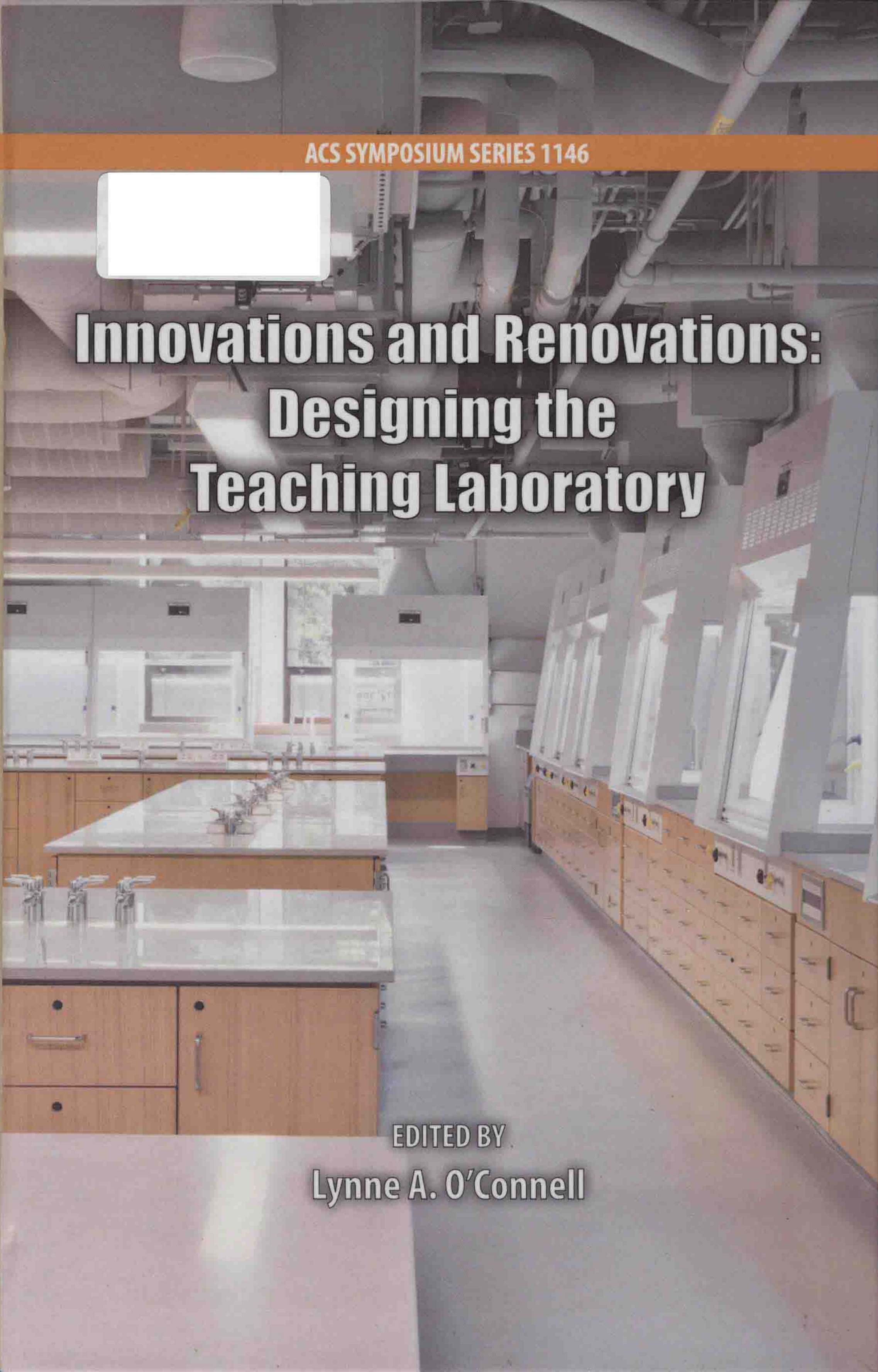

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Innovations and Renovations: Designing the Teaching Laboratory

EDITED BY

Lynne A. O'Connell

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Innovations and Renovations: Designing the Teaching Laboratory

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

Preface

As any homeowner knows, the prospect of embarking on a renovation project is both exciting and scary. Will the finished space function as it was envisioned? Will the environment be both comfortable and aesthetically pleasing? Will the project be completed on time and within budget? Similar questions and emotions come into play when an academic institution undertakes a laboratory renovation or construction project. This highly collaborative process can be both complex and intimidating. Exploring a variety of designs that have succeeded in enhancing student learning in the laboratory and fostering positive attitudes toward science is an important first step on this journey. An impending teaching laboratory renovation project in my own department was the inspiration for the symposium that I coordinated for the Biennial Conference on Chemical Education at Pennsylvania State University on July 29, 2012.

