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A Case of Reform: the Undergraduate Research Collaboratives

Elizabeth Horsch and Mark St. John
Inverness Research Inc.
Inverness, California 94937

Ronald L. Christensen
Department of Chemistry
Bowdoin College
Brunswick, Maine 04011

Elizabeth Horsch (ehorsch@wyoming.com) is a Research Associate with Inverness Research, Inc., Inverness, CA 94937.
Mark St. John is President and CEO of Inverness Research, Inc., Inverness, CA 94937.
Ronald L. Christensen is the James Stacy Coles Professor of Natural Sciences at Bowdoin College, Brunswick, ME 04011

Abstract

Despite numerous calls for reform, the early chemistry experience for most college students has remained unchanged for decades. In 2004 the National Science Foundation issued a call for proposals to create new models of chemical education that would infuse authentic research into the early stages of a student's college experience. Under this initiative, NSF funded five undergraduate research collaboratives. The sites ranged from a single large research university to a collaboration of seven small institutions across a three-state area. Each of the sites developed a unique model for creating and supporting research opportunities for first and second year undergraduates. In this report, we include brief descriptions of the five sites and describe their common components and the variety of implementation strategies. Finally, we examine the impacts of early research on students, faculty members, and institutions and the potential for these research experiences to drive change in science education.

Introduction

It would be hard to argue that general chemistry, in its traditional form, is held in high regard among college students, particularly those for whom it is a required course that often marks both the beginning and the end of their engagement in the chemical sciences. Yet despite numerous calls for reform and efforts to change this ubiquitous course (Cooper 2010), it has remained virtually the same for decades. Traditional lecturing and note taking, followed by periodic testing, were efficient means of communicating information to large groups of students when books were scarce and few could afford them. This has continued to be the dominant mode of instruction primarily because it is familiar and requires little new effort (Boyer Commission 1997). It also relegates the role of the student to passive receptor of information and the role of the instructor to detached dispenser of existing knowledge.

In 2004 the Chemistry Division of the National Science Foundation (NSF) called for the creation of new models of chemical education that would provide opportunities for authentic research in the first and second years of a student's college career. The National Science Foundation has a long tradition of promoting undergraduate research, during the past 25 years with its Research Experience for Undergraduates (REU) program. The significant impacts of REU and similar programs sponsored by NIH and NASA were documented in a recent study. (Russell, et al. 2007). However, the principal beneficiaries of these programs have been juniors and seniors, who already have decided on STEM (science, technology, engineering, or mathematics) careers prior to carrying out undergraduate research. The new NSF models were developed and implemented as Undergraduate Research Collaboratives (URCs) and were driven by the proposition that research experiences in the first and second college years would 1) increase the numbers and diversity of students in the sciences; 2) enhance the capacity, infrastructure, and commitment to excellence in undergraduate education in the chemical sciences and related disciplines; and 3) ultimately bring about changes in education at the disciplinary as well as institutional levels (National Science Foundation 2003).

Five distinctly different URCs were funded under this initiative. The sites differed in a number of important ways: the size of the lead institution, the number of collaborating institutions, the research questions that were addressed, and the number and nature of the students served. Typically, the URCs were housed in the chemistry department of the lead institution. However, the collaborations that developed and the research topics that were addressed often spanned multiple science disciplines. A brief description of each URC and its web address are included in Table 1.

In 2009, NSF awarded Inverness Research, Inc. (IR) a Small Grant for Exploratory Research (SGER) to explore and test the concept of *staged evaluation* using the URC program as a paradigm. A staged evaluation proposes a small-scale preliminary study of a large, multifaceted initiative before launching a full-scale evaluation. A Stage One study is a brief, exploratory effort to clarify the need, purpose and design of a more rigorous evaluation. As part of the Stage One study, the Inverness team observed how the five URC sites interpreted the multiple broad and ambitious goals of the URC initiative and the original solicitation for proposals. The IR team completed the Stage One study of the URCs in the fall of 2010. (Inverness Research 2011). Our purpose in presenting a brief overview of these findings is to describe program characteristics and strategies that are common among the models, which, in our view, have demonstrated potential to transform undergraduate science education in ways that are effective and engaging for students and compelling and valuable for faculty. It is important to emphasize that our conclusions are not based on a rigorous, full-fledged evaluation of the URC program or the individual sites. Nevertheless, we believe that the preliminary findings merit sharing with the wider educational community.

