Research as an Introductory Course: Engaging First-Year Students in Authentic Chemistry Research through the Freshman Research Initiative Program

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This chapter details the establishment of a research group in synthetic organic chemistry comprised mainly of first-year college students who receive degree-relevant course credit for their experience. The three-semester sequence trains the researchers in basic laboratory techniques and essential skills required to effectively propose and implement a research project. This laboratory was developed using the scaffolding of the Freshman Research Initiative, a program designed to engage students in research from the start of their college career at The University of Texas at Austin. The instructional methods developed by this research group are detailed, along with a program overview.

A Research Curriculum Framework

The integration of research with teaching at The University of Texas at Austin has developed around three core principles:

1. The research conducted by students must be authentic. It should be linked to a faculty member's research program, of interest in the discipline, and potentially publishable.
2. The experience must provide course credit toward a degree.

In Developing and Maintaining a Successful Undergraduate Research Program; Chapp, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

3. The opportunity must be accessible to students early in their pursuit of a field.

These core principles are facilitated by the Freshman Research Initiative (FRI) program, which was established by the College of Natural Sciences to provide an efficiency of scale for many individual undergraduate research laboratories operating within this model. The support that the FRI provides (detailed below) has been critical to our ability to offer a research experience to over 800 students each year. However, the critical piece that truly allows students to engage in real science early in their career occurs at the level of the individual research laboratories. In this chapter, we detail one such group, its scientific focus, how it fulfills the research goals of its lead scientists, and how it accomplishes curricular objectives. We then outline the program structure that supports these research groups at scale.

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Research for Freshmen in the "Synthesis and Biological Recognition" Group

The focus of the Synthesis and Biological Recognition research group is the synthesis and binding of small organic molecules to a target protein. This project engages 30+ freshmen each spring semester in authentic, publishable research, while granting course credit that counts toward their degrees. At the start of each calendar year, a new group of freshmen begins in the research group, and that cohort continues researching through December of that year. The first semester is structured to meet course requirements, while the second semester satisfies a research credit that allows a great deal of freedom in student activities.

Initially, the mouse major urinary protein-I (MUP-I) was selected for investigation by our students. This protein is characterized by a hydrophobic active site, which binds a variety of small, lipophilic molecules (*1–4*), several of which are heterocyclic (Figure 1). Hydrophobic association is generally believed to be entropically favored due to desolvation of the hydrophobic binding pocket of the protein as well as the nonpolar ligand, which should increase the entropy of bulk water upon binding; however, in MUP-I, the interaction was shown instead to be largely enthalpy-driven (*2*). We sought to further explore this interesting thermodynamic observation through binding studies with novel ligands, and couple our investigations with protein structure determination to further examine the nature of the protein–ligand interactions.

Additionally, this protein was selected because it seemed an apt target for undergraduate projects. The molecules that MUP-I binds are fairly small, and we envisioned that they could be made via short, multistep syntheses, which would be appropriate for a yearlong project. The promiscuous nature of MUP-I binding allows a great deal of flexibility in the ligands that students choose, as they have a good chance of observing binding, even if their molecule has low affinity (K_a) for the protein. Many of the projects allow students to gain experience with heterocycle synthesis, which is important in medicinal chemistry.

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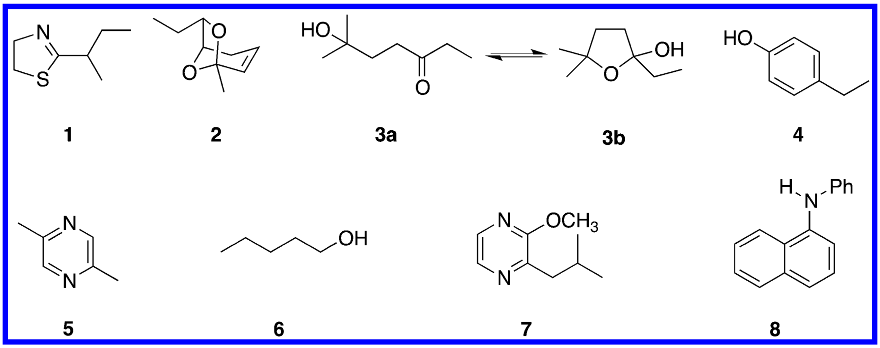

Figure 1. MUP-I pheromones and ligands reported in the literature

In the lab, students explore MUP-I binding by modeling protein–ligand interaction using program database (PDB) files available from the Protein Data Bank, as well as those that have been generated from crystal structures solved in the group. After reading journal articles that detail the thermodynamics of binding to MUP-I, students use known ligands to develop their own project and formulate a hypothesis for their investigations. Projects often involve exploring the consequences of altering hydrophobic groups, hydrophobic surface area, and the electrostatic nature of known pheromones and ligands.

Students in the chemistry laboratory develop synthetic routes to their molecules through literature searches, with guidance from instructors and mentors, and then execute the syntheses to make their targets. Students researching in biochemistry gain experience with protein chromatography and the binding assay used in the group, isothermal titration calorimetry (ITC). Researchers in this lab also set crystal drops and prepare solutions for crystallography; several structures have been solved from student-prepared solutions.

Meeting Accreditation and Research Needs

A key component of our integrated research and teaching model is the substitution of the research experience for courses otherwise required for the degree. In chemistry, it is critical that each FRI research group meets the requirements laid out by the American Chemical Society (ACS), as general chemistry laboratory at the university is ACS accredited. When the Synthesis and Biological Recognition research group began in 2009, the curriculum was built on a platform established by existing chemistry research groups using the FRI model, and was designed to fulfill the Department of Chemistry's requirements for Introduction to Chemical Practice, CH 204.

A list of required skills, developed by the department for traditional lab sections, was used to create the research-based curriculum taught as part of the research training. This list included essential skills and topics that needed to be covered for accreditation:

1. General laboratory skills: Lab safety, observation, basics of report writing and notebook keeping, scientific method, error/statistics
2. Measurement skills: Analytical balance, volumetric pipette, burette, volumetric flask
3. Solutions: Preparation, standardization, dilution
4. Separation/purification: Decanting, filtration
5. Acid–base chemistry: Titration, indicators, buffers, pH meter
6. Qualitative analysis
7. Synthesis: This lab must include the synthesis, separation, and/or purification of a chemical compound, and should include quantitative analysis of yields
8. More advanced topics: For example, UV-Vis spectroscopy and Beer's Law, calorimetry, redox chemistry, microscale techniques

In chemistry, the department gives two credit hours for CH 204, and we offer the same credit for participation in research through FRI; the course number on the students' transcript is identical to the departmental credit. In addition, our students receive one credit for a weekly conference course, and this hour is used as a lab group meeting or lecture.

In order for students to reach the point where they can synthesize an organic molecule and test this compound in a binding assay within a one-year period, training must be focused on developing a skill set applicable to research in organic chemistry as well. With the goal of performing a multistep synthesis of a potential MUP-I ligand in the final spring experiment, the curriculum was designed so that students could gain experience with the following research-related skills:

1. Understanding of amino acids and protein–ligand interaction
2. Stoichiometry of organic reactions and proper notebook set up for these calculations
3. Reaction work-up, which is generally a liquid–liquid extraction
4. Various purification methods and an understanding of when to apply each
5. Compound characterization: Melting points and spectroscopy, including acquisition and basic interpretation of nuclear magnetic resonance (NMR) spectra and infrared (IR) spectra
6. A general understanding of ITC, the calorimetric binding assay that is utilized to study protein–ligand interaction
7. Literature search skills: Students must be able to explore the chemical literature to find their own procedures and protocols

There is obvious overlap in some of the skills required for general chemistry lab and those needed for our research, but the challenge was meeting all of these requirements in 14 weeks of six-hour laboratory periods. Over the five spring semesters that the group has existed, a variety of experiments have been developed and modified to provide these essential skills, and assignments have been created to assess progress toward the mastery of these techniques.

Assigning course grades for research is an important consideration, as a balance needs be achieved between encouraging students to be confident with

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open-ended assignments and evaluating effort and progress. In this research group, each semester, students receive grades for a combination of participation, computer activities involving literature search, pre-laboratory preparation, notebook evaluations, and formal written reports.

One of the most difficult tasks for students at the onset is report writing. In order to encourage proficiency in scientific writing, while not detracting from the research experience, the curriculum has been organized into five major sections, each of which requires one overarching report. There are writing checkpoints over the two- to four-week period of each course section, in which students can get feedback on their report writing progress, and a group email account has been dedicated to writing development. Students prepare a single report for each of five course units, which are detailed below.

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Section 1: Solution Preparation and Acid–Base Chemistry

Section 1 of the spring course includes three individual experiments; the first lab involves a separation where students employ techniques used in organic chemistry to separate sand, salt, and an organic compound. Their purification method must involve both a filtration and an extraction, and they must plan the separation approach themselves using general procedures that are provided.

The second experiment involves solution preparation, acid–base chemistry and exploration of buffers. An excellent experiment used to teach these concepts and relate to aspects of the research is amino acid titration. Using micropipettors, students titrate solutions of amino acids, gaining skills needed for biochemistry research while satisfying the departmental course requirements.

A two–base extraction completes the first unit; students separate three organic compounds—two of different acidity that dissolve in alkaline solutions and one neutral compound that remains in an organic layer. This is one of the more challenging concepts to teach the students; however, it has been quite successful due to the extra attention and personal instruction we give during this experiment. Throughout this week, extra office hours are offered. The lab staff is vigilant and makes rounds to ensure that each student knows what is being separated in each step. There is a flowchart on the group website that clearly details the separation, and the written reports reflect that the students are able to effectively grasp the pKa-based separation strategy.

Section 2: Amino Acids and Modeling

The second section of the spring curriculum is focused on amino acid and protein structure; the fact that the research centers on the binding of small organic molecules to proteins, which are composed of amino acids, is a focus in lectures and discussions. This section includes wet and dry lab components. The amino acid wet lab is where the qualitative analysis experiment is incorporated, which is adapted from a published procedure (*5*). Reagent solutions change color in the presence of different amino acid and protein solutions, providing information about the structure and identity of certain amino acids, as well as the presence of specific amino acids within protein sequences. The procedure has been modified

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to include a part where students identify unknown solutions using the results from the previous tests.

A full week is also dedicated to the dry lab portion of this course section. The dry lab begins with amino acid modeling using model kits. Students build glycine and alanine and record observations about chirality. Models of the *R*- and *S*-enantiomers of carvone are present in lab to view; students waft solutions of each enantiomer and record whether or not they can smell the difference on a shared datasheet, as some people cannot distinguish the enantiomers in an olfactory manner. The importance of chirality in biological molecules is a focus, and models of the teratogenic drug thalidomide (*6*) are used as an example.

The students then move to the computers for their final two modeling activities. First, they learn to generate structures using ChemDraw through a video tutorial available on the group website that details the basic features of the program. The tutorial also delves into stereochemistry using the example of amino acids; students are shown how to flip structures and alter bonds to show chirality. Following this exercise, the freshmen are expected to use ChemDraw to generate their own original figures and schemes for their reports.

In the final computer activity, the students learn to use PyMOL, a program for macromolecule structure representation. Using PDB files, they begin by exploring basic commands and the different levels of protein structure, and then they examine protein–ligand interactions. The tutorial, which was developed with the assistance of an undergraduate student supervisor during the group's pilot year, includes excerpts from a journal article that details the binding of two different ligands to MUP-I. Each excerpt is followed by PyMOL typed commands that lead the students to display the active site and show the binding interactions described in the paper. Students utilize the files they've created when writing both the Section 2 report and their final report for the semester, which is research-based.

Section 3: Purification Methods

The next section of the course elaborates on purification methods, and students apply chromatography to separate the same mixture that they purified through two–base extraction. In their report, students compare the efficiencies of the methods through melting points and percent recoveries. Students also distill a reagent for a reaction they will perform in the next section of the course, providing them with experience executing two new purification techniques.

Section 4: Organic Reactions

The organic reactions section introduces more advanced techniques, such as airfree reactions and compound characterization. This undergraduate research group is affiliated with the laboratories of Prof. Stephen F. Martin, and one of the experiments from Martin's organic chemistry laboratory manual (*7*) is used in this section of the course. Students explore a reaction that produces different products under kinetic and thermodynamic conditions. Discussions about free

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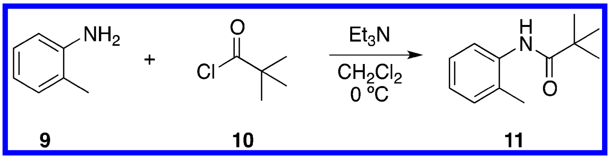
energy, entropy, and enthalpy are a focus, as these concepts directly relate to the ITC experiments performed with student-synthesized ligands.

The second experiment of this section was developed from a protocol published in the Journal of Organic Chemistry (*8*). This three-week experiment begins with the distillation of acyl chloride **10**, which is then used to synthesize *N*-pivaloyl-*o*-toluidine, a primary standard for organolithium titration (Scheme 1). The following week, students titrate *n*-butyllithium using the reagent they have prepared.



Scheme 1. N-pivaloyl-o-toluidine synthesis

At this point, students have only followed one reaction protocol in paragraph format, and they are not quite ready for the leap from stepwise procedures to less detailed journal procedures. A supplemental handout is provided, which clarifies structure abbreviations and challenging concepts to help students comprehend the two-page article. They compare the provided stepwise protocol with the journal experimental section to prepare for upcoming weeks, in which they will be required write their own detailed procedures from those found in the literature.

Students are required to set up their first notebook table for an organic reaction, and they are given a format to follow to determine reaction stoichiometry. The group website contains a "notebook module" where students can work through a sample reaction table; however, this table reflects a different scale from the one they will use in lab, providing them with multiple opportunities to practice their calculations. On the website, pictures of a short path distillation set up help students prepare for lab, as well as notes on airfree technique.

Once the students have synthesized *N*-pivaloyl-*o*-toluidine, mentors assist them in obtaining IR and NMR spectra for their product to ensure that it is sufficiently pure to perform the titration the following week. The *n*-butyllithium titration is generally the most advanced skill the students perform during their first semester, but they are provided with a great deal of resources to help them prepare. The website has a fifteen minute demonstration of the titration process, including worked calculations. Researchers watch the video on their own, answer prelab questions related to the video and airfree technique, and then sign up for a time to titrate in small groups under the supervision of the instructors.

The Literature Exercises

"Literature Exercises" are interspersed throughout the spring curriculum, two of which are integral to the final, research-based experiment. These activities familiarize the students with the chemical literature and search tools, and start off simply, with students first learning about reliable and unreliable sources for

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chemical information. They later must locate a research project-related article given only the journal citation, and answer questions about the article. The next assignment coincides with the chromatography experiment, and students visit the website "Not Voodoo," (*9*) which contains information about organic chemistry laboratory techniques. In addition to reading about chromatography on the site, they also find the paper cited by Not Voodoo (*10*) that explains how to select a column size based on the amount of sample and how to choose an eluant for chromatography.

A more advanced literature exercise introduces students to Reaxys, a program for structure and reaction search. A powerful tool in Reaxys that is utilized extensively in this research group is the synthesis feature, and it is introduced in this exercise. Clicking on the "synthesize" button below any compound brings up the published methods to make the molecule. Students can be provided with reagent guidelines or a list of compounds to avoid. This allows them to find their own procedures to make target molecules, even though most of them have not yet taken organic chemistry. In the Reaxys exercise, students compare the cost of reagents and the yields for other syntheses of *N*-pivaloyl-*o*-toluidine. This raises their awareness about the expense of research, and provides them with practice pricing from multiple vendors, as they will be required to do for their proposed research project.

Section 5: The Research-Based Experiment

The final experiment of the spring is a multistep synthesis, in which students make a potential ligand for the MUP-I protein, or at least begin the first synthetic steps. During the initial week, students perform the fifth Literature Exercise, where they use SciFinder Scholar to find papers to cite in their final research-based report. As a final task, students use Web of Science to perform a cited reference search and find the titles of more recent articles related to the group's research.

Last spring, phenyl-substituted imidazoles **12** were explored as potential ligands for MUP-I (Figure 2). The selected synthesis allowed for the variation of *para*-substituents on the phenyl rings, and four imidazoles were made.

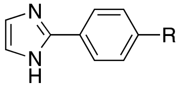

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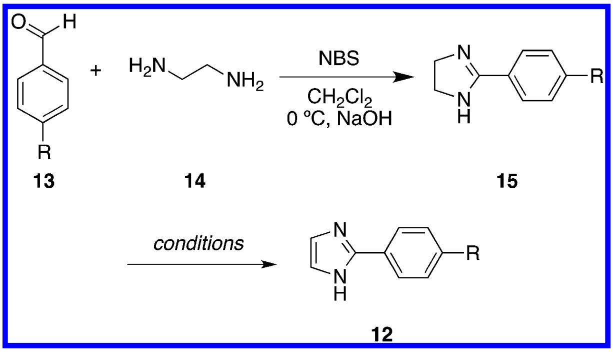
Figure 2. Target imidazoles

Students were given a journal article (*11*) detailing the first step to produce dihydroimidazoles **15** from aldehydes **13**, as shown in Scheme 2; for their prelab, they wrote their own stepwise procedure using the experimental section of this paper. During the first week, while performing the initial reaction, students concurrently worked on the final literature exercise, in which they performed reaction searches to find their own set of conditions to oxidize dihydroimidazole **15** to imidazole **12**.



Scheme 2. Imidazole synthesis

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Students utilized Reaxys again in this literature exercise to determine if their target molecule had been previously made from a dhydroimidazole. This activity also contains instructions to explore "generic groups" that can be used when searching. Accordingly, students replaced the aromatic ring with a generic group representing any substituent and repeated the search, making note of the additional conditions they found with the more generalized structure. Finally, they selected what they felt was the best precedent, based on structure similarity, reagent cost, and yield; they then submitted the journal article along with a pricing sheet and paragraph rationalizing their synthetic step choice. In past years, students were allowed to use any protocols they found that were safe and used reagents available in lab; however, it is much more convenient for the instructors to select a single set of conditions. This past year, the paper that the majority of students selected (*12*) was the protocol used.

The imidazoles were first analyzed by NMR and IR spectroscopy for purity. UV spectroscopy was applied in a Beer's law experiment to obtain extinction coefficients for the compounds in an ITC buffer, which would allow for the accurate determination of solution concentration. Students made solutions of the imidazoles and averaged absorbance data with others working on the same molecule. The results of the Beer's law plots were not of sufficient quality for research purposes; however, students gained valuable experience carrying out most of the techniques required for ligand synthesis and analysis *in a single semester during their freshmen year.*

The skills developed in this research group during the spring are honed during the following summer and fall semesters as students become more independent and settle into their individual research projects. The fall semester offers course credit; however, the requirements are flexible and students can focus more on research. At this point, it is valuable to frame the research experience in context, thus we will describe the course sequence that is typical of the FRI program.

An Overview of FRI Program Timeline

The Synthesis and Biological Recognition group's research laboratory was established through the framework of the FRI program, which provides authentic research experiences for a large number of freshmen, while allowing them to earn course credit that counts toward their degrees. In this program, about a dozen individual groups like Synthesis and Biological Recognition, called “streams,” offer research opportunities for students in chemistry- or biochemistry-centered projects, granting credit through the Department of Chemistry. More streams are offered in other disciplines in partnership with those departments (biology, physics, math, astronomy, and computer science). Each stream has met the requirements of the credit-granting division in a way that compliments the individual group’s unique research project. There are parallels in the education methods developed by the chemistry streams, due in part to the fact that they are meeting accreditation and course requirements; however, each research group adapts the curriculum to provide the students with the essential tools to perform research in a specific area.