The chapters in this volume describe projects at institutions that vary in size and type and are written from the perspective of faculty and staff, and even members of architectural firms who have worked on multiple academic laboratory projects. Large and small schools, public and private institutions, as well as both comprehensive universities and primarily undergraduate colleges, are all represented.

The impact of evidence-based teaching practices on chemistry education, such as the use of guided inquiry and cooperative learning, is reflected in these laboratory designs. Many schools are promoting interdisciplinary collaborations among the sciences by constructing spaces that are shared by multiple departments. In addition, a desire to make the field of chemistry more accessible to non-scientists, by including open communal areas and increased visibility into laboratories, is echoed in more than one chapter.

While common themes do emerge throughout the book, each chapter also offers its own unique perspective. You will learn about the history of teaching lab design via descriptions and photos of the original laboratory spaces, and then see how they were transformed into modern facilities. Laboratory construction projects that have resulted in award-winning "green" buildings are described. You will read about a school that connects the instructor to the students using monitors that are distributed throughout the lab. You will discover the flexibility of "super labs" and the convenience of an environmental chemistry mud room.

Cooperation and coordination are key components of any successful project, and the authors stress the importance of including all stakeholders in the design process. It is hoped that this book will give the constituents at your institution a chance to examine the innovations that have been incorporated into other educational labs and enable everyone involved to make informed decisions as your renovation or construction project moves forward.

I am grateful to the authors of these chapters for their willingness to share their experiences with others. I wish to acknowledge the staff at the ACS Books Editorial Office, especially Tim Marney and Kat Squibb, for their support and assistance throughout the process of compiling this book. In addition, I would like to thank the many reviewers for their constructive comments, as well as R. Lynn Rardin for his advice during manuscript proofreading.

Lastly, the result of my own department's renovation project is depicted in the cover photo, which shows the shared introductory and analytical chemistry teaching laboratory in the Merkert Center at Boston College, completed in August of 2013.

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Chapter 1

Strategies for Chemistry Instructional Laboratory and Curriculum Design

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Chemistry includes both theory and practice, and therefore instructional labs must be designed to support the investigation and synthesis of both ideas and materials. The needs of the physical facility and the curriculum together define the structural design of a particular laboratory, and the design process must account for both. This chapter presents a case study of the design process of a major renovation and expansion project of the Chemistry instructional laboratory facilities at the University of Iowa. The many complexities that can be expected during such a project and strategies for managing them are discussed.

Introduction

Chemists who engage in both chemistry research and chemical education commonly believe that a substantive laboratory experience is a vital part of a rigorous chemistry curriculum (*1*, *2*). Chemistry includes both theory and practice, and therefore instructional labs must be designed so that their layouts support and optimize the investigation and synthesis of both ideas and materials (*3*, *4*). It is the idealized belief that, in the laboratory, conscientious students are able to connect the concrete to the conceptual. Students are able to observe, measure, and engage in scientific thinking in a way that leads to new knowledge and understanding of the symbolic, particulate, and macroscopic natures of matter.

Many have noted, however, that the actual yield of learning in instructional laboratories is less than ideal (*5–8*). The creation of a laboratory teaching environment, both intellectual and physical, that moves the real towards the ideal is a worthy and ongoing goal of quality chemical education (*9*). This chapter will outline strategies that were developed and applied as part of a major renovation and expansion project of the Chemistry Building at the University of Iowa. The University of Iowa is a public research university, with an undergraduate enrollment of 22,000 and postgraduate enrollment of 9500. The focus here will primarily be on the instructional laboratories that serve large-enrollment general chemistry courses, with some comparisons to advanced undergraduate laboratory courses that illustrate the varying needs at different levels within the chemistry curriculum.