We note that at the time of this study the URCs were in their 4th or 5th year of implementation of the five-year program, and our observations are based on a single visit to each collaborative as well as interviews and document reviews. The IR team conducted extensive discussions and interviews with the leaders and implementers of the models and talked with groups of students about their research experiences. The team observed students doing research in laboratory settings and attended student presentations of research results to faculty members and other students. Student-student and student-faculty interactions were observed at each presentation event. Finally team members reviewed documents provided by the collaboratives. Although each site collected and reported data on its model, including the number of students who participated in research, the increase in the number and diversity of students engaged in research, and the numbers of faculty who implemented research in their courses, the sites used neither common assessments nor common reporting protocols. It thus is beyond the scope of the Stage One study and of this report to present the individual data available on each site's model.

In the following section, we describe common components among the five models and our assessment of the impact of the various implementation strategies. In the final section, we discuss the role of early student research in changing and enhancing the overall quality of the undergraduate educational experience and the potential for early student research to drive change in science education.

Key Features of the Five Models

Each site created its own unique model and even the features that were common among the models were shaped by the context in which the model was created and the implementation strategies that were designed to achieve the diverse goals of the URC solicitation.

<u>The Nature and Role of Modules</u>

Observations: Across all the URC models, laboratory research modules were the primary vehicles for introducing first and second year research experiences. Integration into the curriculum varied from short modules that replaced parts of existing laboratory curricula to modules as a feature of significant course re-design. Research topics explored in the modules crossed many disciplines. At the University of Texas URC, there were twenty integrated research streams within the disciplines of chemistry, biology, physics, engineering, and astronomy and each research stream created 10-12 discipline-specific modules each year. At another site, the module topics ranged from the synthesis of new luminescence molecules to the reduction of parasites and diseases in honeybees. Two examples of modules are provided in Table 2.

A faculty member or teams of faculty members created the modules, and the subject and structure of the research modules reflected the research interests of the faculty members at that particular collaborative. Typically these modules were shared among member schools in the URC. Implementation strategies for the modules were site-specific. In some cases the faculty member, or members, who designed the module also taught the module; in other cases, teaching assistants and student peer leaders facilitated the insertion of a module into an existing laboratory course.

Implications: Modules developed by faculty with varied research interests appeared to provide meaningful research experiences for students in many disciplines and in diverse settings. When a faculty member created and taught the module, students indicated that the connection between concepts in lecture and the work in the laboratory was evident and accessible. When modules were simply inserted into the laboratory, students reported that the laboratory experience was more interesting and engaging, but they had difficulty connecting the research with the chemistry lecture. Inserting modules may be a useful strategy for transporting and replicating the research experience at other sites, but, for the students, the correlation between the chemistry content and the laboratory experience may be diminished by this mode of implementation.

<u>The Nature and Impacts of Early Research Experience</u>

Observations: The introduction of research in the first or second year of undergraduate study was common to all five models. However, the duration of the research experience and the strategies for delivery varied. In some collaboratives, a single research module of three to nine week's duration replaced a unit or units in traditional 1st or 2nd year laboratory courses. Institutions in which chemistry was a required course for students in many different majors used this approach to provide a research experiences for large numbers of 1st and 2nd year students. This approach also gave institutions outside the URC access to modules they could insert into their curricula to provide early research experiences for their students. The CASPiE URC site (Table 1) created modules that were specifically designed for export to other institutions.

In other collaboratives, the early research experience was viewed as a first step in a deliberately crafted research continuum. Students were introduced to research as freshmen or sophomores and opportunities to continue research were made available in the following years. At four sites, students who had participated in early research were recruited to become peer leaders. Generally these peer leaders assisted with instruction of the research course the following year, and in some cases, the peer leaders were trained to assume primary responsibility for implementing the research modules in the laboratory course (Weaver, et al. 2006). Often these peer leader students extended their research by concurrently working on projects started during their initial research experience.