Students begin in the research streams as second semester freshmen; however, they join the FRI program as soon as they begin college. The typical course sequence, beginning the fall semester of freshman year, starts with Research Methods, a multidisciplinary course that includes participants from all majors within the College of Natural Sciences and prepares students for the type of thinking they will need to do in their stream research (Figure 3). Students have the opportunity to indicate their research stream preferences mid-fall and are sorted into the individual groups based on interest and availability. By the beginning of the second semester of the program, those wishing to continue from Research Methods into a research experience have been assigned their stream and will continue in that group through the fall of their sophomore year. The course sequence spans a summer session, and FRI students are encouraged to participate in optional summer research. The spring of sophomore year marks a transitional period, where participants will either move into their next research experience, or continue in the FRI program as peer mentors.

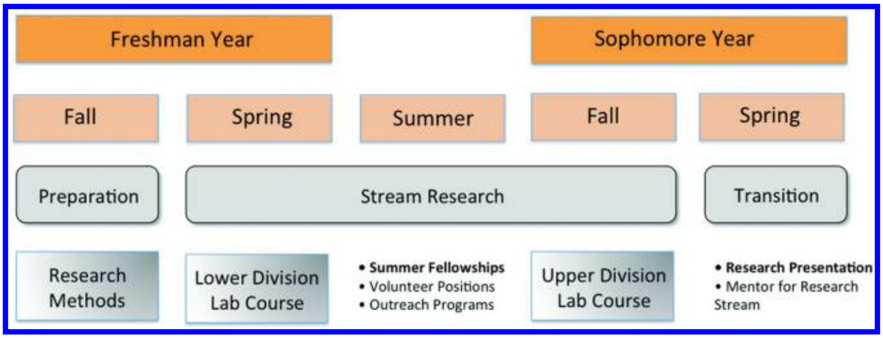

Figure 3. Typical FRI course sequence

Freshman Fall: Research Methods

The first course in the sequence, Research Methods, introduces the research process and, as with the research stream courses, fulfills a degree requirement.

The course familiarizes students with the idea of science as the unknown, teaches critical thinking, and explores introductory concepts fundamental to research across disciplines. Students investigate topics such as laboratory safety, safety data sheets (SDS), handling chemicals, the scientific method, scientific literature, and presentation of data and results. Laboratory sections consist of about 30 students, and provide the hands-on support necessary for them to formulate and carry out inquiries of their own design. Some Research Methods sections begin with observational inquiries, where the students are directed to examine a variable in nature and apply the scientific method in their observation. Later inquiries require the application of measurement and instrumentation, and students are encouraged to check out equipment to collect their own data.

The Research Methods website (*13*) plays an integral role in facilitating independent inquiry for the hundreds of students in the course; it is designed to streamline the project approval process and guide participants toward inquiries that are engaging and instructional, while minimizing the complications that often arise from students performing large scale independent investigations. The site has a “choose your own adventure” structure, posing questions as students formulate their inquiries and informing them of the logistical challenges, safety considerations, and necessary equipment. The website also serves as a medium to request materials to order, organizing the large volume and variety of materials that are needed as 800 students plan to implement original inquiry-based experiments.

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Student Placement: “Stream Sort”

The process by which students are matched with their research stream begins with several key events in the fall, promoted in their Research Methods lecture. The first of these, which is a social event, draws the freshmen out to learn about the program and research in general. Posters are set up—these posters are similar to those presented at conferences, but are designed for a much broader and less sophisticated audience, and students are encouraged to view the posters and ask questions. Although stream personnel attend, this event is focused on providing an unintimidating environment for the students’ first introduction to the research streams, rather than promoting participation in any of the individual groups.

Additionally, each stream holds Open House hours during the fall, and Research Methods instructors encourage their students to attend. Students visit labs in line with their research interests, and lab staff and current participants present the stream research, lead a lab tour, and/or answer questions about the stream and the FRI in general. In the Synthesis and Biological Recognition stream (SBRS), an overview of the stream research is given through a poster presentation, followed by a tour of the lab. Researchers that are currently working in the lab explain the techniques they are carrying out, and demonstrate the use of the research equipment for the prospective students. Additionally, information sessions are held during the fall for all Research Methods participants to demystify the process of selection, registration, and course credit offered by each stream.

Students that investigate their interests, attend open houses and participate in the information session are in the best position to participate in “Stream Sort,” a key administrative task that results in placement of roughly 800 students into the individual research groups. This process occurs in mid-October before spring semester registration and requires that students fill out an online form ranking their top five stream choices. Students are then sorted into the research streams via a process that attempts to maximize the number of students receiving one of their top choices. A typical stream can accommodate up to 35 students, although the model allows for both larger and smaller groups depending on discipline and available resources. Once assignments are distributed, students have an opportunity to request a switch, and until classes start in the spring, complementary switch requests are accommodated as spaces become available.

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Freshman Spring in the SBRS: Best Practices

When freshmen are accepted into the FRI program, an emphasis is placed on the fact that they need no prior knowledge to participate in FRI. However, even the first lab they perform in the SBRS requires a greater level of independence than most of the students are used to. Accordingly, it is essential to provide the incoming class with enough support to build their confidence to try research. In SBRS, we accomplish this by meeting with incoming students in small groups even prior to the first laboratory to welcome them as part of the research team and reassure them that what they are doing could, and should, be challenging.

Another best practice to ease the freshman into the lab is through an electronic discussion forum. In the SBRS, a discussion board has proven useful in addressing the numerous general questions that arise. This discussion is currently hosted on Blackboard, so students need to log in to view it. The privacy of this board allows students to feel comfortable asking informal, general questions, and the requirement to post twice weekly ensures that students continue checking the board and gaining lab insights. Stream members are directed to post anything course-related that is not of a personal nature, a strategy that helps instructors avoid receiving many identical emails that were common in the first year of the stream. As the students become more comfortable about lab, they begin to answer each other's questions and share verbal information given by the laboratory personnel, making the discussion board fairly self-maintaining.

The SBRS has developed an interactive, module-based stream website (*14*) as a mechanism to effectively introduce new students into the lab and alleviate anxiety about performing unfamiliar techniques. Each type of experiment has a dedicated page with interactive modules to accompany the investigation. During a prior fall semester, an assignment to contribute to the website resulted in several student-made videos that the current cohort can use to familiarize themselves with equipment and techniques prior to coming into lab. Additionally, as students delve deeper into the research project, more advanced tools are available to them through the website. Spreadsheets for calculations, collected PDB files of the MUP-I protein, links to key stream journal articles, as well as instructions for requesting chemical orders can be readily downloaded.

Identifying with a particular STEM field was identified by the 2012 PCAST report (*15*) as important for student participation and retention in science, and a way to help the students identify with the stream's field is by encouraging them to read the literature as early and often as possible. Accordingly, a high emphasis is placed on the chemical literature in this stream, and activities that build students skills in searching and reading journal articles are incorporated throughout each semester.

Summer in SBRS: Fellowships, Research Volunteers and Outreach

The program course sequence spans an optional summer session between the freshman and sophomore year, which allows a smaller group of stream students the opportunity to focus on research at a time when they have fewer academic obligations. *The optional summer session is a powerful piece of the program that has kept research in the SBRS moving forward.* Isolated summer research experiences are valuable; however, the continuity that the summer provides between the spring and fall semesters allows students to make a great deal of progress on their projects.

Streams are typically allocated three "full-time" fellowships to offset summer expenses for each student; in the SBRS, these fellowships are awarded to six students to perform research part-time. Those that do not apply or do not receive one of the fellowships can volunteer in the lab, and typically about one-third of the full stream participates in summer research as either fellows or volunteers. With its relaxed atmosphere and increased weekly student hours, summer is an ideal time to explore new research ideas for the stream. Importantly, students who have stayed in the summer often emerge as natural peer leaders for the cohort as a whole in the fall.

The summer session, with its relatively smaller group, is also used as an opportunity to allow some non-FRI students the chance to begin researching. Summer is an excellent time to integrate transfer students into the stream labs, as well as upperclassmen that are interested in research but may have decided later in their academic careers; the SBRS engages one or two students in these situations each year. Outreach is also a focus of the FRI summer program; the Summer Research Academy allows high school students to perform research in the stream labs or participate in a summer version of Research Methods, and the SBRS has involved up to four high school students in research annually.

Following an initial training week, the summer format in SBRS is relaxed, and mirrors a research lab much more closely than the spring, which is structured to preview a variety of skills and meet departmental requirements. Although everyone in this stream performs organic synthesis in the spring, during the summer, students have the opportunity to segue into more biochemistry-based research projects, which take place in Stephen F. Martin's laboratories. Having the two labs running simultaneously in different locations of the building is challenging, but with *20 hours of paid student supervisor assistance*, both laboratories run quite smoothly, especially as the summer cohort becomes more independent and involved in lab upkeep and maintenance through their own group jobs.

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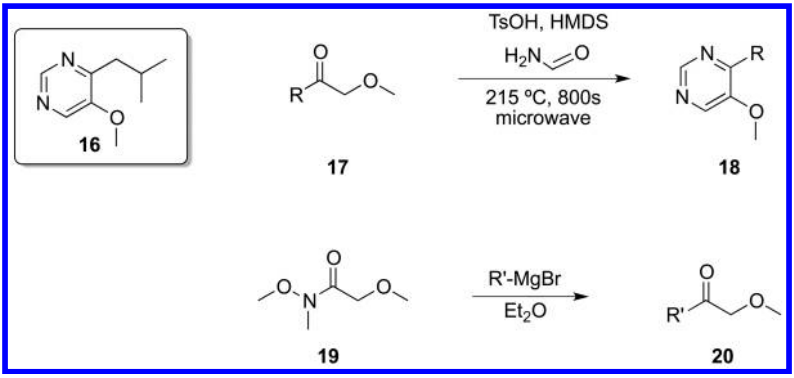
During the summer, weekly journal clubs accompany daily lab work, and students also present their research weekly at “mini meetings.” The SBRS’s chemistry and biology groups meet separately, and the mechanistic aspects of organic reactions and the underlying chemistry of biological techniques are analyzed in these meetings. Both groups meet together on Wednesdays for a one-hour lecture, where additional aspects of the stream research are discussed, such as crystallography, advanced NMR interpretation, isothermal titration calorimetry, and medicinal chemistry in general.

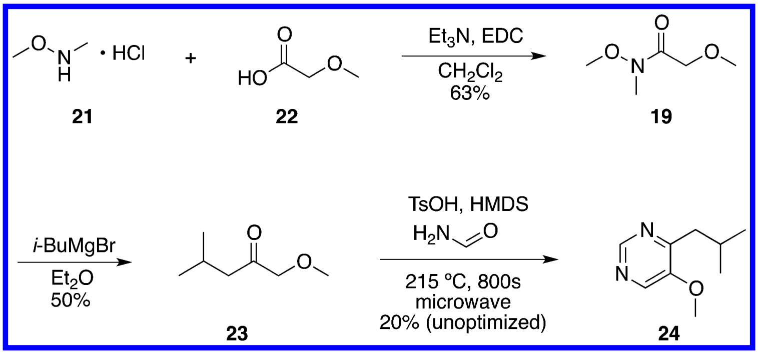
During the summer, SBRS students become quite capable searching the literature through Reaxys, and stream researchers have been successful in developing their own synthetic routes, even with limited understanding of organic reactions. An example of a student-developed project is shown in Scheme 3. The target compound of this investigation was pyrimidine **16**, an analogue of the known ligand pyridazine **7**, shown previously in Figure 1. The student performed a substructure search of the sections of the molecule shown, and set the R groups to generic groups (Scheme 3). She found an example of an α-methoxy ketone **17** that underwent a microwave reaction (*16*) to produce pyrimidine **18**, which contained the desired ring substitution pattern. Her chosen R group could be introduced by reacting Weinreb amide **19** with a Grignard reagent (*17*) that contained the chosen R group.



Scheme 3. Student project-based Reaxys search

Using the literature precedent, this student devised a synthetic route to her novel compound, which is detailed in Scheme 4. The final step, microwave-mediated cyclization of ketone **23** with formamide, afforded pyrimidine **24** in low yield; however, enough of the ligand was produced to test the binding of this compound to MUP-I, and we have studied this ligand by both ITC and protein crystallography.

The 18-year-old summer fellowship recipient that devised this synthetic route was concurrently enrolled in organic chemistry I. The development of this successful synthesis demonstrates that even these young students, given the proper search tools and assistance, can successfully perform research in organic synthesis. It is noteworthy that this project was handed off and another student completed and optimized the synthesis during a subsequent year.



Scheme 4. Student-designed synthesis

Sophomore Fall in SBRS: Returning Students

Students that continue in this stream during fall of sophomore year again receive course credit that counts toward their degree. By this point, students who stayed for the summer have typically advanced substantially on their research projects, and students that did not participate in summer research continue where they left off in the spring. Group work or project "handoffs" ensure that the fall students have the opportunity to make ample progress. The formal weekly lecture held in spring is replaced by a group meeting in the fall, where students present their research results.

The fall semester presents its own challenge, as the students from the summer have read a great deal of journal articles and have developed an excellent skill set from working part time in the lab. Often members of the summer group emerge as natural leaders, and the fall provides an opportunity to observe their teaching ability and utilize their improved skill set. Accordingly, in the SBRS, each summer student is designated a small group of fall students to lead. This helps to ease the group that did not participate in summer research back into the laboratory prior to them proposing their original project idea. Each group consists of one or two summer group (SG) members, two to three fall group (FG) students, and one mentor who is a point person for the entire group.

The first job of the SG student is to train the FG they are leading to perform their group jobs, so the members of the group are generally assigned related laboratory responsibilities. SG students resume their research projects from the summer, performing their reactions with assistance from the group. It is common for an FG student to select a project related to that of their SG leader, although some FG members regain their independence in the lab quickly and come up with unique project ideas.

SG and FG meet separately for mini meeting and journal clubs, so that the progress of SG may be advanced, while catching FG up on some of the more critical papers related to the stream research. Journal club in the fall is held weekly with SG and FG alternating.

There are fewer fall assignments, which allow students to focus more on their research projects. The main assignments include a protein-modeling project to

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hone PyMOL skills, notebook assessments, research updates, a research proposal, and a final report. In early October, the research proposal is due. By that point, students usually have begun their own research or at the very least, have been fit with a unique project and have ordered their chemicals. The final research paper includes the progress they have made on the research project, full experimental procedures, and characterization of any compounds synthesized. All chemistry students must report full spectral data for any new compound they have made and include scanned copies of the spectra they have acquired to prepare for potential publication.

Beyond FRI: Moving the Research Forward

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Students who complete the three-semester FRI sequence are encouraged to leverage their experience and the relationships they have built with the stream faculty to further explore opportunities on- and off-campus. In addition to having the opportunity to continue to do research in the core lab of the department faculty that the stream is affiliated with, they may also enter an FRI-sponsored rotation program to explore other areas of research, and are competitive for REUs, summer research at national labs, and internships. There is an opportunity for FRI alumni to present their research on campus during spring of sophomore year at the university-wide Undergraduate Research Forum, which is part of research week. FRI alumni can also serve in supporting roles in both Research Methods and streams as undergraduate teaching assistants or mentors. Additionally, students who have participated but do not see continuing with research as part of their trajectory can now explore other areas entirely, with over two years remaining on campus to expand their horizons by shadowing doctors, studying abroad, or volunteering.

The aim of our program is to help students continue researching if they desire—but not necessarily in the stream laboratory, so one of the program's measures of success can actually delay research progress in the individual streams. Project handoffs have helped the SBRS keep the research moving forward. A student may make a certain amount of progress on a multistep synthesis, but leave a sufficient amount of work for a student the following year. The consequence of this is that research moves gradually, since there is a training period in spring during which little research progress can be made.

Students that have completed the two semesters in the stream sometimes elect to return in spring of sophomore year as research volunteers, and there is an option for them to receive independent research credit. These students work in the lab while the spring cohort is just beginning to learn basic skills and techniques. The independent researchers are encouraged to share their knowledge with the stream freshmen. This interaction is inspiring to the new group of students, as the level of the independent researchers gives them an idea of how much they can expect to achieve after just one year of stream research.

The FRI mentors, described in more detail below, assist the most in keeping the projects moving forward. The trickle down knowledge that they share with the mentees provides continuity to the stream research. The guidance that they provide the students based on their own research insights, as well as their continued participation in the research, has been key in passing along the research knowledge.

FRI Program History

The FRI began in 2005 with an internally funded pilot program for 43 honors students. That year, several university faculty initiated undergraduate research courses that were, in essence, extensions of their own graduate laboratories. These initial research streams represented three separate research areas in chemistry, biochemistry, and molecular biology and were led by a single non-tenure track instructor working closely with the faculty. The following year, the program was awarded grants from the NSF and the HHMI, opening the program to non-honors students in the College of Natural Sciences and quadrupling its size. More streams were created in biology, chemistry and computer science fields, and PhD-level scientists were hired to oversee each stream alongside the principal investigator who initiated each lab. These new non-tenure track faculty members were chosen primarily based on graduate research experience directly related to the stream, and a new position was created at the university: the Research Educator (RE). In some groups, a graduate student or team of graduate students were selected to fill the RE role.

Currently, the program has 25 active streams in a variety of natural science disciplines, including astronomy, biology, biochemistry, chemistry, computer science, and physics. The program has been sustained by grants from the HHMI, contributions by PIs from their NSF program grants, industry support, and internal funding from the University. In 8 years, nearly 3000 University of Texas students have participated in the FRI program; in 2013, approximately 870 students started in FRI, about one-third of the incoming natural sciences class.

FRI Laboratory Personnel

Comparison to Traditional Laboratories

The FRI infrastructure blends the framework of research and teaching labs (Figure 4). Traditional research laboratories typically accommodate very few undergraduate students, with the majority of the research group consisting of postdoctoral fellows and graduate students, overseen by a principal investigator (PI). This structure has the benefit of allowing a great deal of interaction between the PI and the group members, but typically the number of undergraduates able to participate in this type of structure is small, and limited to a few highly competitive upperclassmen. The teaching laboratories at our University accommodate many more students in a large lecture/traditional lab format, but individual instruction is almost entirely performed by Teaching Assistants (TAs) as opposed to the PhD level instructors, whom students have little contact with. This is a necessary flaw, as the instructors usually have the responsibility to oversee all labs of that type, and these labs are required by many students' degree plans.

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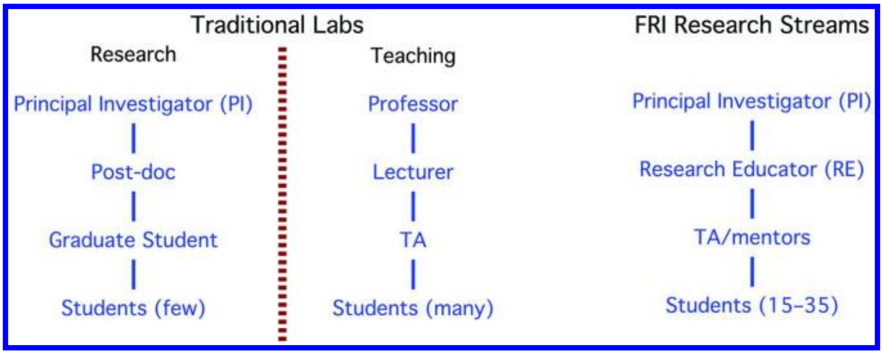

Figure 4. Lab infrastructure

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FRI labs, by contrast, allow the students to interact with two PhD level scientists, the PI and the RE, who are both invested in the research project. Students immediately identify the value in what they are learning, as they quickly observe that it relates to a real research problem that is important to the faculty they interact with.