Historic Background

There is an unmistakable relationship between form and function in instructional laboratory designs (*10*). Thus, as design decisions are made that fix the layouts and infrastructures, implied decisions regarding near- and long-term functions are made with both dollar costs and opportunity costs. Consideration of these costs makes the process complex and painstaking. Competing needs and constraints must be identified, analyzed, prioritized, and acted upon as the design process progresses. The process is often slow, but each individual design choice must be guided by a vision of the larger goals.

For renovation and expansion projects, new instructional laboratories need to complement the existing institutional structure, and therefore, as the design project begins, the analysis of existing laboratories and their functions informs the process that defines the traits of the next generation of laboratories. In a historical context, this defines the manner by which evolution of the instructional laboratories occurs. Since the outcome can only be understood within the broader context of the institutional heritage, we will give a brief history of former instructional laboratories.

The central portion of the Chemistry Building was approximately 80 years old at the time of our recent renovation and expansion. However, its structure revealed that renovation and expansion are a natural part of healthy institutional growth and development. As shown in Figure 1, the central portion of the Chemistry Building was constructed in 1923, with five floors of space containing classrooms, a large auditorium (400 seats), a medium auditorium (60 seats), a chemistry library, offices, and instructional and research laboratories.

In 1927, a northeast wing was added to house the Botany Department. In 1960, a significant expansion of laboratory space was provided by the addition of a northwest wing, and in 1963, a second large auditorium was added to the building (Figure 1).

It is interesting to compare and contrast the instructional laboratories of the past with those of the present. Figure 2 shows students in instructional labs during the 1930's. Although the use of lab benches and chemicals is a feature that is shared with modern workspaces, the standards that relate to safety equipment and practices are obvious areas of change. It is also interesting to note the lack of chalkboards or other instructional tools within the laboratory space, and from the regular array-like distribution of students, it also appears that independent lab work was the paradigm.

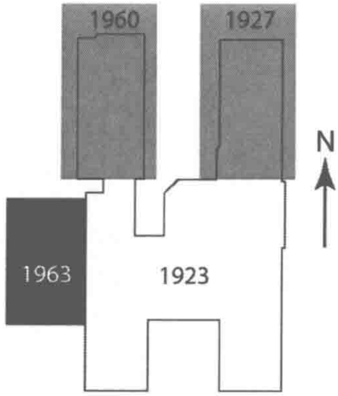

Figure 1. The Chemistry Building at the University of Iowa was built in 1923, with additions in 1927, 1960, and 1963.

Although there were renovations to the original laboratories in 1960 and 1985, the laboratories still relied primarily on infrastructure that traced back to the 1923 construction. Meeting the maintenance, energy costs, and modern safety standards were among the ever-increasing challenges of supporting instructional laboratory operations. Further, since labs were brought online through a stepwise process of expansion and renovation, the laboratories were often unique in structure and widely distributed throughout the building. Overall, this led to operational inefficiencies. Since research and instructional laboratories were in adjacent spaces, the traffic of students from the lecture and lab courses through research areas led to security and safety concerns.

For example, instructional labs were distributed between the northwest, southeast, and southwest wings of the building on three different floors. Three general chemistry labs were located on the second floor southwest wing (2nd-SW) along with the central chemical storage and reagent preparation areas. Two more general chemistry labs were located on 2nd-NW and one on 3rd-NW. Two organic labs were located on 4th–NW and one on 3rd-NW, which had reverted to research use because of temporary declines in enrollment. The organic/inorganic laboratory for Chemistry majors was located adjacent to the instructional NMR and GC/MS instrument room on 2nd-SE. A wet lab with adjoining instrumental laboratory was located on 2nd-SE and was used by physical and analytical chemistry courses. Overall, all ten labs and one prep-lab were in active use, with one additional lab used for fluctuations in course enrollments.