Implications: Across all sites, students in the focus groups and in the individual interviews were generally positive about their research experiences. They appreciated the opportunity to choose a topic, design their own research procedures, and to argue and debate the interpretation of data with their research team and the faculty. They noted that their research was more engaging than reading from a lab manual and following a set of instructions, and they commented that their work had a purpose and that faculty and fellow students valued their findings. Generally, modules replaced existing materials in the laboratory so the laboratory time required for a course was not extended. However, since the research usually involved groups of students and the planning, coordination, and data collection often required out-of-class time, students at one large research institution indicated that they found it difficult to fit the time required for research into their already busy academic schedules.

Students reported that projects that provided a continuity of opportunities for research beyond the introductory level increased their appreciation of the value and importance of research and the nature of the science enterprise. The work of Sadler and McKinney (2010) supports this finding. Students also indicated that the opportunities to continue with research increased their interest in potential careers in science. The IR team noted that many students, on their own, actively sought and obtained continuing research opportunities as interns with outside organizations or with research faculty in their own institutions.

Sharing Research Results

Observations: Each site created opportunities for students to share their research findings. Often student presentations occurred at regularly scheduled meetings of the faculty and students within the collaboration. Student preparation and presentation of their research findings before an audience of faculty and peers created opportunities for sharing new scientific knowledge between students, between faculty and students, and among faculty members across the collaborative. Some collaboratives also supported student presentations and posters at regional and national scientific conferences, and several sites included student authors on published papers in scientific journals.

Implications: Presentation appeared to be a significant tool for giving students pride of ownership in their research results. The currency of exchange in these sessions was shared knowledge regardless of the age or status of the participants in these discussions. At these presentations, the IR team saw evidence of authentic and quality research activities at an appropriately high level of rigor for undergraduates. Findings derived from on-site observations of student presentations were confirmed by the independent review of the quality of student research that was conducted by the chemistry expert consulting with the research team. The team particularly noted the confidence students displayed in discussing their findings with knowledgeable faculty members and fellow researchers. Several groups of students expressed their satisfaction in knowing more about their research topic than did their audience.

The Nature and Impact of Collaboration

Observations: All models created collaborations and often these collaborations impacted the nature of the science experience for students and faculty. These collaborations existed between faculty members who worked together to create the modules both within and among the institutions, between faculty and students as they worked together on a shared research project, and between students in their cohort groups. For example, a faculty member at one site created a module that challenged students to determine the characteristics of ionic liquids. He reported that as a result of this shared research agenda, he gained an extensive database for his research and a pool of experienced student researchers.

Implications: Sites reported that interest in research among faculty at smaller institutions increased, and collaboration with larger institutions provided opportunities for training and access to modern instrumentation generally unavailable at these sites prior to this collaboration. In smaller universities, the URCs helped build foundational research capacities, including greater access to instrumentation and faculty expertise, increased administrative support for student research, and resulted in greater ability to attract outside funding. The IR team also noted that the sites reported an increase in the number of grants written and funded to support research at smaller institutions.

Particularly at smaller institutions, faculty members actively sought opportunities to collaborate with other faculty members and students around research. In the larger universities, the project provided empowerment and support for faculty who were champions of curriculum improvement at their institutions. Regardless of the size of the institution, faculty members who participated in creating and implementing the research experience were more likely to engage students in a shared research agenda. A URC leader suggested that, unlike faculty in traditional university courses, these faculty members shed a cloak of institutional detachment and accepted a measure of personal responsibility for the academic success of their students (Dutta 2009).

The development of relationships based on shared research interests among younger faculty members across institutions was another outcome of the collaborations. One young faculty member noted that older faculty at his institution had been supported in scientific collaboration in the post-Sputnik era, but these kinds of opportunities had not been available to him and his colleagues. As the older group retired, the culture of cooperation among colleagues across institutions was disappearing. The URC initiative appeared to rekindle these scientific collaborations. This finding was reported by faculty at three of the sites and appeared to be a result of the opportunities the URC provided for interactions across institutions.