The RE is responsible for the daily instruction in the FRI lab, as well as most of the lab management. The FRI laboratory staff may include graduate TAs; however, the more senior FRI students that serve as mentors fulfill a similar role as that of the graduate students and TAs in the traditional lab infrastructure. Many undergraduates can perform research in a single FRI lab, and the number of students in a stream may range from about 15–35, depending on the type of lab and amount of supervision needed.

The FRI Mentors are a critical part of our framework, and students selected for this leadership role are usually sophomores who have completed the FRI course sequence in the stream and have shown a passion for research. When selected to be a mentor, the student also joins the Peer Leader Academy, a training program offered to all peer mentors, tutors, and undergraduate TAs in the College of Natural Sciences, which affords them a nationally recognized peer teaching certification through the College Reading and Learning Association. To attain this, peer mentors are required to participate in skill building training sessions that allow them to advance in areas such as professional conduct, problem solving, conflict resolution, and emergency preparedness. Typically, the RE also provides additional mentor training for stream-specific needs.

Mentors are encouraged to continue their own research projects alongside the students they instruct. In streams involving chemistry or biology bench work, the mentors may also help manage much of the lab logistics, such as recording items needed and pricing them for orders, restocking supplies, helping maintain equipment, and troubleshooting problems.

Mentors often play a key role in the development of curriculum for each stream. In the SBRS, they have written assignments as well as first drafts of answer keys. Having mentors work through the assignments that instructors create and provide feedback about level of difficulty, clarity of descriptions, and overall impact of the task enables our REs to challenge students appropriately, without discouraging and alienating younger students who are not yet prepared for the rigor of a graduate level lab. Although they do not award grades, mentors can evaluate on a rubric and give narrative feedback, greatly increasing the quality of assignments such as reports and laboratory notebook entries prior to TA or RE evaluation.

The connection the mentors have with their students provides key support that is essential to the success of the program. When students are discouraged, mentors provide encouragement from the perspective of former students who have experienced the same frustrations of research and the long hours in lab. In this way, the mentors serve as liaisons to the current group of students and identify which students are struggling, if a concept or an assignment is too difficult and if additional guidance is needed.

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A Closer Look at the RE Role

The introduction of a dedicated faculty member to direct each stream is one of the key aspects that has made it possible to engage large numbers of freshmen in publishable, authentic research. The stream PI usually has a general research project idea for the stream undergraduates, and a goal for what they feel the students should accomplish. It is the RE's responsibility to translate the PI's research aims into a curriculum that both allows the students to quickly become trained in the essential skills they need to execute the research project and fulfills the curriculum requirements of the listed course.

In most cases, the RE is the main instructor of the FRI lab, responsible for daily instruction, oversight and management of the student cohort and mentors. A weekly lecture hour is scheduled for each stream, which may serve as either a group meeting or formal lecture. Although some PIs give stream lectures, it is often the RE that leads this meeting by lecturing, moderating discussions, or managing student presentations.

Each stream's research is conducted using space and facilities outside of the PI's laboratory that are appropriate and fully functional for that area of research, and the REs manage the use of this space. Streams that focus on theoretical work often use a computer lab and meeting areas, while most experimental groups work in a research laboratory typical for their discipline, often sharing space with other similar streams to improve efficiency. Because multiple streams share research spaces, laboratories must safely accommodate large groups of students.

Logistical considerations arise with heavily used space, and *organization of activities and scheduling is critical* to guarantee that each stream has an equal opportunity to make research progress, while ensuring that the number of students in lab does not pose a safety hazard. Many REs have found the implementation of an online calendar to be extremely helpful in scheduling. In some FRI labs, all bench space and equipment can be reserved using the calendar, while some groups simply limit the overall number of students that can sign up at one time. Although student self-scheduling has worked for many streams, in some groups, the RE sets specific lab times for students. Often, students working on similar

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projects will be scheduled together under the supervision of a single mentor that is well versed in the techniques the group will be performing. FRI labs are often open long hours on semester weekdays, and many labs are open on the weekends. During the semester, typical lab hours can range from 9 a.m.–9 p.m. The REs must coordinate their own lab time, along with the mentors' hours, to ensure adequate supervision and guidance, while still allowing students enough work time to keep the research moving forward.

Given the relatively small cohort of an FRI stream, REs have the opportunity to work individually with students to help them develop their writing and presentation skills. Many REs have developed a thorough approach to teaching scientific writing that encompasses critical reading, peer reviews and assignment rewrites. Dissemination of research results is also a focus, and REs often work closely with the students on research presentations given both for other stream members and at on-campus events. Additionally, REs are encouraged to attend professional conferences with the undergraduates, helping the students to organize travel and guiding the preparation of a quality presentation for the event. The College of Natural Sciences offers stipends that the students can apply for to assist with their travels, and FRI students often receive support to attend professional conferences.

Keeping track of individual research progress in a large, diversified group is a unique challenge in the FRI model. *Electronic forums have been a successful solution to this problem* in larger streams, and have become an effective communication tool for research. The RE for the FRI Virtual Drug Screening stream uses a Wikispaces page (*18*) that is updated every two weeks as an electronic journal of each student's research; entries highlight the key results that have been recorded in their lab notebooks over the time period. The FRI Aptamer stream RE utilizes a publicly viewable blog (*19*) for posting research progress, and has been contacted on multiple occasions by researchers in the field inquiring about protocols and projects. The students present their research on the blog, omitting some detail that may be publishable, and also leaving out data that may cause misinterpretation of early results. Some streams share progress in a less public manner; often a stream Google account proves useful for collecting progress reports.

Finally, some program administration is delegated to REs, and each RE has additional responsibility for a programmatic piece they most closely identify with or feel would best augment their professional development. The RE meets with the FRI Director every other week to plan and discuss progress. Critical FRI Program components managed by Research Educators include:

1. Recruitment, application processing, and Freshman Orientation
2. Stream Sort
3. Placement in advanced research opportunities after FRI
4. Public Relations
5. Industry Relations
6. Outreach
7. Mentor selection and training

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Success of the FRI

The FRI program's success at the university is evident through faculty and administrative support, the popularity of the program, and the students' pride when they talk about their streams. Student perceptions have indicated the value of undergraduate research (*20–22*), and FRI program data affirms the benefits.

For example, student retention within science, technology, engineering, and mathematics (STEM) fields is a challenge faced by many universities across the country. Prior to 2005, an assessment of student outcomes in the College of Natural Sciences identified several factors that correlated with an increased risk of non-completion of a degree in the college, including: low SAT scores (<1100 combined math and verbal), a household income of less than $40,000 per year, and neither parent having completed a four-year degree. Additionally, females in mathematics, astronomy, computer science, and physics, and underrepresented ethnicities in the sciences in general were shown to be less likely to graduate with a STEM degree. Moreover, these groups showed low participation in research—an activity with demonstrated positive impact on retention and STEM degree attainment (*20–22*). FRI recruitment strategies have directly addressed limiting factors to participation and have increased research involvement for each of these groups, compared to pre-FRI levels. Additionally, FRI program data (*23*) indicate that participation in research through the program *improves retention* and *graduation rates* among all students, and the greatest improvements in rates are seen in groups most at risk. FRI program data also show *improved academic performance* by FRI participants across all groups—these data will be disseminated in a forthcoming publication.

Additionally, the impressive number of publications that have been produced through FRI with student coauthors attests to the program's success in providing students with an authentic research experience. FRI students have coauthored over 150 peer-reviewed publications that are either published or in press, and nearly 100 FRI students have been coauthors to date; representative examples in astronomy (*24*), chemistry (*25*), biology (*26*), biochemistry (*27*), and computer science (*28*) illustrate the program's success in this area.

FRI in Context: Large-Scale Research Programs

There is a strong historical context for the implementation of large-scale research programs in the United States. Most institutions offer course credit for participation in research (Undergraduate Research Opportunity programs, or UROPs, notably that at the University of Michigan, Loyola Marymount University's Sea-Phage program, The University of California, Santa Barbara's Large-Scale Undergraduate Research or LURE program). Some institutions give course credit for research-like or research preparatory work (Center for Authentic Science Practice in Education or CASPiE program at Purdue, the Integrated Quantitative Science program (*29*) at the University of Richmond). Summer research opportunities for students have been a focus of programs such as NSF REUs. Generally, the students leave their home institutions and travel to another university to perform a research project.

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The FRI approach to the curriculum blends aspects of both the coursework-based research experiences and summer research immersion; however, some of the success can be attributed to the continuity of the research. Students continue on the same research project over the summer, allowing a great deal of progress to be made in a one-year period. Students *receive course credit that counts toward their degree* during each long semester. Rather than being a competitive application process that admits only top applicants, admissions coordinators seek to *increase participation in underrepresented groups*, giving a diverse group of students with varying levels of ability the opportunity to try research, which is similar to Michigan's UROP that has also shown increased retention in underrepresented groups (*30*).

Conclusion

The FRI program engages students in *authentic research* early in their college career, while allowing them to earn *course credit* for participation. This program has shown that young students, *even first semester freshmen*, can engage in research and be successful. Coupling course and graduation requirements with a curriculum that focuses on developing skills in a specific research area is an effective tool for getting young students involved in research in the first place, and advancing them to the point where they can make real research progress in a one-year period. Integration of research into the curriculum gives students the feeling that research is part of their academic experience; however, the optional summer that FRI spans allows students the summer experience as well, where they can focus primarily on their projects.

The continuity of the year in the stream, facilitated by an optional summer research experience, has aided research progress in the Synthesis and Biological Recognition stream by not only advancing the research projects, but by producing natural student leaders for the fall semester. In this organic chemistry-centered FRI research group, most of students have not yet taken organic chemistry; however, they begin their first week in lab shaking a separatory funnel and progress quickly to the point of running multistep reactions. Showing students the joys and pitfalls of research at the start of their academic career allows them to decide at an early stage if research is a potential career option and gives them enough time to build a full resume of research experience by the time they pursue graduate or professional school.

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Chapter 10

Making the Transition: From Performing Graduate and Postdoctoral Research to Directing Undergraduate Research at a Small College

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Undergraduate research is an extremely important part of the education and training of new chemists but many new faculty members at small liberal arts colleges are not prepared for the transition from doing research at a large university to managing a research group at a small college. This chapter will describe some of the major challenges in transitioning from performing research at a research university to directing a research group at a small college.

Introduction

This chapter is targeted toward new faculty at small liberal arts colleges, as well as graduate students, postdoctoral scholars, and chemical professionals who are considering a career in chemical education. Under the current Carnegie Classification of Institutions of Higher Education (*1*), these schools would be classified as small (<3000 students) four-year, primarily residential baccalaureate colleges in either the “Arts & Science” or “Diverse Fields” groups. The importance of undergraduate research in the education of future chemical professionals is well understood (*2–5*) and many colleges and universities are requiring a research component in their bachelor of science degree curriculums. However, new faculty are often unprepared for the transition from performing research at a university under the direction of a principal investigator to conducting undergraduate research on their own. There are many unique challenges that new

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ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

faculty members at small colleges face, particularly in establishing a productive undergraduate research laboratory and adapting their research ideas to work in the setting of a typical small college. Table I highlights some of the most important differences between the two research environments. This chapter will attempt to highlight some of those challenges and provide some suggestions to help establish a productive research group in the setting of a small college.

Table I. Major differences between the research environments at a research university and a small college

Factors That Affect Research	***Research University: The environment in which you are used to working***	***Small College: Your new reality***
Faculty Course Load	PIs typically teach one course a semester and have graduate teaching assistants to help grade.	You will most likely teach four or more courses a semester and do all of the grading yourself.
Number of Students Available to Perform Research	Every year there are many new graduate students to recruit to join research laboratories.	The number of chemistry majors can vary drastically between years. If you only target chemistry majors for conducting research you may not be able to find enough students.
Time Students will Spend Doing Research	Graduate students typically spend 40–60 hours per week in the lab for 4–6 years.	Undergraduates typically spend 3–4 hours per week in the lab for 1–4 semesters. If funding is available students may also work fulltime in the laboratory for 8–10 weeks during the summer.
Research Space	More funding usually leads to more research space.	Research space is usually fixed and often the space will be shared by more than one faculty member or by laboratory courses.
Instrumentation	Instrumentation is plentiful and redundant, with technicians to fix and maintain instruments.	Often only one of each instrument exists and is shared between laboratory courses and research. Faculty are responsible for instrument upkeep and repair.
Research Expectations	Many publications each year.	Expectations vary greatly from college to college.

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Table I. (Continued). Major differences between the research environments at a research university and a small college

Factors That Affect Research	*Research University: The environment in which you are used to working*	*Small College: Your new reality*
Tenure	Primarily depends upon funding and publication record with teaching record playing only a minor role in the process.	Often depends primarily on teaching evaluations and college service, rather than research.
Funding	High levels of funding are required to run a research group with equipment, students, and personnel, in addition to supplying the university with the necessary overhead to maintain the facilities and resources of the department.	The amount of funding you need varies greatly depending upon the research you are doing and the support level you have from your department and college. Most small colleges will not require you bring in overhead paying grants.

Every small college treats research differently. There are two criteria that you need to consider when accepting a position at a small college and building your research program. 1) What are the expectations for your research, i.e., what do you need to do to secure tenure: do you just need to perform some research with students or are there a certain number of publications expected to result from the research? 2) What level of support is provided internally by the school, both in terms of financial support and facilities?

Some administrations will greatly support research and have dedicated funding for undergraduate research within the department budgets as well as additional funding though internal grants. At the other extreme, some colleges will not have active research programs at all. Most small colleges lie somewhere in the middle, where the administration supports and encourages undergraduate research but may not have the resources to adequately or completely fund it. They may have some internal grants that can be used to purchase equipment and chemicals or to fund travel to conferences, but they rely on the principal investigator to secure the bulk of the funding for their research program. In order to properly develop your research program you need to know what the resources and expectations are at your college. Establishing realistic goals and time frames for your research is very important. If you establish unrealistic expectations for your particular environment, you will be unhappy and your research and students will suffer.

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Getting Started

You just accepted your first faculty position at a small liberal arts college. You know what you will be teaching; you know what is expected of you in regards to teaching, service, and research to gain tenure; you know what resources are available to you for teaching and for research; and you have some ideas about what you want to research. Now comes the hard part, establishing your research lab and recruiting students to join you on the adventure.

Adjusting Your Expectations to Your New Reality

If you are like the majority of first-time faculty members, you are coming from a graduate research lab or postdoctoral fellowship at a major research university and are used to the resources, equipment, instrumentation, and funding associated with an intense research environment. Unless you attended a small college for your undergraduate education you have no idea what to expect when you arrive on campus other than small class sizes and an emphasis on teaching. One of the biggest struggles you will have is to adapt your research ideas to your new reality. You will almost certainly find yourself with fewer resources and less equipment than you are used to, instrumentation that while adequate for educating undergraduates will almost certainly be fewer in number and less advanced than that at the research institution you are coming from, and a small research budget.

Most new faculty are still focused on the expected research outcomes that they experienced at their graduate or postdoctoral institutions and the criteria that are generally used to judge scientists: the number and quality of their research publications. The whole goal of your graduate and postgraduate education was to carry out productive research that resulted in a publication for yourselves and your principle investigator, so that the PI could use this publication as evidence of productivity to secure more funding. While publications are certainly important, an adjustment has to made in the mindset of the new faculty member that when educating undergraduates, publications are far from the most important thing. Nobel Prize winner Thomas Cech wrote an eloquent essay on the advantages of receiving a science education at a liberal arts college (*6*) in which he highlights the fact that the most important aspect is not the publication record of the undergraduate scientist but the personal attention the undergraduate receives during the experience from his or her mentor.

If you set your research goals with that in mind, you will find that assessing your success will depend not on the number of publications you write, but on the future success of your undergraduate research partners based on the training you have provided them. At the start of your career the research projects that you want to carry out may not be possible with the resources that you have on hand, but that should not stop you from establishing what goals you want your students to attain and how you are going to manage your research group, even if you have to design projects completely from scratch to work in your new setting.

I have had the opportunity to work at two institutions that value the contributions of undergraduate research to the educational process. Due to the difference between the two institutions I have the good fortune to be able to establish my research laboratory twice! In my first position I joined an established department with a record of successful undergraduate research and resources that enabled me to conduct successful research from my very first semester. I left that position to move to a smaller college and develop a brand new biochemistry bachelor's degree program. The differences in resources, instrumentation, and equipment meant that my research projects had to either be majorly adjusted or abandoned for new ones. This experience has led me to recommend that new faculty design their research program in a three-fold approach. First, establish what you want the learning outcomes to be for your students after completing a research project with you. Then, based on the resources available, your own interests, and the interests of your students, pick the projects that you will research. Third, establish funding and long-terms goals for the purchasing of new equipment and for funding trips to scientific meetings so that you students can present their research.

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Desired Learning Outcomes

While publications are the desired outcome at research universities, the ultimate outcome of undergraduate research education should be the hard and soft skills your students gain while conducting research. Before I accepted my first undergraduate research student, I made a list of goals with which I wanted all students who entered my laboratory to leave, whether they stayed for one semester or several years. I explain the goals to any student who joins my laboratory and I also provide them with a welcome kit/lab manual that goes into detail on several of the items listed. The list of skills includes the following:

Safety Skills – All students conducting research in this laboratory should understand the basic safety rules of working in a chemistry laboratory and know all of the safety considerations of any chemical or equipment that they are using.

Teamwork Skills – All students conducting research in this laboratory will work in groups and learn how to delegate responsibilities and communicate with group members in a team setting.

Notebook Skills – All students will learn how to keep a professional-level research notebook.

Online Literature Searching Skills – All students will learn how to conduct thorough searches of the chemical literature using web-based software and databases.

Experimental Skills – Students will further develop the techniques they have learned in laboratory courses as well as learning advanced techniques specific to biochemical and organic chemistry research.

Presentations and Communication Skills – All students will learn to present their research by writing research reports each semester and presenting a research poster or presentation at the college's annual research day. Advanced students may have the opportunity to present their research at the ACS National Meeting in the form of a poster or presentation their junior or senior year. Occasionally, research will progress to the level of publication-quality results. When this happens all students who worked on the project, even those who have graduated, will be authors on the manuscript. The students currently in the laboratory will be responsible for writing the initial draft of the manuscript.

I use this list as a guide for each student who joins my laboratory. Some will come to me with excellent writing skills but terrible teamwork skills. Others will be great at following directions but seemingly unable to think on their own. Each student is different and needs a different course of direction as they progress through their research experience. I judge my success level not on what is physically accomplished in the laboratory, in terms of number of successful experiments, but by the students' growth in these key areas that are completely independent from the subject of the research projects.

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Picking Research Projects

When I first started my teaching career, I was certain that I would continue performing research on projects related to my graduate and post-doctoral research. For a while it provided very active and productive research experiences for my students but I quickly realized that maintaining the funding levels necessary to do the research that I wanted to do while teaching a full course load and performing all of the other college services that were expected of me was unrealistic. I instead started to focus on projects that were more easily performed with the skill level of the students, equipment, and instrumentation that was available and eventually found that the best research projects actually came from ideas the students were interested in and brought to me.

Now when students approach me about performing research I ask them to come up with a project that they would like to research. The majority of students will have either summer vacation or the break between fall and spring terms to come up with research ideas; we can communicate by email during this time to help guide the students in their selection process. Most of the time, the projects are not feasible due to equipment restraints or cost, but it gives me a great idea of what the students' interests are and also their intellectual ability. If the students cannot come up with any ideas on their own, I give them the option of joining research projects other students are already working on or give them a few ideas about projects that I am considering starting. In all cases, I make the students do background research and literature investigations of the projects. Once the student has taken the time to research a topic and formulate an idea, we discuss the possibility with regards to our facilities and equipment and many times are able to take the initial idea and formulate it into a project that is "doable" over the course of a semester or two.

Funding

Finding funding resources at a small college is just as hard as it is at major research universities. In the current economic times, funding is tight and hard to come by. I am not going to review all of the major governmental or private sources of funding (Research Corporation, ACS-PRF, Dreyfus Foundation, NSF-RUI, NIH-AREA) here because with a quick Internet search you can find information on all of them. Instead I am going to suggest some alternative sources that are often overlooked.

Internal funding is by far the easiest to obtain and the quickest way to fund your research. Be sure to find out exactly what money is available on your campus from your administration, faculty union, student council, etc. Most colleges have research grants that can be applied for each year, but often there will also be other sources of funding that may not pay for research but can fund travel expenses. One of the most important things that I try to do for my students each year is to get them to regional and national meetings to present their research and to interact and engage with other chemists. Traveling to these meetings is expensive, especially when airfare and lodging is required. Many schools will have travel funds that are available to undergraduates to attend meetings. Encourage your students to apply for them. Make your students joins the ACS, if for no other reason than so that they can apply for travel grants and get reduced registration fees at meetings.

Your local community is another great source for funding. Local chemical companies are often very helpful in funding small projects or providing resources such as instrumentation or specialized equipment. Large companies will often have academic liaisons for specifically this purpose. Often the hardest part is meeting the right people who can help you. One way to facilitate this is to reach out to the local companies through phone calls or email. Joining your ACS local section may also be an effective way to meet new contacts. Find out if your department or college has any internships in the area and target those companies for support.

Change your mindset so that you do not just think of funding as someone giving you money to do research. Instead, think of it as any resource that does not require you to spend money. Maybe it is the use of an instrument at a nearby university or the donation of liquid nitrogen from a local company. Networking in your local area can enable you to do a lot of research with a very small budget.

How To Recruit Your First Students?

Coming up with goals for your research group, novel research ideas, and funding doesn’t do you any good unless you can recruit students to work with you. At a small college this is actually a major problem because from year to year the number of chemistry majors can fluctuate greatly. While there are certainly many colleges that attract large number of science majors a year, at most small colleges that number can vary greatly between different class years. It is not uncommon to have one or two majors graduating one year and to have 15-20 majors the next year. It is important that, while you focus on the chemistry and biochemistry majors, you do not limit yourself to just these students. Be willing to take students from any major on campus who are strong academically and have a strong interest in chemistry.

The single best way that I have found to recruit students is to teach freshman and sophomore level laboratory courses and to use your research interests as examples in lecture classes. Teaching laboratory classes gives you access to the students in a confined setting for several hours at a time. It gives you a unique

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opportunity to get to know your students and their interests. If you can get a good student engaged in a conversation about research then you can usually convince them to do research. Sometimes it will become clear that their interests lie more in the area of one of your coworkers, and when this happens it is an excellent opportunity to form a collaboration in which the student can work for both of you!

Another very successful way to recruit students is to have your research posters hanging up in the hallway by your office so that students can read them while they are waiting to see you during office hours. If you don't have any research posters to hang up, which is likely to be the case your first year, then make a poster that highlights your research interests and specifically says that you are looking for highly motived students to help you carry out the research.

The more activities that you can do that force you to engage with the students and have conversation with them, the more success you will have recruiting researchers. Offer to give a departmental seminar on your research interests to the students and your colleagues. Go the Chemistry Club meetings and offer to help them out with their projects. If your college doesn't have a Chemistry Club or ACS Student Affiliate chapter, help the students start one. If the students see that you are interested in them and their education they will want to work with you.

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Building Your Research Program

Managing Your Lab

Once you have more than a couple of students working with you, you must consider how you will manage your research lab. The tempting thing to do is to micromanage and make sure that everything (inventory, cleaning, routine maintenance, etc.) is taken care of by doing it yourself. However, the best thing you can do for your students is to treat them as professionals from the very beginning, even when they are completely in the training phase and you would never leave them alone for even a minute. Establish a list of responsibilities for which everyone in the lab is individually responsible, e.g., cleaning and putting away glassware before they leave the lab, informing you when chemicals are almost empty, making sure that the last person in the lab turns off the water and lights, etc. Then establish a list of task that are assigned to individual lab members, e.g., who is in charge of the vacuum pump, the solvent inventory, the glove supply, etc. I prefer to run my lab similarly to a graduate research group and at the beginning of each semester we divide up the responsibilities and students know that how well each student performs his or her task is taken into account when assigning their grade at the end of the semester.

However you decide to run your laboratory, an excellent resource for all new faculty is "Making the Right Moves" (*7*) published by the Burroughs Wellcome Fund and the Howard Hughes Medical Institute. The guide is available for free on the HHMI website (*8*). While it is primarily written for new faculty at research universities, almost every chapter can be directly applied to managing a research group in a small college setting. It has excellent chapters and resources on developing an effective leadership style, mentoring, time and project management, data management, and setting up collaborations.

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I manage my lab with the goal of preparing the student for conducting independent research in graduate school or in the industrial setting upon graduation and so the major areas that I focus on are safety, teamwork, literature reading skills, record keeping, presentations skills, and scientific communication. I provide all students with a Group Manual that contains safety information, general laboratory procedures, equipment information, proper notebook-keeping instructions and examples, and scientific writing resources and examples. I have found that physically handing them a manual not only provides them with a quick reference guide to what is expected of them, but they also take the information more seriously because I have gone through the effort to prepare the manual for them.

Safety

Safety is best taught by practicing it all the time. Students must adhere to all safety rules whenever they are conducting research and if they are caught not following the rules, they are asked to leave the lab for the day. The best thing you can do while you are training your students is make them look up the safety information for all chemicals they are using and then review all safety issues involved in an experiment with them before they start the experiment. The way I do this is before I let students perform an experiment, I give them the procedure and have them prepare to tell me what all of the safety issues are with the procedure and what can be done to minimize the issues. Then I give them "what-if" scenarios of other things that could be going on in lab while they are performing their experiment and what they would do if something happened. For example, what would they do if a water line broke and sprayed water on their experiment or what they would do if the power went out and the fume hoods quit working. Most of the time students don't realize just how dangerous chemical research is because they have the mindset that we wouldn't allow them to do anything that could hurt them. In my opinion this is the single biggest way that colleges and universities fail their undergraduate chemistry students, by not teaching them how to think about safety. We do an excellent job of giving them a list of safety rules to follow but we don't take enough time to go through the little details of what they need to consider when actually performing an experiment on their own and not in the teaching laboratory setting.

Team Work

While it is not always possible due to the number of students performing research, I have found that the best way to prepare undergraduates for the teamwork that will be required of them in graduate school and the industrial setting is by having them work in groups of two-three students on a single project. I help them formulate the plan for what needs to be done and what procedures need to be followed but I leave it up to the students to decide who does what parts of the project and when they do them. The first time I tried this, I expected it to be a disaster with one person doing most of the work and the others watching, or the students wouldn’t be able to get along socially. However, what I discovered was that the students were actually more productive because they could share the effort and they actually got more research accomplished. They coordinated their schedules so that when things like pouring a column and making a buffer needed to be completed before their normally schedule research time, they shared the responsibilities. It also forces them to be more responsible with their record-keeping because they have to share it with their lab partners. The peer pressure they get from each other is much more motivating to them than any other technique I have utilized.

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Literature Reading

One of the best ways to prepare students for their future careers is to help them learn how to read and discuss the scientific literature. One way is to have group meetings where students present a paper to the whole group; another way is to pass out papers that everyone reads and then have a discussion about them the following week. I typically do this two or three times a semester, depending on the number of research students.

When a student joins my lab, I take the first few weeks of the semester and teach them how to use the various chemical search tools that are available on-line, e.g., SciFinder, Web of Science, Science Citation Index, Beilstein, the ACS Publications website, and Google Scholar. If your college does not have access to these search databases, it is well worth your time to take a field trip to the library of a local research university that has access to show your students what resources are available. If your college does not subscribe to many research journals then you will have to find the closest university to you that has access to the chemical literature or utilize interlibrary loans. We also work on developing their ability to read and comprehend scientific literature by doing background reading on their project and then having one-on-one discussions about the reading. This may seem like a lot of time taken away from wet chemistry and data production if you have the mindset that getting publication-quality research completed is the most important facet of your research program. However, if you step back and look at it from the perspective of educating the students on how to perform research, you will see that learning how to conduct literature searches and formulate a research plan is one of the most important skills that they will need in their future careers as chemists but it is one of the skills that often does not get taught in traditional lecture and laboratory courses. It also gets left out of undergraduate research in favor of teaching laboratory techniques right from the very start. During these weeks, I also have the students start working in the laboratory learning how to prepare stock solutions, buffers, clean glassware, learn safety procedures, and other fundamental techniques that they will need for their project. For the first few weeks of the semester, a typically three to four hour research session will include 30 to 40 minutes of discussion and computer tutorials and two-three hours of wet chemistry in the lab. The students are also assigned homework that includes doing literature searches and reading articles or procedures for the next week's research session.

Record Keeping

Keeping a professional-quality research notebook is the one skill that all students need to have prior to graduation. Keeping an accurate record of what was done during an experiment is something that a student needs to learn to do. Undergraduates get lots of experience with notebooks in their laboratory courses but many times the expectations of what goes into a laboratory notebook are much lower than what will be expected of a student in his or her first job. Making sure that students understand that a notebook is a real-time record-keeping device is hard work. It seems to be human nature in the laboratory to want to write things down on scratch paper and copy them neatly in the notebook at a later time. You have to be diligent about making sure they are keeping records as the experiment is happening by watching them and reminding them to put the observations and data in the notebook as they collect it. I always provide my research students with examples of good and bad notebook entries and remind them that with a good notebook entry, another chemist should be able to repeat the experiment using just the notebook entry and no other resourses. Nearly every day that they are in my laboratory I remind them that if they do not keep a good notebook in an industrial job they will be fired, because notebooks are the de facto records of what was accomplished and when it was accomplished and are often the deciding factor in patent disputes.

In addition to notebooks, I also have my students write a research summary at the end of each semester that is formatted in the style of the Journal of the American Chemical Society. I provide the *JACS* author guidelines (*9*) to the students and have a copy of the ACS Style Guide (*10*) for them to use while writing their summaries. It helps them to build their science writing skills and forces them to follow a set of prescribed style guidelines. These research summaries are also very valuable resources to students who will pick up the project at a later date.

One other aspect of record-keeping that you need to think about is your own. How are you going to handle all the data that you and your students collect? Chances are that publications will come from data collected by several students over a number of years. It is also highly likely that the instrumentation used to collect the data will not only be shared by you and your colleagues but also by the teaching laboratories, making storing data on shared computers a risky proposition at best. You need to be organized from the very first student and develop your own systems for keeping track of what was accomplished, by whom, and where the raw data is filed and stored. Unlike PIs at research institutions, you will not have the luxury of being able to focus primarily on your research. You will be devoting the majority of your time to teaching and college service so it is extremely important that you are organized from the very beginning and have a system in place before you start generating data. A dedicated laboratory computer where all data can be stored is a great investment. The use of a free cloud storage service such as Google Drive, Dropbox, or Copy is also an excellent idea for storing and backing up data. This allows for easy sharing of data and makes the data available from any computer. I have found that the best way to keep track of individual students' data is to give each student a USB flash drive on which to store all research documents and data. I find the USB drive to be more useful than an online cloud storage service simply because some of our instruments are not connected to the Internet. I make it clear that the USB drive is lab property and must be returned to me at the end of the semester along with their research summary. I also have my students keep a hard copy of data in a three-ring binder. At the end of each semester, I copy the contents of the USB drive onto my office computer into a research folder that contains subfolders for each semester and each student. I also back up the hard drive of the lab computer once a week and at the end of each semester. When students leave the lab, I take their individual binders and collate the data into a project binder that I have stored in my office.

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Recruiting New Students

After a year or two you will find that you no longer have to put as much effort into recruiting students because your current group members will do it for you, provided you have given them a valuable experience. Establishing a reputation as a caring instructor and excellent teacher will go a long way to keeping your research group full of highly qualified undergraduate researchers. Whenever possible take your students to local, regional, or national meetings, the experience they get out of networking with their fellow chemists is invaluable and the reputation you get, amongst the students, as a faculty member who takes one's students to meetings in other cities can be one of your biggest recruiting tools. Once you start to graduate students and help them with their graduate school selection and application and with professional school applications keep track of the students' successes visually in your lab or office so that new students can see the results of conducting undergraduate research with you. An easy way to do this is to take a group picture of all the graduating seniors each year and then label it with where the students went to graduate school, professional school, or started their first job.

Presentations/Publications

The best thing you can do as a new faculty member is establish high expectations for your students. Make them aware of the expectations on the very first day they inquire about doing research with you. One expectation that every student I have ever conducted research with has met is the expectation that at some point during the year the students will present their research, either as a poster or PowerPoint presentation, at a local, regional, or national meeting. For first-time research students, this presentation usually occurs during our on campus scholarship day when students from all over campus can present their research. For more advanced and senior students, this presentation normally occurs as a poster presentation at the spring ACS National Meeting. The expectation of having to present the research to other people is a great motivating force for the student and the resources and networking that you expose them to by taking them

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to regional and national meetings can often be a deciding factor in their future career choice.

Your record of accomplishment of having students present posters and presentations at regional and national meetings will also help you as you prepare for tenure. Ultimately, publications may be needed to secure tenure, but the number and format will vary depending upon your college. In addition to the well-known national and international journals, there are often local venues for publishing research articles. Many states have a science teachers association that publishes monthly, quarterly, or bi-annual publications. Don't be afraid to submit articles to these journals. They may not be as prestigious as the well-known journals but often at small colleges the tenure committee is looking at number of publications rather than the impact factor of the journal in which they are published. Ultimately, where and when you publish will depend upon your particular needs for tenure and promotion and on how much funding you are able to procure.

Continuing To Fund Your Research

Once you have established a research group and have a good reputation as a faculty member with the students you will have the time and the students necessary to carry out more elaborate research projects and seek more ambitious grants, such as NSF TUES grants for equipment and NIH R-15 grants for research. At some institutions grant-writing will be an expectation for tenure or promotion. At other institutions you will just need to provide enough support to conduct your own research. Find out if your campus has an office of sponsored research or other help for writing and submitting grants. Most small schools will have an administrative member who is responsible for applying for grants for the college and often this person will also work with faculty to submit individual grants. If nothing else they can provide a proofreading service to you and help with your budget submission. The easiest way to find out what is available on your campus is to ask your department chair and your academic dean.

If your college doesn't have a monetary support system set up for conducting research, be your own advocate and work to encourage them to do so. A pot of 25,000 to 100,000 dollars a year for faculty research awards of 1000 to 5000 dollars per award is not that much money in the overall working budget of even the smallest colleges. If the administration knows that there are faculty who will use the money they will often provide it, because they can use it as a recruiting tool to attract better students and potential donors. Successful representation at regional and national meetings will go a long way to get you more support from your administration. Make sure that you highlight student accomplishments on your department website and hang your research posters in the hallways of your department. Contact the college newspaper and see if they will do a story on students presenting at national meetings. Adapt to the small college setting; just because the college is small doesn't mean that the administration can keep up with every activity of every department, but being a small school they do care and want to know. Send emails to your Dean or Provost when students present their research

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off campus. Make sure that the administration and others notice the work you and your students are putting into research on campus.

Discuss research funding with your department members. You may be able to get creative to defray the cost of doing research. You may not be able to get more money in your department budget but you should be able to pool together your resources so that you use the funding that you have effectively. An example of this would be to purchase solvents and chemicals in bulk and share the cost of them between the entire faculty conducting research and the department purchasing the chemicals needed for the teaching laboratories. Working together can make a little funding go a long way.

Conclusions

While the expectations and opportunities for conducting undergraduate research will vary greatly between colleges, the ideas presented in this chapter can help you in developing and maintaining a strong undergraduate research program at a small college. If you focus on the students and the skills that you can provide them for their future success, you will find the process very rewarding and the extra work that is required to secure the equipment and funding necessary to build your research program will be worth it.

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Chapter 11

Global Curriculum Changes To Facilitate Undergraduate Research Experiences

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Participation of undergraduates in research has increased over the years in response to initiatives from various professional societies and educational organizations. Undergraduate research provides a unique learning experience benefitting the student, faculty mentor, and institution. At the U.S. Naval Academy, we completely redesigned our chemistry majors' curriculum to require senior projects of *all* of our majors. The restructured laboratory curriculum is based on four semesters of integrated laboratory, a sequence organized around broad themes in chemistry such as separation/purification, synthesis, qualitative analysis, and quantitative analysis rather than traditional subdisciplines within chemistry. The integrated laboratory curriculum has facilitated the inclusion of a research or capstone experience for *all* of our chemistry majors. Here we report the development of our integrated laboratory sequence, the two tracks for our senior students to participate in research/capstone projects, challenges with implementation, outcomes, and advice to other institutions. These changes required significant effort in redesigning our curriculum and the acceptance of undergraduate research as a culminating experience worthy of faculty and administrative support. However, we have felt it was worth our effort as our number of majors has increased, students seem dramatically more satisfied with the major, interactions between students and faculty have increased, and research productivity seems to have been enhanced.

In Developing and Maintaining a Successful Undergraduate Research Program; Chapp, T., et al.;
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Introduction

Undergraduate research provides a unique learning experience for the student, one that often goes beyond the scope of a traditional lecture or laboratory course. According to the Council on Undergraduate Research (CUR), undergraduate research is broadly defined as "an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline" (*1*). The American Chemical Society (ACS) Committee on Professional Training (CPT) states "research is the development of new knowledge or understanding in order to advance science" (*2*). No matter the definition, numerous benefits of undergraduate research are cited in the literature (*3–9*) including some assessment studies (*10–13*). Some of the student benefits include development of problem-solving, laboratory, and communication skills; enhanced intellectual engagement; growth as a scientist; and personal development in the areas of self-confidence, independence, and motivation for future studies. The profound shift in student attitude regarding their own education as a result of participating in research is elegantly summarized by Professor Emeritus John Ross of Stanford University:

> In a class, the students and professor face each other — the teacher, who is thought to know all, on one side, the students, who are told what they are expected to learn, on the other side. Compare this to an undergraduate participating in research with a professor, postdoctoral or graduate student. Now they are on the "same side" of an experiment facing together the unknowns of nature; the undergraduate sees quickly that the coworkers do not know it all, but they do have a background which he/she is missing. The content of the courses becomes relevant and useful, and the attitude towards courses changes quickly (*14*).

Research also benefits other participants. Faculty mentors interact more closely with research students than students in traditional courses and generally get to know their research students better. While this mentorship role is rewarding to most faculty, the experience can also enhance faculty research involvement and productivity. Institutions benefit from more highly trained and engaged graduates.