Increasing the Number and Diversity of Students in Science

Observations: All sites succeeded in increasing the number and diversity of students with access to early science research experiences. Total annual student engagement at all sites was approximately 2500 students in 2008-09, year 4 of the initiative. Numbers per site ranged from ~60-1000.

Sites varied in their recruitment practices and efforts to attract students who historically would have been less likely to pursue science paths. One site aggressively recruited women and minorities and students with risk factors such as low socio-economic status, low SAT scores, and limited parental education and carefully tracked these students as they continued their science programs. Studies on retention rates in science for these students compared to a control group of like demographics showed a three-year retention rate of 88% compared to 65% for the control group (Shear 2009). In another study designed to measure performance in upper division courses in the student's major science field, the GPAs for these students were significantly higher than for other students in the same college (Shear 2009).

Implications: Through student self-reports and our observation of student presentations we found multiple instances of student success in science and improved self-confidence in their capacity to do science that likely would not have happened without the early research activities. When the IR team interviewed a group of students who had participated in early research and who then parlayed that experience into junior or senior internships, these students noted that based on their SAT scores, they originally had perceived themselves to be incapable of doing science and ineligible to apply for opportunities in science. Their research experience was critical to altering their estimation of their capacity to succeed in a scientific career and their confidence to seek continued research opportunities.

It also appears that the lack of diversity of students who elect to enter a scientific field may be strongly influenced by the institution's admission requirements, either actual or assumed. The overt or covert use of factors such as low SAT scores, low socio-economic status, minority and female status and parental education may unnecessarily limit both the number and the diversity of students who choose science careers.

Institutional and Disciplinary Challenges

Observations: Implementing student research involves higher costs and greater space requirements per student compared to the traditional science laboratory. Undergraduate research also is labor intensive for the faculty. Large institutions with well-established research faculty face challenges in embracing beginning undergraduates as potential contributing members to the research endeavor. Faculty members at smaller institutions typically have heavy teaching loads, so time to create authentic research experiences for 1st and 2nd year students comes at the expense of other teaching and research demands on faculty time. Additional factors that create potential barriers to developing and implementing early research opportunities include traditional and established course sequences for science majors and discipline standards imposed by external organizations, (e.g., the Committee on Professional Training of the American Chemical Society). Finally, at many institutions, faculty promotion and tenure practices are based on rewarding research and are not structured to encourage innovations in teaching. Consequently, senior faculty members who are well established and who have significant research support may have little incentive to support curricular change.

Implications: Strong administrative and institutional support is a critical factor for the successful integration of early research in the chemistry curriculum. This includes support for reallocation of resources including faculty time and physical space, changes in the tenure and reward practices, and leadership at the senior faculty level in re-examining the purpose and process of undergraduate science education.

The Case for Reform

Implementing early student research faces significant institutional and discipline barriers, but our study offered evidence that the URC programs made demonstrable changes in science education and the scientific culture at these sites. Science became more engaging, authentic, and accessible for students. The number and diversity of students who chose to continue in a science field increased. Collaboration decreased faculty isolation and increased the research capacity of the institutions. New professional relationships were kindled across institutions, particularly among younger faculty. All of these outcomes were evident to varying degrees across the five collaboratives.

In our view, the most notable outcome was the demonstrated change in the roles of the students and the faculty members who were involved. Students discovered their capacity for research and came to view themselves as active participants in producing new knowledge and in developing the ability to do science early in their academic careers. Concurrently, participating faculty members recognized students as valuable collaborators in a shared enterprise and accepted responsibility for the success of these students. Because introducing early student research changed the perception of the traditional roles of students and instructors, we believe that early participation in student research has strong potential for changing the teaching and learning of science at the college level.