Because of these benefits, interest in facilitating undergraduate research has grown over the years in response to initiatives from the National Science Foundation (NSF) (*15*), CUR (*1*), National Conferences on Undergraduate Research (NCUR) (*16*), and other organizations, as well as faculty desires to enhance the undergraduate experience. The 2008 ACS Program Guidelines for Bachelor's Degrees clearly support the inclusion of undergraduate research in an ACS-accredited degree (*2*), with the newly proposed 2014 ACS Program Guidelines "requiring a capstone experience (broadly defined) for certified majors" (*17*). The ACS CPT Supplement states that "research can be the most rewarding aspect of an undergraduate degree" (*18*).

While many institutions have promoted participation in undergraduate research through summer research programs and faculty initiatives, few *require* a research experience of all of their majors. During the academic year, research

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may typically be offered as an optional or elective course, work-study option, or extracurricular activity generally on a short-term basis and sometimes only available to select students. This limited or less structured approach seldom provides the full benefits of an in-depth research experience to a large majority of students. As Bauer notes, “the longer one had participated in research, the greater the perceived benefit” (*19*).

At the U.S. Naval Academy, research is viewed as such a valuable and unique learning experience for undergraduates, one that develops higher-level thinking skills and enhances student-faculty interactions, that we redesigned our curriculum to provide such an opportunity for *all* of our majors. Our global approach to curriculum reform required much planning and cooperation among our faculty members. Our hope is that other institutions may benefit from our experiences and perhaps enhance their research opportunities for undergraduates.

The restructuring of our curriculum began around the development of an integrated laboratory program which provides a foundation in all the subdisciplines of chemistry and prepares students for research. The new curriculum was first implemented in the fall of 2001 (for the Class of 2004). Foundation laboratory and lecture courses were redesigned to be completed by the end of junior year. One of the main goals of this significant curriculum change was to create time for our majors to participate in an intensive research or capstone experience during their senior year. A detailed description of the integrated laboratory curriculum and its development has been published previously (*20*) and will be summarized here, but the focus of this paper is the research/capstone component (*21*) of our revised curriculum.

Our Institution

The U.S. Naval Academy is a highly selective undergraduate institution of about 4400 students that prepares young men and women to become professional officers in the U.S. Navy and Marine Corps. While unique in its mission, the Chemistry Department at the Naval Academy is ACS-accredited with 30-40 chemistry majors each year, some of whom continue to medical or graduate school following graduation. In the 2008-2009 Annual Report of Earned Bachelor Chemistry Degrees published by the CPT (*22*), the Naval Academy graduated the largest number of ACS-accredited chemistry majors (38) among Predominantly Undergraduate Institutions (PUI) and was ranked 12th overall for all institutions. Our Chemistry Department is large, consisting of 41 faculty members, 32 of whom are civilians, either tenured or in tenure-track positions. This is a consequence of all freshmen being required to complete a year of general chemistry and our commitment to class sizes of no more than 20 students. Except for military training courses, our curriculum is similar to that of engineering or technical schools. Since our students participate in military training during their summers, we must provide their research experience during the academic year. Additionally, our students must graduate in four years.

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Integrated Laboratory (IL) Curriculum Description

Integrated or unified laboratory courses have been utilized in several chemistry programs over the past 30 years with varying success (*23–28*). An integrated laboratory course includes experiments that simultaneously explore or illustrate concepts from two or more traditional subdisciplines of chemistry (organic, inorganic, analytical, physical, and biochemistry). Our integrated laboratory (IL) curriculum was developed as part of a comprehensive overhaul of our majors' curriculum in response to:

1) the 1999 ACS Program Guidelines published by the Committee on Professional Training (CPT) (no longer posted), which mandated incorporation of basic biochemistry content into the curriculum and stronger emphasis on student research;
2) our own desire to introduce more student choice in the majors' curriculum; and
3) the need to create space in the curriculum for a capstone or research experience.

To help meet these requirements, we embarked on a complete redesign of our laboratory program. Previously our major was based on separate lecture and laboratory courses in the traditional subdisciplines of organic, inorganic, analytical, and physical chemistry. To make room for biochemistry and enhance opportunities for student research, 11 credit hours of traditional laboratory courses were replaced with eight credit hours of an integrated laboratory sequence, and a research experience was included for all students in the senior year (Table I). The four-semester sequence of integrated laboratory courses is organized along broader themes within chemistry with most experiments investigating multiple areas of chemistry simultaneously (see Reference (*20*) for specific details of the IL experiments). It also has the pedagogical advantage of showing students a more realistic view of how chemistry is actually performed in research and industrial settings. Beginning in the sophomore year, students are introduced to basic techniques and instrumentation. The sequence progresses as a continuum aimed at developing student skills in laboratory methods, record-keeping, literature searching, and communication while also supporting the concurrent chemistry lecture courses and ultimately preparing students for research. All the major subdisciplines of chemistry (organic, analytical, inorganic, physical, and biochemistry) are integrated into the sequence including some advanced topics. In 2004, our first class of chemistry majors graduated under the new curriculum.

In 2006, CPT proposed further revisions to the ACS Program Guidelines (no longer posted). In this document, CPT specifically mentions the use of integrated laboratories stating that "the laboratory component of the foundation experience will be at least 180 hours, ideally involving all five major areas of chemistry. One mechanism for achieving breadth is integrated laboratory experiences". Our revised curriculum adheres to the current 2008 ACS Program Guidelines and the newly proposed 2014 ACS Program Guidelines.

Table I. Comparison of the Old and New Course Curricula (core laboratory credits shown in parentheses). (Adapted from Reference (*21*).)

	Sophomore		*Junior*		*Senior*	
	Fall	*Spring*	*Fall*	*Spring*	*Fall*	*Spring*
Lecture Courses in Old Curriculum	Organic Lecture I	Organic Lecture II	Quantitative Analysis	Physical Chemistry I Inorganic Chemistry I	Instrumental Analysis Physical Chemistry II	Inorganic Chemistry II Chemistry Elective
Old Lab Curriculum	Organic Lab I (2)	Organic Lab II (2)	Quantitative Analysis Lab (2)	Physical Chemistry Lab I (1)	Instrumental Analysis (2) Physical Chemistry Lab II (1)	Inorganic Lab (1)
New Lab Curriculum	Integrated Lab I – Reactions, Separation and Identification (2)	Integrated Lab II – Reactions, Chemical and Instrumental Analysis (2)	Integrated Lab III – Physical Principles and Quantitative Methods (2)	Integrated Lab IV – Advanced Laboratory (2)	**Research or Capstone**	
Lecture Courses in New Curriculum	Organic Lecture I	Organic Lecture II Analytical Chemistry I	Analytical Chemistry II Biochemistry Physical Chemistry I	Inorganic Chemistry Physical Chemistry II Seminar	Advanced Chemistry Elective Courses Seminar	

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As a result of the IL sequence, the laboratory courses that previously took six semesters to complete (through the end of the senior year) are now completed in four semesters (from the first semester of sophomore year to the end of junior year). Thus curriculum time is created in the senior year for 10 credit hours of a senior project, advanced coursework and seminar. Further, the IL sequence provides the foundational skills needed to conduct a senior research project — basic training in laboratory techniques, exposure to a variety of instrumentation, literature searching and referencing, maintaining a laboratory notebook, general laboratory safety, interpretation and reporting of scientific results, and elements of experimental design. By interacting with various faculty members teaching the IL courses and with exposure to all the major subdisciplines of chemistry, students can select advanced courses and senior projects that match their interests and skills. Finally, because our majors complete their core chemistry education by the end of their junior year, they are better prepared to select between two tracks for their senior-year project: research or capstone.

Research and Capstone Options

In their senior year, our majors participate in a research or capstone project. The separate research and capstone options are provided to offer flexibility and choice for our students, two attributes which were notably limited in our previous curriculum. The capstone track offers a research-like experience where students work in pairs on a one-semester project generally selected from a list of faculty-generated possibilities. Ambitious capstone students can also devise their own projects, with faculty approval. The research track follows the traditional model of research with a student working with a faculty mentor on an independent project. There is no minimum grade-point-average required for selecting research, only the identification of a faculty mentor and project prior to the end of the junior year. For either the research or capstone option, nine credit hours of advanced work are required. For the research option, six credit hours (lab) are devoted to independent research and three credit hours for an advanced chemistry elective course. (Although not codified as a requirement, a two-semester commitment is the expectation, and the norm, for students electing research.) For the capstone option, three credit hours (lab) are required while six credit hours (or two courses) are intended for advanced chemistry elective courses. In addition, a one-credit seminar course is required in both options.

The research option is an in-depth research experience where a student, during their junior year, selects a research mentor, designs a research project and writes a research proposal. During his or her senior year, the student carries out this project, reporting their results at the end of the fall semester in a campus-wide poster session and, at the end of the spring semester in a comprehensive written report and either an oral or poster presentation. This experience follows the CUR and ACS descriptions of undergraduate research in that it involves an original investigation aimed at creating new knowledge and the findings are "intended for dissemination among the relevant community through established means such as conference presentations and peer-reviewed publications" (*1*). At the Naval Academy, there are no graduate students, so research students work closely with their faculty mentors. Typically the work involves one-on-one interaction with a research mentor in his or her field of expertise, though some mentors advise more than one student creating a group atmosphere in the laboratory. In either case, students are required to complete individual projects, reports, and presentations although some of their laboratory work may overlap or include some collaboration. In addition to their poster and oral presentations at the Naval Academy, almost all of our research students present their findings at large scientific conferences, such as National ACS or NCUR meetings. Almost one-third of the students pursuing the research option have become co-authors on research publications.

The capstone option was designed primarily for students who want to take additional elective course work and/or are unable to commit to a two-semester research project. This option provides a broader selection of projects in areas of traditional student interest, such as food science and environmental chemistry, and allows for a research experience in areas not actively explored in the ongoing programs of the faculty. Logistically it is structured as a one-semester laboratory course with a scheduled meeting time and location. Depending on enrollment, one or two faculty members are assigned to "teach" the capstone course and, thus, the capstone option reduces some of the need for individual research mentors. Unlike research mentoring which is taught as an overload, capstone provides teaching credit for the instructor(s). Another distinct difference from research is that capstone projects are conducted in groups of two students, with a group paper and oral presentation required at the end of the semester. The capstone experience culminates in a campus-wide poster presentation which provides an opportunity for capstone students to communicate their results to a wider audience. While capstone projects may not necessarily be an original investigation creating new knowledge, they are a research-like experience for the students. Most of the projects rely on procedures from the literature and more often than not those procedures are challenging to replicate and extend, requiring students to synthesize information, make decisions, and improvise — all aspects of research. The capstone environment mimics a busy research laboratory with pairs of students working on various aspects of their projects, utilizing instrumentation, analyzing data, and consulting references. Students learn the value of communication and collaboration since they work as a team, and some students actually prefer this type of laboratory experience over the one-on-one model of research. Lopatto reports survey results that find "students in high research-like courses report learning gains similar in kind and degree to gains reported by students in dedicated summer research programs" (*13*). Titles of a few example senior projects are shown in Table II, and the requirements and timelines for research and capstone are found in Table III.

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Table II. Examples of Research and Capstone Projects

Research Projects	*Capstone Projects*
• Conformational Influences of Fluorine Substitution on Peptides Derived from β-Amino Acids • Characterization of Microalgal Lipids for Optimization of Biofuels • Determination of the Effects of Dissolved Organic Matter and Water Salinity on the Photolysis Rates of Nitroaromatic Compounds • Purification of DegP for Biochemical Characterization of Periplasmic Proteolytic Adapters	• Determination of Capsaicin in Hot Peppers • Quantitative Comparison of Antioxidant Levels in Organic and Non-Organic Foods Using the Briggs-Rauscher Reaction • Kinetics of Alcohol Oxidation by Chromic Acid • Analysis of Myrosinase Denaturation in Broccoli at Various Cooking Times through the Quantification of Sinigrin by HPLC

Table III. Requirements and Timelines for Research and Capstone

Requirements	*Timelines*	
	Research	*Capstone*
1. Project Selection	Spring, Junior year	Fall, Senior year
2. Proposal Submission	Spring, Junior year	Spring, Senior year, by two weeks into semester
3. Project Work	Fall and Spring, Senior year	Spring, Senior year
4. Written Reporting	Fall and Spring, Senior year	Spring, Senior year
5. Oral Reporting	Fall Poster Session, Spring Poster and/or Oral Presentation, Senior year	Spring Poster and Oral Presentations, Senior year

Considerations for Planning a Major Curriculum Change

Undertaking a major curriculum change such as ours requires careful planning and preparation. Discussions of the changes began well before implementation in 2001. The entire department became involved in the fundamental design and all were expected to be involved in the IL and research/capstone courses themselves. With "ownership" by the entire department, success of the program does not rely on the continued zeal (and effort) of a few faculty members.

Specific guidance in the development of the IL program was delegated to an Integrated Laboratory Committee, a group of instructors from each of the traditional subdisciplines. The original sequence of IL experiments was constructed from the existing sequence of discipline-oriented experiments by the committee. Their first major task was to narrow the list of good experiments into ones which could be adapted to integration, were essential for the support of a corresponding lecture course, or both. This could not have been accomplished without the backing of the whole department and some external summer support by the administration. New experiments have also appeared as individual faculty members (some on the committee, some not) chose to prepare such materials. The IL Committee has evolved into a sort of governing body for the entire IL sequence, surmounting the often-cited concern that no single discipline would take responsibility for such multi-discipline courses. The committee is responsible for maintaining the unified notebook and reporting requirements. Working in close cooperation with the course coordinators of the different IL courses, the committee also keeps track of student activities in the separate courses to maintain a continuum of experiences for the students. As in other aspects of the program, such cooperation appears to be an essential element of success.

Both the Cartwright (*28*), and Miller and Hage (*23*) surveys cited an advantage of efficiency in space or equipment usage perceived by their respondents. While we agree that this probably is the case, a four-semester IL program such as ours demands that serious thought be applied to planning and physical layout of the teaching spaces in order to reap the benefits. With the IL sequence, both sophomore and junior laboratory classes are often operating simultaneously. Because a common thread in the sequence is application of analytical methods and use of instrumentation, experiments are such that both groups could require the same instrumentation. Since our initial planning of the IL sequence coincided with the design phase for a major building renovation, we were able to ensure physical access for both groups by placing major equipment in an instruments suite in a central location. While common instrumentation such as IRs and GCs reside in the IL laboratories themselves, more specialized instrumentation is located in the instruments suite. This allows all students, both IL and research/capstone, access to the instruments in our department. Certainly scheduling of instruments is needed and this is coordinated among the IL courses.

In the laboratories, additional space for group work is available to support the round-robin nature of some of our experiments. A “round robin” is used when there is limited equipment or instrumentation. Multiple experiments are conducted simultaneously as students rotate through the round robin sequence. Student group sizes are kept small (three or fewer) to maximize student exposure to instrumentation. The use of round robins has influenced our recent instrument purchases. For some analytical instrumentation (IR, UV-Vis, AA, GC), we have made the conscious decision to procure two or three simpler systems, rather than a single research-grade instrument with all the “bells and whistles.” The increased availability of instrumentation clearly simplifies scheduling problems and minimizes the extent of round robins.

For research and capstone projects, the physical layout of our laboratory spaces was also a consideration. The capstone option is treated like a course and scheduled for two three-hour meetings per week in an advanced laboratory. This laboratory room may be shared with an advanced elective course (forensics, polymers, etc.) or other courses. There is no unique design to this laboratory other than it contains sufficient bench and fume hood space to accommodate all the students (up to six pairs) and it is located close to our instruments suite. The laboratory also contains desks in the center of the room to accommodate

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lecture or recitation activities, thus enhancing the utility and flexibility of the space. Having research laboratories in close proximity to faculty offices allows more efficient mentoring of research students. These rooms are large enough to be shared by two faculty members and up to four research students. Shared laboratory spaces promote collaboration among researchers, enhance safety, and reduce some redundancy in needed equipment (such as balances and ovens).

Challenges in Maintaining and Sustaining Student Research

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Sustaining a large undergraduate research program poses some significant challenges. Among these are funding, faculty workload, student-faculty matching, instrumentation and scheduling. As described below, we have found solutions for many of these issues and, as outlined in the Outcomes section, we feel the benefits to our department and students justify the effort.

Providing a research or capstone experience for all of our seniors (numbering over 30 per year recently) is costly — approximately $1200/year per student in supplies and services, excluding travel. We have been fortunate to receive some external funding from the Office of Naval Research (ONR) and the Defense Threat Reduction Agency (DTRA) to support material purchases and student travel to meetings. Some faculty members also utilize their external grants or outside research collaborations to supplement student projects where appropriate. Future support may be obtained through gift funds or alumni donations.

As we established the required senior projects, there was understandable concern among the faculty regarding workload. Our administration has encouraged student research as a way to promote problem-based learning, and also views participation with student researchers positively in promotion and tenure decisions. However, faculty members do not receive any teaching credit for time spent mentoring research students. With six contact hours per week per research student, this added load can be significant, particularly for junior faculty. Receiving teaching credit for mentoring capstone students was part of the reason for structuring that course as we did and it relieves some of the pressure on the research mentors. Fortunately, our department is large enough to have covered all the student research requests to date. Some faculty members “share” students on collaborative projects and many accept more than one student per year. In addition, most faculty members can arrange their teaching schedules to allow at least one full “non-teaching” day (no class requirements) to devote to research and mentorship. Our department has considered providing partial teaching release time on a rotating basis to faculty members who have consistently mentored student researchers over the years. This would be administered in a way that ensures that the institutional emphasis on teaching is not lost. Unfortunately, limited resources have prevented implementation of any teaching release plan.

Another consideration is the process of pairing students with research mentors. Although introduced early in the major by advisers and IL instructors, in the spring of their junior year, students are officially briefed on the two options for senior year, research or capstone. They are encouraged to talk to current seniors about their projects and visit faculty members to discuss their research programs. The seminar course, which meets weekly and is required of all juniors and seniors, provides a venue for short presentations by faculty members and senior research students. Additionally, research and capstone posters of previous students are prominently displayed throughout the department. We have typically allowed students to freely select mentors/research areas and have avoided instituting quotas or "steering" students to work with certain mentors. Our large department and the fact that our students see many of our faculty members in the IL courses (which are team-taught) have facilitated the pairings. Historically, most if not all juniors interested in pursuing the research track have been able to find a faculty mentor and select a project of mutual interest. If a student cannot identify a mentor or research project of interest, capstone is a viable alternative.

While our student-faculty pairings have generally worked out, recently some issues have become evident. In some cases, faculty mentors have been inundated with student research requests causing them to accept too many students (and too much workload) while others do not seem to attract student researchers. Also, some students wait too long before selecting a mentor then are disappointed when that mentor is no longer accepting students. A "mad scramble" sometimes ensues when word gets out that popular mentors are "taken." Our department has discussed implementing a more formal selection process whereby students list their three mentor preferences and reasons for working with those mentors, and faculty decide on the pairings. By requiring three choices, students would need to talk to more faculty about their research, and think more about their decision. With faculty cooperation, students might be more equitably distributed among the department, thus sharing the mentoring workload and allowing more faculty to participate. Ways of better utilizing the junior-year seminar in the selection process have also been discussed. It should be noted that we have no plans to force any student-mentor pairings as that would not provide a good experience for either party.

With their chemistry course load minimized in the senior year, scheduling of capstone and research times is easier than might be expected. As mentioned previously, the capstone option is treated like a course and scheduled for two three-hour meetings per week in an advanced laboratory. Students selecting the research option must coordinate with their mentors to find mutually agreeable research times (again, two three-hour blocks per week are typical). Since our students tend to be overscheduled, we find it helpful to "protect" this research time by creating official course sections and enrolling students at these mutually agreeable times. Typically eight or so research times provide enough schedule permutations to accommodate all students in the research track. Of course, a faculty mentor advising two students will schedule both students at the same time if possible. Since research is typically conducted in space dedicated to supporting faculty scholarship, we do not have conflicts with other courses. However, one area of potential conflict is access to analytical instrumentation. In such cases, the foundation courses (typically one of the IL courses) have priority and the research student must arrange an alternate time to access the instrumentation.

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Outcomes

Our first class of chemistry majors to complete the new curriculum graduated in 2004. Overall, student opinions of the new curriculum, as evidenced by course evaluations and focus-group interviews, have been positive. The main negative comment from students has been the workload of the IL courses, particularly in the junior year (*20*). In response, we have made some adjustments to reduce the workload, such as streamlining some of the report requirements and post-lab questions, moving a credit hour (of analytical chemistry lecture) from junior to sophomore year, and scheduling due dates of laboratory submissions more carefully (not all at the end of the semester). By the end of the senior year, students have been overwhelmingly positive about their education, particularly the research or capstone experience. In a *Chemical and Engineering News* article, the opinion of some chemistry majors (Class of 2010) was clear: "the integrated laboratory program, they all concurred, added to the challenge of majoring in chemistry but was also highly rewarding because it prepared them well for conducting independent research during their senior year" (*29*).

With the implementation of our new majors' curriculum and its senior project requirement, we see benefits beyond student perceptions. We have observed an increase in the number of our majors (all ACS-certified), as illustrated in Figure 1. Before the curriculum change, we averaged about 21 majors per year with some annual fluctuations. Since the curriculum change (for the Class of 2004), we have graduated an average of about 32 majors per year. We have generally attributed this increase to the new curriculum with its enhanced research opportunities but have not completed any rigorous studies of cause-and-effect relationships. Having senior chemistry majors who enjoy their research and capstone experiences, as well as promoting the major through poster sessions and student travel, has been beneficial in recruiting new students to the major. Our new curriculum was introduced in 2001, concurrent with planning of a complete renovation of our building, which was finished in 2004. This significant change could also be partly responsible for increasing the number of students choosing to major in chemistry at the Naval Academy. However, nine years after the renovation, we have still maintained an average of over 30 majors each year.

We also see greater engagement of students in their projects. In our previous curriculum, research was an elective option for students which counted towards graduation. However, a second semester of research was an extra course, not required either of the major or for graduation. In addition, research was difficult to arrange into the tight schedules of the old curriculum (i.e., two other laboratory courses were taken senior year) and students often did not fully see all subdisciplines of chemistry before selecting a research project (i.e., quantum chemistry and inorganic chemistry laboratory were taken senior year). The result was that relatively few of our students could obtain a research experience. Since most research experiences benefit from a sustained effort over an extended period of time, we felt that a minimum of two semesters of research was needed to achieve the desired outcomes. With the new curriculum, we have observed an increase in the number of students who pursue two semesters of research, even though it is not explicitly required. As illustrated in Figure 2, before the curricular

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change, an average of six students conducted year-long research projects. Now there is an average of 22 students, a majority of our majors, participating in year-long research experiences. Since research is now a programmed track during the senior year, it is not surprising that research participation has flourished.

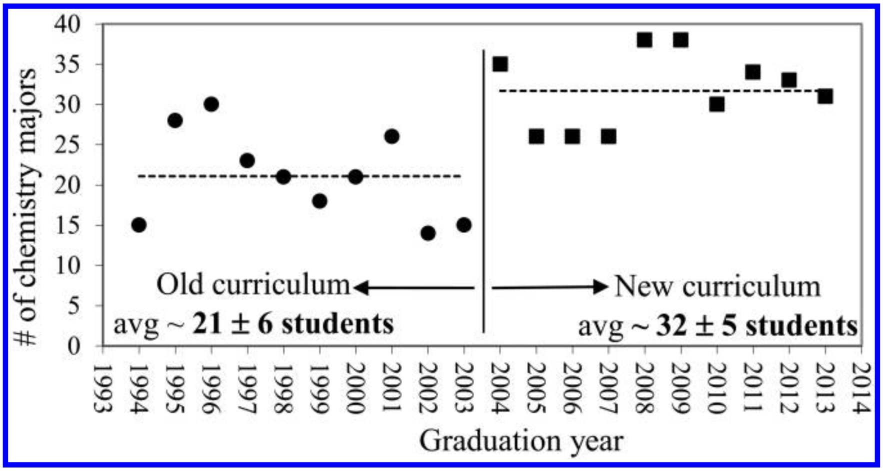

Figure 1. Number of ACS-Accredited Chemistry Majors at the U.S. Naval Academy from 1994-2013. (Adapted from Reference (21))

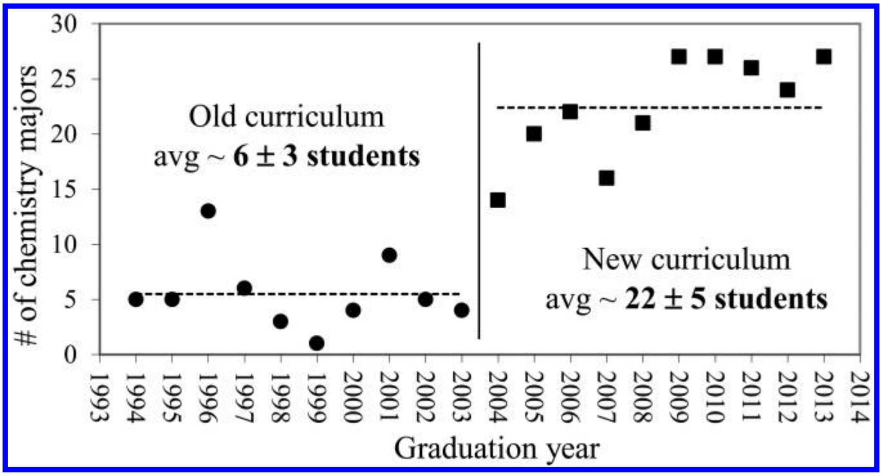

Figure 2. Number of Chemistry Majors Conducting One Year of Research in the Chemistry Department at the U.S. Naval Academy from 1994-2013. (Adapted from Reference (21))

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Table IV. Snapshot of Chemistry Majors' Participation at Conferences and Meetings from 2008-2013

Year	*Total # of Students who traveled to a meeting*	*# of Students Attending National ACS Meeting*[a]	*# of Students Attending NCUR or ECSC*[a]	*# of Students Attending Other Meetings*
2008	23	11	6	6
2009	28	16	12	0
2010	24	11	9	4
2011	22	12	8	2
2012	25	19	6	0
2013	22	19	0	3

[a] ACS = American Chemical Society, NCUR = National Conference on Undergraduate Research, ECSC = Eastern Colleges Science Conference

Table V. Student Researcher Co-authorship in the Chemistry Department at the U.S. Naval Academy from 1994-2013. (Adapted from Reference (*21*).)

	Years of Graduating Classes	
	1994-2003 (old curriculum)	*2004-2013 (new curriculum)*
Total Number of Chemistry Major Graduates	211	317
Total Number of Year-Long Researchers	55	224
Number of Publications with Student Co-authors	18	55
Number of Unique Student Co-authors	18	67
Percentage of Chemistry Majors Who Publish	8.5%	21.1%
Percentage of Student Researchers Who Publish	32.7%	29.9%

While other departments at the Naval Academy offer research opportunities for their majors, the Chemistry Department's research program is the most robust. Only a few departments offer two-semester research experiences, and no other department provides this option to all of their majors. Other departments, such as those in engineering, rely more on capstone experiences which tend to be team projects. Of a total of 122 students participating in independent research courses at the Academy in the fall semester of 2013, 35 were chemistry majors (29%), which is the highest participation rate among all departments.

Further, we see a small but increasing number (13 in the last five years) of students opting to start their research as juniors. These students will complete three or more semesters of research but only two of these will count towards fulfilling their graduation requirements. Typically, these students have validated one or more required courses or have overloaded one or more semesters in order to create time in their schedules for research as juniors. Thus we expect that this number will always be relatively small.

Presentation of research findings at meetings is one way to contribute to the greater scientific community. Hunter (*30*) and Mabrouk (*31*) suggest that “undergraduate students who participate in conferences appear to develop a broader perspective on science, its practice, and their own future role in the scientific community” (*31*). Student attendance at scientific meetings has increased since our curriculum change. Before the curriculum change, about a third of our research students attended scientific meetings. After the curriculum change from 2008-2013, about 90% of our research students attended a meeting or conference. In 2010, of our 24 research students, we sent 11 students to the National ACS meeting, seven students to the Eastern Colleges Science Conference (ECSC), two students to NCUR (National Conference on Undergraduate Research), and four students to more specialized national or international meetings. Recently, travel has been affected by various factors (decreasing budgets, sequester, travel restrictions), but we were able to send 19 students (of the 27 research students) to the 2013 National Spring ACS meeting. A “snapshot” of some of our recent student travel is shown in Table IV. Essentially all of the students presented their results, either in a poster or oral session. Students who attended the meetings stated that they learned more about the chemistry community, gained an appreciation of the working chemist, and improved their communication skills. Given the cost, student travel to these meetings would not have been possible without external support. Students are not expected to finance their own travel to the conferences.

Publication in peer-reviewed journals is a common measure of research productivity. Since the curriculum change, we have observed a significant increase in the number of chemistry majors who appear as co-authors on peer-reviewed publications, as shown in Table V. In the 10-year period since our first majors graduated under the new curriculum, we have graduated 317 chemistry majors and 67 of these (21.1%) have been listed as co-authors. This percentage will grow as papers co-authored by recent graduates (Classes of 2012 and 2013) are published. During the last 10 years of the old curriculum (Classes of 1994 to 2003), 211 midshipmen graduated as chemistry majors and only 8.5% of these were co-authors. Even when corrected for the increased number of year-long research participants, the percentage of student researchers who publish remains about the same, from 32.7% to 29.9%. A listing of the articles with student co-authors can be found in the Supplemental Material of Reference (*21*).

While we have observed increases in student authorship, we caution readers that undergraduate research should be viewed as a learning experience for the student, not a tool for enhancing research productivity (although both may be possible). Faculty need to be realistic about the capabilities of an undergraduate working six hours per week on a project typically beyond their

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classroom/laboratory experience. While their work may not always be of publication-quality, many students, even those not in the top of their class, benefit from the experience and grow as scientists. Conversely, students need to be more than "data collection machines." They should be involved in the planning of experiments and interpretation of data. Otherwise, it's not an educational experience.

As mentioned above, our faculty members were understandably concerned about the time commitment involved in supporting senior projects for all of our majors and the impact on their own scholarly productivity. In the 12 years since the new majors' curriculum was implemented (starting in 2001), our chemistry faculty have published an average of 40 journal articles and made 50 scientific presentations per year. The departmental average publication and presentation rate for the previous 10-year period was 31/year and 33/year, respectively. Note that the above publication numbers include those with student co-authors (recently an average of 6.5 publications/year) which accounts for some of the increase. Concurrent with the curriculum change were a number of other factors which also likely impacted scholarly productivity. Foremost of these was the building renovation completed in 2004. This caused a temporary dip in publications/year into the mid-20s for the following two years but resulted in some building changes (i.e., research spaces adjacent to faculty offices, updated facilities, etc.) which have enhanced productivity. In addition, two tenure-track faculty members have been added to the department since the curriculum change. Although complicated by multiple competing factors, we feel that a most conservative interpretation of the above data shows that faculty scholarly output has not diminished as a result of supporting senior projects.

For research, we have allowed our students to select their faculty mentors freely. While we have not studied why students choose certain faculty mentors or research areas, we have compiled which subdisciplines students selected. Averaging the data from 2004-2013, about 30% of our students selected faculty mentors in the analytical chemistry subdiscipline, 27% selected organic chemistry, 26% selected biochemistry/biology, 11% selected inorganic chemistry, and 6% selected physical chemistry. These distributions may reflect the number of faculty in each subdiscipline available to mentor research students (27% of the faculty are analytical chemists, 21% organic chemists, 21% biochemists or biologists, 15% inorganic chemists, and 15% physical chemists), but it may also reflect the strong applications-orientation of our students.

In terms of student enrollments in research versus capstone, about 76% of our majors select the research track (10-year average). This may be expected given the nature of our majors who are about 40% medical-track candidates and our large faculty with diverse research interests. Because higher capstone enrollment provides some benefits to the faculty, such as teaching credit and more opportunities to teach advanced elective courses, we promote both options to the students. However the benefits of an in-depth research experience have been clear to a large majority of our students and many have selected this path. In 2012, we administered a student survey (open inquiry format, 82% response rate) of the capstone and research experiences. The main reason students selected capstone over research was that capstone was a smaller time commitment (22%). Of the students who selected capstone, 85% stated they would choose it again. The overwhelming reason students selected research was that they wanted a challenge or to work on real science (45%). From our experiences, we generally see a broad distribution of student abilities (higher- and lower-achieving students) in both the capstone and research courses.

In the same survey, research students were given a set of statements shown below with Likert scale choices of strongly agree, agree, neutral, disagree, and strongly disagree:

1. My research experience was intellectually rewarding/challenging.
2. I was satisfied with my research experience.
3. My research experience improved my ability to solve future problems in the fleet OR in my subsequent career.

My independent research project helped me gain experience in the following areas:

4. With scientific writing (e.g., proposals, papers etc.).
5. Developing & presenting an oral talk on a scientific subject.
6. Developing & presenting a poster on a scientific subject.
7. Planning/conducting experiments.
8. Interpreting the results of scientific studies.
9. Applying results obtained by others (e.g., published work) to my own work.
10. Critically evaluating scientific studies (mine and others).
11. Overcoming unexpected challenges in the project.
12. Learning new methods of data collection and analysis.

A plot of the percentage of students that strongly agree and agree with each statement is shown in Figure 3. From these results, it seems clear that student response to research is overwhelmingly positive and that students feel they have gained skills from the experience. For eight out of the 12 statements, 100% of the students strongly agreed or agreed with the statement, with the lowest response being statement 12 at 87% (strongly agree or agree).

Since the curriculum change, our department has made efforts to assess our students' learning of chemistry and their views of the major. A departmental Assessment Committee is tasked with managing and archiving our assessment efforts in an annual report. The main ways in which chemistry majors are assessed include:

1) national standardized exams
2) comparisons of current student performance with student samples from previous years (i.e., a longitudinal comparison of performance on common exam questions)

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3) standardized department-wide grading rubrics (for presentations and some laboratory reports)
4) end-of-semester student feedback forms
5) focus-group interviews

ACS Standardized exams have been used in several courses including organic chemistry and physical chemistry, with results compared to national averages. For the past three years, the ACS Diagnostic of Undergraduate Knowledge (DUCK) exam was administered to all graduating majors (in our seminar course) to measure the quality of their undergraduate education. The DUCK exam is useful for identifying content areas where our students may need improvement. Additionally, Medical College Admission Test (MCAT) results for our majors taking this exam are available to compare to national statistical data. Based on recent results, we observe that our majors generally perform well compared to national standards. Under the old curriculum we have little assessment data other than student survey results and student grade point averages (GPA). In the old curriculum (Classes of 1998 to 2003), the average GPA was 3.25 ± 0.06, and in the new curriculum (Classes of 2004 to 2013), the average GPA was 3.34 ± 0.05. While a slight increase in GPA is observed, we cannot directly compare student chemistry knowledge due to lack of data. However, our current assessment efforts allow us to more accurately track student performance compared to national averages, and longitudinal comparisons provide more specific program information. Anecdotally, we feel the IL program and research/capstone efforts have not negatively impacted student learning.

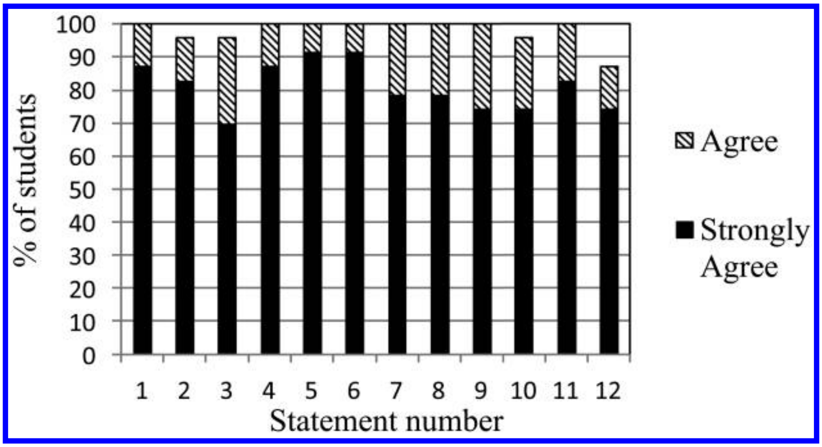

Figure 3. Percentage of Chemistry Majors Selecting Strongly Agree or Agree on Statements 1-12 in Class of 2012 Research Survey

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Advice

The mission of the Naval Academy is unique. However, our ultimate goal of producing technically competent, broadly educated and articulate critical thinkers is not different from that of most colleges and universities. While all the curriculum modifications described here, developed in light of the specific challenges and opportunities at the Naval Academy, may not completely transfer, we feel that some elements of our revised program can be implemented at other institutions. Thus we offer the following advice to institutions considering restructuring or modifying their curriculum to include required research or capstone projects.

Curriculum time must be available or must be created to support these projects. By slimming our foundation laboratory courses from 11 to eight credits through the integrated laboratory sequence (*20*), we were able to provide time in the curriculum for an advanced research or capstone experience. Our undergraduate research experience is provided during the academic year, generally in two semesters during the senior year. This is a consequence of our students not having time during the summers for research (they are involved in military training), and the requirement that our students graduate in four years. For other institutions, there may be more flexibility in offering summer or multiple-year research experiences. We find, however, that an extended research project, rather than a one or two month summer research experience, provides some unique benefits. With two semesters, students have time to master laboratory techniques and apply them independently in the laboratory while generally being able to obtain results for their efforts. Some research requires time to synthesize and purify materials, develop methods, or construct instrumentation, and other projects are time-intensive by nature, such as aging studies or growing biological cultures. Furthermore, more time allows students to experiment in the laboratory and try new ideas without the pressure of having to obtain results immediately. Time to reflect and plan experiments generally leads to better results. Some of our students only start obtaining “good” results in their second semester. Finally, interactions between student and mentor grow over the semesters and research becomes a more enriching experience for both. Extended projects are encouraged by the ACS. According to the 2008 ACS Program Guidelines (*2*), research and capstone could be considered “in-depth” course work since they build on prerequisite foundation courses. Furthermore, undergraduate research can account for “up to 180 of the required 400 laboratory hours” (*2*) in an ACS-certified degree. Our suggestion for undergraduate research is to provide more than a summer or one-semester experience, without overloading the student, to fully realize the benefits of research participation.

Senior projects are resource intensive. Smaller departments, which may not be able to handle the research mentoring load or have limited resources, might consider implementing the capstone option where students undertake advanced, guided experiments. The capstone course has been highly successful for us and provides students with an experience similar to research, particularly if student-developed (and faculty-approved) projects are used. In our department, teaching credit is awarded to capstone mentors which eases faculty workload.