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Table 1. Undergraduate Research Collaboratives

Name	Lead Institution	Members	Program Description
Exploring New Models for Authentic Undergraduate Research in Two Year College Students (AUR URC) **http://stemenginesurc.com/**	City Colleges of Chicago- Harold Washington College	Seven of the two year City Colleges of Chicago, three suburban community colleges, three baccalaureate-granting schools.	The program provides three different research options: 1) Scaffold training- students work with one or two faculty mentors on an individual research project; 2) Distributed team research - teams of students work on a common project with three faculty members from chemistry and biology. 3) Academic year- a team of up to five faculty members mentor eight to ten students who design their own research project.
The Center for Authentic Science Practice in Education (CASPiE) **http://www.purdue.edu/discoverypark/caspie/**	Purdue University	Two research universities, two comprehensive institutions, and five community colleges.	The program developed a set of eight research modules designed to be embedded in the laboratory sections of existing traditional 1st and 2nd year chemistry courses. Modules have been implemented in the mainstream introductory chemistry and organic courses of the initial group of schools and seventeen participating institutions outside the collaboration. Thirteen peer-led, team learning (PLTL) workshop units were created and used by student peer leaders to facilitate implementation of the modules. (Weaver et al. 2006)
Northern Plains Undergraduate Research Center (NPURC) **http://www.usd.edu/arts-and-sciences/chemistry/northern-plains-undergraduate-research-center/**	University of South Dakota	Seven universities and colleges in South Dakota, Iowa and North Dakota	The program provides resources and structure for curriculum revision, faculty development, a one week introduction to research for 1st year chemistry students; a ten week summer research program for students who have completed either general chemistry or organic chemistry; and a collaboration-wide symposium for students' research presentations.
The Ohio Consortium for Undergraduate Research- Research Experiences to Enhance Learning (OCUR-REEL) **http://ohio-reel.osu.edu/**	Ohio State University	Chemistry departments of 14 public colleges and universities in Ohio.	The program replaces traditional 1st and 2nd year lab instruction with in-class research modules included in courses as a part of the students' introduction to chemistry. Faculty members in environmental, inorganic- materials, and organic chemistry develop and teach these research modules.
The University of Texas Undergraduate Research Collaborative (UTURC) **http://fri.cns.utexas.edu/**	University of Texas-Austin	College of Natural Sciences (CNS) at the University of Texas-Austin	The program is a three-semester linked sequence of courses, research and internships that introduces students to scientific research at the start of their academic careers. The first semester is an introduction to research methods; in the second semester, students enter one of 20 or more research "streams" within the CNS departments of chemistry, biology, engineering, astronomy and computer science. Faculty members in these departments design and teach a research lab experience for thirty students based on the faculty member's research interests. The research " stream" includes a fully functional research lab in which students do research and attend weekly lectures.

Table 2 Examples of Student Research Modules

A REEL module: A research module (RM) in use at several institutions involves the synthesis and characterization of non-toxic inorganic pigments. This module, which generally replaces four or five weeks of traditional general chemistry laboratory instruction, seeks to develop pigments that replace potentially harmful elements like lead or chromium with safer alternatives. Pedagogically, this RM includes several topics that are appropriate for general chemistry students but often given limited attention, such as what gives rise to colored compounds and the relationship between molecular structure and properties. Student hands-on use of modern instrumentation, including X-ray diffractometers, diffuse-reflectance UV-Vis spectrometers, and high-temperature laboratory furnaces, are an integral aspect of the research experience. An effort is made to include numerous authentic scientific tasks in the RM, including collaborative work in small groups, the student-led generation of research questions, the preparation and characterization of compounds, data analysis, and the presentation of results to peers via poster sessions and research talks. In addition, by having a very large number of student-generated research questions contribute to a larger overarching research theme, significant scientific gains are possible. A research article from the non-toxic organic pigments RM is cited in the references (Dolgos et al. 2009). Overall, fifteen REEL-derived research articles have been published and several others are anticipated.
A UTURC module: One UT-Austin freshman research initiative (FRI) research group, the Aptamer Stream, allows students to work at the interface of biochemistry and biotechnology to produce nucleic acid aptamers, which function with similar specificity and affinity to antibodies. Students perform in-vitro selections against target molecules for biosensor and therapeutic applications. In doing so, they learn about oligonucleotide structure, causes of human disease, and bioengineering strategies. As part of their independent projects, students learn both basic chemistry concepts and techniques and more advanced molecular biology techniques such as bead sieving, the polymerase chain reaction, and gel electrophoresis.