Because faculty members generate the list of possible capstone projects, the projects can be tailored to your resources, expertise, and students' interests. In some ways, mentoring capstone students can be more challenging than research students if the capstone projects are outside the expertise of the assigned capstone instructor. Careful consideration of the offered capstone projects and the background of the assigned capstone instructor is suggested. Capstone experiments should not be traditional "canned" experiments but may be based on current events, faculty research projects, or interesting chemical questions. Departments offering both ACS-certified and non-certified chemistry degree options might require the research component for ACS-certified majors only.

For larger departments, visiting professors, post-doctoral fellows, and graduate students can help to mentor research students and supervise projects. Dolan and Johnson have shown that such mentoring has significant advantages for the mentors (*32*). A large laboratory group can provide a collaborative and dynamic research environment which appeals to many undergraduates. However, the main responsibility for the education of a research student lies with the faculty adviser, who should provide clear project objectives, proper safety training, and monitoring of progress. Peer mentoring by advanced undergraduates can also be an option and Lopatto suggests that "undergraduate researchers have a better experience if they work with other undergraduates as teammates or peer mentors" (*13*). We have observed success with peer mentoring as a few juniors began research early and overlapped with senior researchers.

Requiring students to give an oral or poster presentation of their project enriches the research or capstone experience. In our department, all research and capstone students present posters and give oral presentations of their work, as well as provide comprehensive written reports. These presentations occur locally but some students give additional presentations at external meetings or conferences. The campus-wide poster sessions are considered the "final exam" for the course and are scheduled during the final exam time. Faculty and staff interact with students during the two-hour block. Certain faculty members are also designated as "poster evaluators" and evaluate students and their posters with a provided grading rubric. The faculty mentors consider these evaluations in determining final grades for their students. All faculty members participate and refreshments are provided which imparts a social and celebratory atmosphere to the event. Students enjoy talking about their research with faculty and viewing what their peers have accomplished. It is an excellent way to end the semester. Administrative members of the institution, such as the Dean and Research Office staff, are invited to the poster session as well as representatives from funding agencies. This provides exposure for the department and is beneficial in obtaining financial support for student projects. For the first several years of the new curriculum, posters were limited to students majoring in chemistry and presented only within the department. More recently, the Naval Academy has implemented a campus-wide poster session at which students from all majors present their project results.

In addition to poster presentations, research students give oral presentations in our seminar course. These presentations illustrate to juniors the possibilities for future research projects and highlight the research interests of our faculty as

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well as develop the communications skills of our seniors. Capstone students give oral presentations during their capstone course and receive critiques from their mentors and classmates. For institutions where travel to external meetings may be problematic, these “in-house” presentations provide a viable alternative with the benefits listed above. Expanding the sessions to include other departments would provide a larger context to the research and greater interaction between departments.

The physical layout of our teaching and laboratory spaces has supported our integrated laboratory and research objectives. Other institutions should consider laboratory layout and adjacencies as future renovations are planned. Our curriculum change occurred at about the same time as the planning for a building renovation. Knowing our vision for the new curriculum with its focus on integrated laboratories and student research projects, we designed our building appropriately. A central instrumentation suite serves both the integrated laboratory and research/capstone students. Traditional boundaries of an organic versus a physical chemistry laboratory are erased as the teaching laboratories have become interdisciplinary, integrated laboratories. Research laboratories were designed to include sufficient bench and hood space for students and faculty. Locating the research laboratories close to faculty offices is crucial for mentoring research students.

This advice is clearly not prescriptive, but might benefit other institutions contemplating more widespread involvement of their undergraduates in a research experience. A cursory internet search will identify other institutions requiring research for all (or a large majority of) their undergraduate majors. There appear to be as many variations in the methods to achieve that goal as there are institutions seeking it. The Naval Academy may be unique in that our students are the most restricted in terms of time, requiring the curricular modifications we described to make universal research involvement possible while maintaining ACS certification. Other institutions not subject to such strictures may find an easier path to the same benefits we observed.

Conclusions

At the U.S. Naval Academy, a global curriculum change initiated by an integrated laboratory sequence has facilitated the inclusion of a research or capstone experience for all of our chemistry majors. This change required enormous effort in redesigning our curriculum (*20*, *21*) and the acceptance of undergraduate research as a culminating experience worthy of faculty and administrative support. However, we have felt it was well worth the effort as our number of majors has increased, students seem dramatically more satisfied with the major, interactions between students and faculty have increased, and research productivity seems to have been enhanced. The profound shift in student attitude and perception regarding their own education as a result of participating in research has been noted by other educators and the subject of recent assessment studies.

Without the curriculum change and the programmed space for research or capstone in the senior year, undergraduate participation in research in our department would not be where it is today. Other institutions contemplating enhancements to their research programs should consider making global adjustments to their curriculum to allow research experiences to be fully incorporated into the curriculum and culture of the department.

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Chapter 12

Undergraduate Research in Chemistry at a Small Liberal Arts College

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The author describes some experiences involving undergraduate students in chemistry research projects at a small liberal arts college that has extremely limited facilities. Suggested criteria for choosing appropriate projects for undergraduates are presented. Challenges and potential pitfalls are described as well as successes. The author also illustrates one approach to mentoring undergraduate researchers.

Introduction

Experiential learning such as participation in research is known to provide benefits to students, including gains in content knowledge and laboratory skills as well as increased student satisfaction and retention in post-secondary education (*1–4*). The environment of the predominantly undergraduate institution (PUI) is particularly conducive to this because of the customary closeness between professors and students, which mirrors the classic master-apprentice model of passing knowledge from one person to another. Many great research experience programs have been developed in the sciences, often taking place during the summer break, including dozens of REU sites funded by the NSF serving hundreds of students a year (*5*). On a smaller scale, countless individuals have found ways to support undergraduate research at their home institutions, for example integration with graduate students (*6*), research training in instructional labs (*7*), and community-based research (*8*).

When I joined the faculty of my current institution 10 years ago, there did not appear to be any student-faculty research taking place on campus. Like many other small PUIs, it was focused on traditional classroom teaching. In addition,

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although individual scholarship and professional development had always been components of a faculty member's portfolio, the college had very few resources to offer faculty and nothing for students interested in research. I became involved with the ACS Society Committee on Education (particularly the Undergraduate Programs Office) and the Council on Undergraduate Research (*9*). Both of these organizations offer valuable advice and programs and I highly recommend them. Through my membership in CUR, I was motivated to identify a small group of faculty and administrators on my campus sympathetic to undergraduate research. This ad hoc group was instrumental in initiating a campus-wide discussion, developing programs such as our annual Student Research Symposium (*10*), and increasing the visibility of the student research that is ongoing. I am now the Coordinator of Undergraduate Research for my campus and happy to report the environment for student research on our campus has improved substantially in the past decade, though challenges remain.

In the following pages, I will describe how I have approached research with undergraduate students over the past 10 years. The primary focus of my job is to teach chemistry to undergraduates. As I interpret that task, it includes involving students in the research process, because chemistry is fundamentally an experimental discipline. Our graduates should have experience in chemical research for the same reason they should be able to write coherently or give a presentation to an audience of strangers: because these are activities expected of professional chemists. On the other hand, my institution has no research laboratories and provides almost no support for research. I participate in research with undergraduates because of its value to the student rather than to further my career. This focus will be evident in the following paragraphs and may not be transferable to those working at institutions with greater research expectations. However, I hope to encourage other professors at colleges with similarly limited resources to add whatever research activities they can for the ultimate benefit of the students.

Choosing Projects

As a graduate student, I chose my doctoral advisor because I was excited by the work of his group, and not with any thought of my eventual career. Once I decided to become a professor at a PUI, it was very unlikely I would be able to pursue anything like my dissertation work due to the high cost of materials and instrumentation. Many people are able to successfully adapt their graduate or post-doctoral projects to a different environment but I needed to conceive of new project ideas. Some of my early ideas were inspired by browsing through journal tables of contents. While I browsed, I kept in mind four self-imposed criteria.

First, the chemistry had to be robust enough that beginners have a reasonable chance of success. I expected to need to teach students everything from lab techniques to chemical theory to analysis skills because beginning students' knowledge is often fragmentary or absent. While I wanted intellectually challenging and scientifically useful projects, I also wanted mistakes to be salvageable and I did not want students to become too discouraged by repeated failure. One cautionary example: a colleague designed a project that involved removing a tiny gland within the brains of insects in order to study its effect on the insect's behavior. Brain surgery on juvenile insects was done under a microscope, necessitating extremely fine motor skills and detailed knowledge of insect anatomy. The undergraduate student researcher had so much difficulty performing the surgery that almost no insects survived to be studied and she became quite discouraged, ultimately resulting in a last-minute reformulation of the whole project.

Second, I wanted to avoid unusual instrumentation, if possible. I was confident that almost all schools would have access to basic FTIR, UV-vis, and NMR spectrometers. Anything else might require a neighboring school or business that would allow me to use their instrument, a contract analysis lab, or fundraising to purchase an item. While I was willing to make alternate arrangements, I did not want the entire project to depend on them. For a project on liquid crystals, my student researcher and I used an ordinary Mel-Temp apparatus to screen new compounds for possible liquid crystal phase transitions. After screening, we took the candidate compounds to another college in our neighborhood for Differential Scanning Calorimetry to confirm the transition temperatures.

Third, I looked for end products to which undergraduate students could relate. Students are most excited by ideas they can immediately connect to their own experiences. For example, a project involving soil pollutants was attractive to students interested in environmental issues and a project designing artificial bone substitute materials was appealing to students hoping to study medicine.

Fourth, knowing that most undergraduates have relatively short periods of time available for research, I preferred projects that were divisible into smaller segments so that each student might reach a satisfactory conclusion within no more than a few months. It is better to extend a project after accomplishing its original goal than to run out of time before completing an overly ambitious objective. A series of two or more students' results can be combined later for publication.

Based on these criteria I was able to outline several project ideas that I felt were scientifically appropriate and personally interesting. Over time, some have evolved while others have been discontinued and replaced. I have found that having a variety of research interests is beneficial. It allows me to adapt quickly to the interests of the student and to different funding opportunities. Some people may not have the flexibility to drop one research project and pick up a completely different idea each year, but it has worked well for me. I do not mind working on one idea, then shelving it for a year or two to do something else.

Operational Details

Every fall, at the beginning of our senior research methods course, each professor describes the project ideas he or she wants to pursue. Students in this course then choose one project to work on for the year, with the associated professor acting as mentor. Recently, I have proposed projects ranging from environmental analysis of some component of air, water, or soil, to syntheses

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of ionic liquid crystals, to development of analytical methods for detecting insecticides in bed netting. Some years, I attract a couple of students to one or more of these ideas. Because the class size is very small (an average of three graduates a year), I cannot assume I will have any students working with me in a given year. Fortunately, I have had at least one student in nine of the past 10 years. Offering a variety of project ideas may give me an advantage over some of my colleagues with more tightly focused research plans. Students who are undecided about their research interests tend to want to explore their options a bit, and often seem relieved that I will guide them through the development process rather than insisting they attempt a project I've already established. Occasionally, a student presents an independent idea and asks me to help develop it into a project.

Unlike larger universities, colleges like mine have few, if any, facilities for faculty research during the academic year. All our labs are teaching labs and all our instrumentation is in constant use by the students in our classes during the academic year. In addition to the lack of facilities, our heavy teaching loads mean that carving out even a few hours per week for personal research is a struggle. Therefore, except for work that is produced in the research methods course (which is of highly variable quality because the course is required for all chemistry majors regardless of interest or ability), essentially all research must take place during the summer break. Students require incentives to give up their summer break at the beach and their chance to earn money for tuition and other expenses by working a part-time job. It is a rare student who is able to participate in a summer research project solely for the experience. At some schools, students may be able to earn academic credit for research, but that has not been a viable option here. I have always paid students a small stipend for summer research.

There are many sources of funding available, from large government organizations to small local foundations. Many of these opportunities are advertised online or through professional organizations. It is useful to sign up for email alerts and newsletters in order to receive notifications. One can use the U. S. government's website to search for grants from federal organizations (*11*). If your campus has staff assigned to grant writing, take advantage of their help locating, researching, and submitting grant proposals.

In my career so far, I have been fortunate to receive some great funding opportunities. During my second year at Aquinas, a nearby environmental education center began offering small summer research grants for local undergraduate science students (*12*). These grants provided a stipend for the students and a small supplies budget. The facility also offered lab space, housing, and meals to encourage students from different institutions to get to know one another during the summer. Although I had never done any environmental chemistry before, I described the grant program to students in one of my classes and immediately got two volunteers. We applied for and received a grant to perform chemical analyses of the lake water on the environmental center property. The students and I had a fabulous time collecting weekly samples by boat and performing analytical tests back in the lab. It was a real adventure to be doing chemistry outside the confines of the science building. The following year two other students and I were awarded a second grant from the same organization to analyze metal ion concentrations in the soil. This time, we collected samples on

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solid ground, but the same thrills were there. Both project ideas were originally conceived in collaboration with the students, to capitalize on their interests. Though the chemistry was more or less novel to all of us, I contributed more advanced skills in experimental design and scientific writing, and modeled professional behavior in the lab and at report meetings with the other grant recipients, while the students provided persistent enthusiasm and most of the manual labor.

More recently, my institution set up an in-house program to support research projects. The Mohler-Thompson Summer Research Grant program, named for its two major benefactors, provides stipends for both members of a student-faculty team as well as a modest supplies budget and free on-campus student housing. I have received grants from this program four times to work with four different students and on three different topics. Several of my colleagues have used these summer grants as a way to collect preliminary results to use when applying for larger grants from outside agencies, however the program's primary purpose is to provide on-campus research opportunities for our students.

Another fertile opportunity for research is to be open to collaborations. Two years ago, one of our alumni introduced me to an undergraduate research group based at St. Mary's College (*13*) working on paper analytical devices for detection of counterfeit pharmaceuticals. All of the science faculty at my institution were invited to a tour of the group's facilities and warmly encouraged to get involved. I immediately accepted the invitation. I attracted two students from our research methods course to try out a few ideas during the academic year. This went well enough that I was able to continue working on a similar project the following summer with a Mohler-Thompson grant. Having collaborators has given all three of the students a sense that their work extends beyond our campus. They honed their communication and networking skills in front of strangers during group report meetings at St. Mary's College. My collaborators also provided scientific and emotional support for me which countered some of the isolation I felt being the only chemist involved in research on my own campus at the time.

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The Undergraduate Researcher

Undergraduates are not graduate students. Though obvious, this fact is easy to forget. Many undergraduates are capable, intelligent, enthusiastic researchers. However, they also have many other responsibilities including coursework (some of which may be outside of the sciences), jobs, and athletics. They often have very explicit requirements for graduation that must be completed within a relatively short period of time (no more than four or five years) and have not committed to days or nights spent entirely in the lab. Students understand that doing research with a professor is an honor, and therefore they are sometimes reluctant to express any objections to their professors' plans, even if there is a conflict. I strive to be protective of my research students and sensitive to their needs and desires to do other things. I feel that one of my obligations is to help them learn to balance disparate responsibilities and I am careful not pressure them to neglect some in order to devote maximum time to research.

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There is no single quality that makes a student successful in a research project. The students I have mentored ranged from having completed just one year of college to juniors and seniors. Not all of them have been chemistry majors. Some of my colleagues offer research positions by invitation to specific students they know from class, but I generally advertise around the science building that I have a position available and collect applications. I ask applicants to submit a resume and a cover letter explaining what they want to achieve by participating in a research project. Having to exert even this minimal amount of effort is enough to eliminate those who would probably be unsuitable. After I read the letters, I interview the applicants one-on-one and, as we discuss the potential research project, I listen for genuine interest in the project and willingness to learn. While knowledge of chemistry and lab ability are important factors, I do not always choose the student with the highest GPA and I rarely require applicants to have completed more than first-year chemistry courses. I also consider the impact that a summer research experience might have on the student's future plans. One who has already decided on graduate school or who has already had a research experience elsewhere may not benefit as much as another student who is unsure about her future or who has had no experience of chemistry outside of class.

Mentoring

Undergraduates do not usually have many years of experience doing or thinking about chemistry. They have not developed much chemical intuition yet, and are not always able to correctly predict the outcome of a proposed action. Calculations that are second-nature to me may take the student a significant amount of time to work through, and errors might be made. Even if she is a top performer in class, there is still a lot the student does not know. Students at this stage are only beginning to be independent learners. It usually does not work to just hand the student a book or article and expect him to absorb and apply it. These are skills that take time and repetition to master, and another of my responsibilities as the mentor is to foster them in my students.

Mentoring is not a skill that is formally taught or even informally encouraged in many graduate programs. Mentoring is more than supervising the student's work. It includes shepherding the student from beginning to end of the project, and maintaining a relationship thereafter. One good resource for faculty mentors is *How to Mentor Undergraduate Researchers* (*14*). This short book for professors beginning to mentor research students contains practical information such as setting appropriate expectations, writing letters of recommendation, and research ethics.

I like to meet with my student researcher at least once a day during a summer project. I have no graduate students or research staff, so I am personally responsible for mentoring the undergraduate student. Often, we are working side by side throughout the day, but when this is not possible I schedule regular meetings to talk about progress and next steps. During the academic year when students are not working on research every day, I meet with them at least once per week. Especially at the beginning of the project, the student may feel overwhelmed and need extra reassurance or direction. It is important to be patient and maintain a positive attitude, even after mistakes and setbacks.

Usually I require the student to locate and read some of the relevant literature. I may share one or two articles if I already have them on hand, but the student must learn to use SciFinder and other databases to find additional background material. Depending on the student's familiarity with these tools, I provide some level of basic orientation and instruction and I will suggest additional search strategies if the student has difficulty. Then we sit down together and talk through each paper in detail to make sure we both understand it. These conversations also help to build a comfortable working relationship.

Once the student begins working in the lab, I make sure we review all safety precautions from appropriate personal protective equipment for various tasks to reading Material Safety Data Sheets for each chemical we will use. I do not allow my students to work in the lab alone; if I am not able to be there myself, I make sure another qualified person is present. I have found it useful to explain that this is for the student's safety rather than a sign of a lack of trust. I assist in setting up and using any instruments and other equipment the first few times. I check each type of calculation until we are both confident in the student's results. Initially, I like for both of us to do the same calculation simultaneously and then compare. This makes it much easier to check the result and is a confidence boost to the student when we get the same answer.

All of my research students must properly maintain a lab notebook throughout the project. I think this is critically important for students to learn early in their careers, as it will be a part of any future research job. Based on the level of the student's experience in chemistry lab courses, I provide additional instructions with reference to *Writing the Laboratory Notebook* by Howard M. Kanare (*15*). I usually purchase a good-quality bound notebook for the student and keep it in my professional library when the project ends. Thus, the student is conscious of recording information not only for himself but for me and any student who might continue the work in the future.

At the end of the project, I require the student to write a report in the style of a journal article. We work on it together over several weeks, beginning with an hour or two a day and increasing as the lab work winds down. Since we have, by this time, already read and discussed many published articles, the student is aware of the characteristic structure. I advise starting with the Materials and Methods section, because it is typically easiest for the student to understand, proceeding to the Introduction, and finishing with Results and Discussion. I think this order helps the student progress through cognitive levels from simply reporting what she did, to summarizing what she learned from reading the literature, to finally drawing connections and conclusions based on the results. I read multiple drafts and comment on each part. From this experience, the student develops scientific writing skills and gains a high-quality paper for his or her portfolio. The paper also contains a complete record of the results of the project, which is valuable to future students, and is potentially publishable.

From the beginning of the project, I plan for the student to present a poster at several venues. These have included sessions sponsored by the funding organization, research showcase days on our campus, local undergraduate

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research conferences, and ACS Regional meetings. Sharing results is essential to practicing science, and most undergraduate students have no other opportunity to experience the scientific community. At meetings, students learn how to behave professionally, they see their work in a wider context, and they may make advantageous connections with other scientists or recruiters. If the terms of the grant allow, I set aside part of the project budget to cover registration and travel expenses for the student to attend a meeting. Students may also be able to acquire financial support from other campus sources (e.g., Student Activities or Dean of Students offices) or through the ACS Local Section.

Potential Pitfalls

Be aware of the potential for your work to be marginalized because your coworkers are "merely" undergraduates. Although this attitude appears to be in decline, it does exist. Also guard against deprecating your undergraduates' work, even inadvertently. If you have devised a reasonable experiment and the result is good, it deserves recognition equal to that done by any other researcher. However, depending on your campus culture, you may need to educate members of the administration about the extra benefits of undergraduate research. If so, starting with your Admissions department might help, as that office is naturally inclined to publicize undergraduate success stories as a way of attracting new students. Cultivate support from your chairperson, dean, or other sympathetic administrators. After your students present posters at scientific meetings, display those posters in a high-traffic area on campus. When you publish a paper with a student co-author, deliver copies to key administrators and other colleagues. Suggest that the campus newspaper (or other media) produce an article on your students' work, or prepare one yourself and send it in. As mentioned previously, the Council on Undergraduate Research has many resources specifically addressing these issues.

Another potential danger is overcommitment. If you cannot give the undergraduates the time and attention they need, the experience may be unproductive. How many students are you able to mentor effectively at the same time? For me, the limit is two within the parameters I have described here. The research topic also matters. Though I have had students propose their own topics that were successful they must be within my area of expertise in order for me to provide sufficient oversight. Thus, analysis of inorganic soil contaminants was acceptable, whereas a student who proposed to study the chemistry of a plant extract was directed to a departmental colleague who specializes in biochemistry. Lastly, do not allow enthusiasm for undergraduate research to lead to neglect of other responsibilities. Be realistic about all the expectations of your position.

Problems can occur with students. The types of problems I have dealt with have been relatively minor, such as absenteeism, allowing unauthorized persons into the lab, and failure to meet deadlines. I recommend using a simple contract at the beginning to clearly define the expectations of both the student and the mentor. The contract can include the start and end dates of the project, working hours, stipend amount, and any unusual conditions. List the positive outcomes

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you anticipate for the student such as experience in research, a presentation at a scientific meeting, or a publication. If the student understands the expectations and probable outcomes, it is more likely that the project will proceed without incident. Confront any missteps calmly and maturely and be careful not to assume the student misbehaved out of disrespect for you. Maybe your instructions were unclear. Maybe there was some problem of which you were unaware. For more serious student issues, know your campus's emergency protocols and contacts at the student affairs office and do not hesitate to use them if you have reason to be concerned.

Conclusion

In the 10 years I have worked at my present institution I have mentored six summer research projects and 18 academic-year research projects engaging a total of 22 undergraduate students. The results of each of the summer research projects have been presented as posters at ACS Regional meetings by the students involved. Eleven of the student researchers went to graduate school, two went to medical school, and two became high school science teachers after completing their undergraduate degrees. At least four of the others found full-time positions with local industry.

Training undergraduates to be ready for graduate school and careers in chemistry is vital to their future success. Experience with research is an important component of that training. My aim in this paper was to describe the ways I have been able to involve students in research projects, despite the challenges faced at a small PUI with minimal institutional support for research. My advice to others in similar environments is: do not hesitate to start at whatever level you can manage. Be an advocate for undergraduate research on your campus, and keep an eye out for opportunities to expand the program, reach for new funding sources, and collaborate with colleagues. The ultimate beneficiaries of your work will be your students.

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Chapter 13

Finding the Time, the Money and the Students: Building an Undergraduate Research Group in Chemistry from the First Day of an Academic Career

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Building an effective research group with undergraduate students almost exclusively is an extensive endeavor. Herein can be found the agglomerated ideas and lessons learned about this unique research style by three faculty (the authors) at different points in their academic careers: assistant, associate, and full professor. The authors aim to help new faculty from the first day of their careers who wish to pursue this style of research work. The authors discuss how to find and allocate the time to accomplish original research, how to procure funding during financially challenging times for academic institutions, and how to attract and retain good students to meaningful research projects.

Introduction

Teaching, scholarship, and service are the three pillars upon which good faculty members build academic careers. For many academicians at primarily undergraduate institutions (PUIs), balancing the demands of establishing and maintaining good scholarship are far more difficult than balancing those of teaching and service. In spite of the challenges associated with performing research at PUIs, succeeding in scholarship is important for the faculty, the students, the institution, and the greater good of the field of scholarship.

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Directing undergraduate research and producing meaningful results is the ultimate win-win scenario for succeeding in scholarly endeavors, in spite of the difficulties associated with it. First, undergraduate research is highly beneficial for the student researchers. Undergraduate research has been listed as a high-impact practice (*1*), and it enhances student learning and success (*2*). Undergraduate research improves retention and academic success (*3*, *4*) as well as critical thinking skills and a number of other scientific skills (*5*); furthermore, students who participate in undergraduate research are more likely to enroll in graduate school (*6*). Additionally, several studies have demonstrated that undergraduate research increases understanding and confidence (*7*, *8*). Second, undergraduate research is also valuable for the professors leading such work. Working with undergraduate students can provide high-throughput results, depending on the level of interaction with each student researcher and the choice of project. In addition, at PUIs, work with undergraduates is becoming increasingly valued and ever more necessary for tenure and promotion. Moreover, the product of such work may potentially lead to increased exposure as the faculty member and students attend local, regional, and national conferences to present their results or publish their work in peer-reviewed journals. Finally, undergraduate research promotes engagement between faculty and others in their field, an introduction to the field for students, and interaction between faculty and students (*9*). The result of such interactions is a group of energetic and intellectually-engaged faculty members and emerging science students.

Finding the Essentials: Time, Money, and Students

Time

Before discussing methods for obtaining the essentials for undergraduate research, there needs to be an acknowledgement of some of the potential limitations of work with undergraduate students. Many limitations center on one’s time, or the seeming lack thereof. Put simply, professors are busy. It can be difficult to balance the time devoted to course work and service with time devoted to research. Furthermore, it is perhaps even more challenging to set aside *time to work with research students* from what can be called “*alone time*” available to be dedicated specifically to research. Students, of course, are busy as well. Even when students are reliable and show up to research regularly, it is difficult during the academic year to find large blocks of time during which students and faculty can work together. Additionally, even for relatively simple and straightforward projects and techniques, undergraduate students may require significant training in laboratory techniques, data analysis, and written and oral presentation of results. As a result, some students require substantial supervision and attention. Furthermore, undergraduate students are often only able to perform research for a few consecutive semesters during their undergraduate years. With acknowledgement of these possible struggles in the undergraduate research setting, it is important to remember that undergraduate research is almost always worth the investment when a longitudinal perspective is considered.

So, an important question becomes: how does a faculty member find the time for solid, productive, undergraduate research? First, one must consider finding time for the professor to lead such work. It is important that a faculty member find time alone to focus on research. This solo time is important for staying apprised of the latest developments in the literature, developing current and new ideas for projects, preparing grant proposals, and writing up data as manuscripts. Some find that the early morning hours are the best for alone time while others prefer later times in the day. Others prefer to "escape" in their office during the middle of the day by closing their door. Good professors often learn the patterns in each day, week, and term when students do not routinely stop by and use that time to catch up on research-related tasks; other professors may choose to schedule in specific hours for such work. A key in determining such time for oneself is to ensure that research is the focus of that specific block of time. It may become prudent to disconnect from e-mail, phones, and other potential distractions. Sometimes, faculty at rural institutions or smaller schools with few same-discipline colleagues have the problem of too much alone time! Regular involvement in local/regional scientific organizations can help with this challenge.

Next, since student schedules have limited flexibility, it is the responsibility (and it is advisable) of the professor to select projects appropriate for the students. Consider the time requirements for each project. If a reaction requires eight hours to reach completion and may not be left unattended, it is probably not appropriate for the undergraduate schedule. However, if a reaction can be prepared within a three-hour block and can be left overnight (16 hours or more), it is more likely to be appropriate for such students. Any time a project can be sliced in three(or shorter)-hour blocks, it becomes more suitable for undergraduates. Faculty may consider whether the compounds, samples, other solutions, etc. are sufficiently stable for longer periods of time (several hours, days, weeks, or even a semester or more). This may alleviate the need for the students to spend their research hours preparing solutions or starting materials. In truth, there may be certain procedures outside the time-reach of undergraduate work. Faculty members may find themselves performing such work or postponing it until longer academic breaks. Also, when performing large numbers of instrumental analyses, autosamplers are favorable if the budget or project can be made amenable to their use. Further, in some laboratories, it is more appropriate to provide technique tutorials during a traditional academic year, especially for research novices. The primary disadvantages of this, however, are that productivity is often measured not by how many techniques students master but, rather, by the resulting data acquired with those skills.

There are additional ways to capitalize on the short time available to undergraduate students. One idea is to incorporate research theory into laboratory courses. Both faculty and students can benefit from intertwining research into theory classes. The large number of students performing research-based experiments can provide a massive amount of data. Furthermore, classroom-based scientific research provides an efficient means of introducing large numbers of students to the techniques or applications they might encounter later in research laboratories. For example, if the professor leads synthesis-based projects, it may be possible to screen several reactions in a classroom environment. There will

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be a large amount of data collected in a short period of time, ultimately resulting in higher throughput. Moreover, the students can be introduced to synthesis techniques that will be used in later classes or in research. If the professor leads a mass spectrometry-based research project, for example, it may be possible to introduce the instrument in class with research-based applications. While traditional tactics like collaborating on a joint project with faculty from your own or a neighboring institution are also great ways to deal with a lack of time, integration of research into teaching takes advantage of the primary thrust of most PUI faculty positions: daily pedagogy.

Money

Chemistry-based research is expensive. Reagents are costly, small equipment costs add up, and larger, more complex instrumentation expenses can be exorbitant. At many PUIs, the resources readily available to professors and their team of students may not be sufficient for the work chosen. This being said, there are many places to seek research funding. When requesting funding for projects at PUIs, it can be beneficial to consider not only the research project, but which organizations, industries, and concerns are interested in funding the future scientists.

The National Science Foundation (NSF) is one of the first organizations that science professors consider when seeking funding for undergraduate research in science, technology, engineering, and mathematics (STEM) fields (*10*). The array of NSF programs is diverse, and many are well-suited for undergraduates. The NSF Research in Undergraduate Institutions (RUI) Program is designed to support faculty research at PUIs "through funding 1) individual and collaborative research projects, 2) the purchase of shared-use research instrumentation, and 3) research opportunity awards for work with NSF-supported investigators at other institutions" (*11*). For those who have a flair for curricular-based development and research, and for those who are interested in the scholarship of teaching and learning, the NSF Catalyzing Advances in Undergraduate STEM Education (CAUSE) program might be appropriate. The CAUSE Program (which recently replaced the Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES) Program) is aimed at supporting educational research within the STEM disciplines "to better understand and improve undergraduate STEM learning and persistence of students from all groups and to support STEM workforce development" (*12*). Also, for PUI researchers who are interested in purchasing larger instrumentation (such as nuclear magnetic resonance (NMR) spectrometers, liquid chromatograph-mass spectrometers (LC-MS), or confocal microscopes, for example), the NSF Major Research Instrumentation (MRI) Program may be an avenue to consider (*13*). The goals of the MRI program are to fund the acquisition or development of instrumentation to expand the scope of the research at a variety of institutions.

Even with the plethora of NSF opportunities, there are other options for funding for PUI-based research. There are a number of other organizations and programs, big and small, which specifically support undergraduate research. Another federally funded program that may be of interest to those whose research

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has a biological emphasis is the National Institutes of Health (NIH) Academic Research Enhancement Award (AREA) R15 program; the R15 is designed to increase NIH-funded research at institutions that have not been major recipients of NIH funding (*14*). Within the Department of Defense, the Office of Naval Research (*15*) and the Army Research Office (*16*), as well as the Department of Energy (*17*), all have a history of supporting academic research. Most state governments also have an office and department that fund educationally-based research, inclusive of colleges and universities.

In addition to government funding, a number of foundations support a variety of different research endeavors. The American Chemical Society has a number of offices, such as the Petroleum Research Fund (PRF) (*18*), as well as some of its divisions (*19*), that support research, including undergraduate research. Research Corporation also offers programs that can fund in this area (*20*), as does the Council for Undergraduate Research (*21*). Other applications-centered foundations, such as the Juvenile Diabetes Research Foundation (*22*), may be appropriate depending on the research area of interest.

Another broad source of funding is large industries such as: BASF (*23*), Dow (*24*), DuPont (*25*), Monsanto (*26*), Eli Lily (*27*), and Ford Motor Company (*28*), to name a few. Profitable industries are happy to support future scientists who may join their companies. More broadly than this, the Nonprofit Quarterly and other such organizations provide periodic announcements of funded research opportunities, some of which are tightly directed, and some of which are specifically aimed towards funding undergraduate researchers (*29*).

Moreover, many academic institutions offer some internal funding opportunities. When embarking on an academic career, begin by negotiating the best start-up support possible as a first level of intramural funding. Once on campus, apply for suitable internal funds whenever possible. They are often helpful for purchasing small equipment and funding summer research student assistants.

As a further possibility, what is commonly referred to as "angel" funding is at times available to faculty at any stage in their career. Within colleges and universities, this can manifest itself as alumni funding in one form or another. It may be administered through an academic department, through a dean's office, or through the provost's office. At times, such funding is specifically earmarked by the donor for use towards undergraduate research. This is worth pursuing when it appears, because it is far less time-consuming and competitive when compared to the availability of funds through national agencies.

In good times and bad, it is also worthwhile to consider some alternatives to major spending on expensive instrumentation and equipment (faculty members are always on a budget, no matter how big or small). In performing undergraduate research, sometimes there is not a need for the newest, most state-of-the-art, highest sensitivity instrumentation or equipment. In such a case, several alternatives for procuring equipment become possible. For example, make monthly visits to hospital disposition centers, the disposition centers of any nearby, large, research-based universities, and the Defense Reutilization Management Office of any nearby military bases to see if equipment is available for purchase (*30*). When researchers at such institutions retire, move out, or

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simply replace their own equipment, they often choose to “dispose” of older equipment; and the federal and state governments are generally required to sell such items in an attempt to recover some of the money from what was purchased through tax dollars. Items such as small and large centrifuges, autoclaves, vacuum pumps, and larger instrumentation such as mass spectrometers, fluorimeters, and microscopes sometimes become available. More mundane items such as office furniture, lab stools, trash cans, and other needed items are on occasion at disposition centers. Older instrumentation and supplies also become available as industries purchase newer items (*30*). Departments managers in major companies are often happy to free up space and donate older, working equipment to a worthy cause.

Beyond traditional funding opportunities, contract work and consultation done for a local company, with instrumentation available at your own academic institution, can become a source of funds in what is generally thought of as an informal industrial-academic partnership. While industry often has significant resources with which to address and solve a particular problem, sometimes industrial human power is lacking. Thus, it becomes profitable for the industrial partner in such an informal collaboration to provide some level of funding to an academic researcher, who then can work on and further a shared project. Many times, the industrial partner is happy to find that such funding is being spent to help undergraduate researchers, either in the form of summer stipends for students, or for supplies and equipment throughout the year. Such partnerships can often be achieved by attending Local Section ACS meetings or other regional conferences where academic and industrial professionals come together.

Ultimately, when any outside funding is taken into account, the statistics of success, the need for initial data, and institutional/agency deadlines must also be considered. Fortunately, as has been demonstrated, there are a great number of sources, making reasonable funding possible for the prepared and diligent faculty member. Institutions may even have grant-writing staff dedicated to working with faculty on proposals, particularly with institutional data.

Students

No matter how much time is available, how large a budget is, how well-stocked one’s research laboratory is, or how great research ideas are, the productivity of undergraduate research is directly related to the quality of the undergraduate students who will complete such work. As a result, finding good students is essential, even if it means a faculty member must expend considerable effort. Fortunately, most PUI research investigators are privileged to spend a significant amount of time getting to know good students in several academic settings. Some professors appreciate the opportunity to meet students in large undergraduate lecture and laboratory courses. These larger courses are usually at the freshmen and sophomore levels, when the students are younger and eager; the students’ youth permits more time for training and capitalizing on the skills the students have mastered.

Laboratory classes can be a particularly fertile ground from which to recruit new students into a research group. Faculty members who teach such courses have

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at least a semester in which to observe which students do high-fidelity, careful work, as well as which students are interested in broadening their experience in a research laboratory.

Also, in order to recruit students into a research group, it is helpful for faculty members to promote their research in and around their university. One of the most fruitful and simplest methods to advertise one's research to the undergraduates is to hang previously presented research posters in well-traveled hallways. Doing so introduces undergraduate students to the idea of research, demonstrates to them that it is possible for them to participate in something advanced and professional, and illustrates what type of instrumentation is used and what applications are investigated in the professors' laboratories, even if the students initially understand little more at their first exposure.

Some professors are also skilled at incorporating the principles and applications of their research into their lecture or laboratory lessons. The effect of the introduction of such ideas into courses is similar to that of hanging posters that have been presented at a scientific conference. One benefit of implementing the research theories in the curriculum is that, should any of those students join the professor's research group, they have been introduced to the research area in advance of joining the lab.

In conjunction with attempting to recruit new students, publicizing research projects and results around the university by attending and presenting at all intramural research events, including poster days, university research symposia, coffee talks, and other venues, is always beneficial. When appropriate, it is ideal to have one's research students present at such meetings. When students observe other students presenting original research, they are encouraged (and perhaps even competitive) to gain such an experience themselves.

Finally, professors are encouraged to notify their institutional public relations office of any presentations at external conferences or meetings, and of any publications and awards. Students appreciate the recognition of their mentors, advisors, and teachers; and this form of recognition ensures a wider awareness on campus of a person's research efforts and results.

Conclusion

This chapter represents a starting point for new PUI faculty, introducing a few of the means for developing and maintaining a successful undergraduate research program. The challenges of undergraduate research are surmountable and can be tackled with resources that are either readily available or attainable with time. Beyond this, probably the best assets are almost always the professor's own colleagues. Colleagues in each faculty member's department or college (as well as colleagues at institutions of similar size) often know best the struggles likely to be encountered and the best avenues for procuring the essentials that are needed for crossing and overcoming any hurdles within their own institution. Professors at all academic levels would exercise wisdom to cultivate relationships with their colleagues that include advice sharing and rich discussions of teaching and research philosophies.

The positives of undergraduate research are many, and the challenges are far outweighed by the benefits. The most in-depth student interactions occur in the research environment. The students gain experience in critical thinking, are offered the opportunity to apply previously-mastered laboratory techniques and to learn new techniques, and are also afforded the chance to present their research at meetings, conferences, or in written publications. Working with undergraduate students in the research setting, encouraging student-driven idea generation, and observing the students mature as scientists in their field is often described as the most rewarding teaching and learning interaction.

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