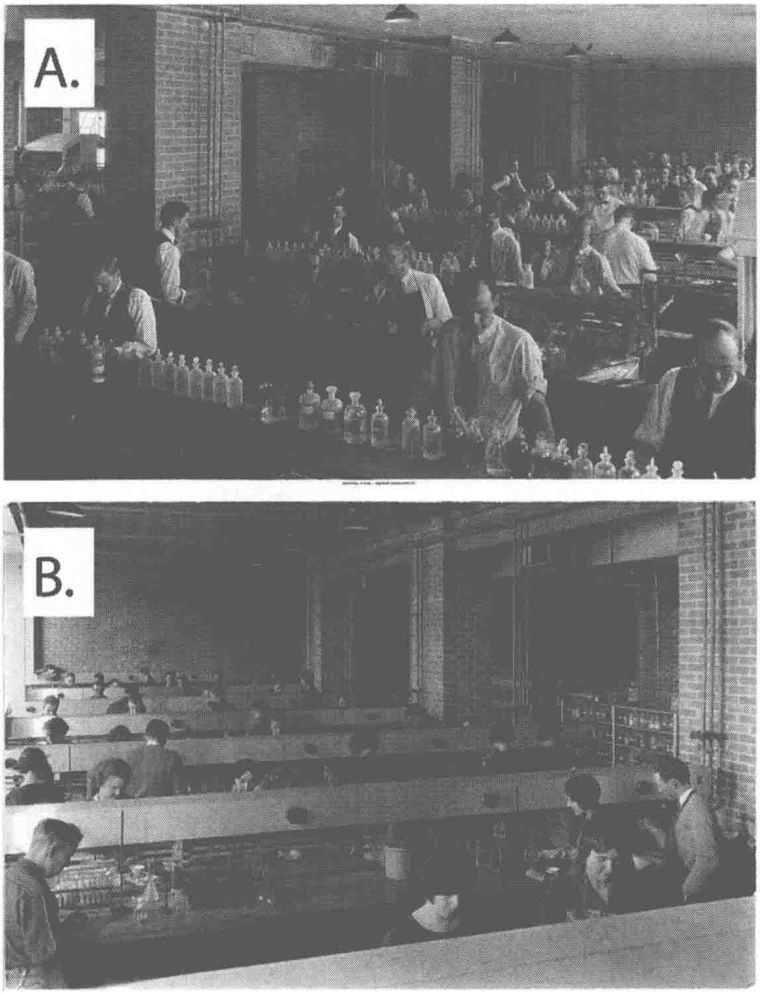

Figure 2. A. Students in an inorganic lab during the 1930's. B. Students in synthesis lab during the 1930's. [Reproduced by permission: Frederick W. Kent Photograph Collection, The University of Iowa Libraries, Iowa City, Iowa (11, 12)].

Renovation Project Overview

In 2003, The University of Iowa proposed a major renovation of the Chemistry Building and, in 2004, obtained funding authorization from the Governor and State Legislature. Significant planning moved forward quickly, and a lead group of University administrators, space and facilities management representatives, Departmental representatives, architects, and engineers was formed. In the end, the project would create 48,750 ft^2 of new space and 102,000 ft^2 of renovated space, with a project budget of over $35 million (*13*). The work was completed in phases to enable normal occupancy of the building in areas not directly impacted by each phase, and the project lasted through 2010.

The primary focus here will be on Phase 1b that demolished core components of the building and then reconstructed an expanded core. The concept of a central core expansion emerged early in the design process. The choice was made to allocate this space towards instructional tasks, after it was learned that the widths of laboratory spaces in the existing wings of the building did not meet the code requirements for egress.

Phase 1b led to removal of large and medium auditoria from 1923 that had undergone only minor changes; these structures are indicated by the dark-shaded regions in Figure 3A. Because of the University's need for a large auditorium, the demolition of the central core structures was made possible by the construction of a large auditorium in the adjacent Pomerantz Center that opened in 2005. Thus, all designs must be evaluated in the context of both immediate and long-term campus-wide needs.

A new central core was designed that would function as the central distribution point for utilities for the entire building, and thus would facilitate future renovation of other building areas. The core significantly expanded the building, as illustrated by the dark-shaded region of Figure 3B. Infrastructure modernization included new electrical systems, emergency power, addressable fire alarms, and telecommunications and data lines. Updated mechanical work included HVAC (heating, ventilation and air conditioning) with exhaust heat recovery, low-flow fume hoods (which reduced engineering, construction, and equipment costs associated with ductwork-mounted active controls and dampers for varying fume hood air exhaust), fire suppression, and piping of deionized water, air, natural gas, vacuum, dinitrogen, and hot and cold water (*14*).

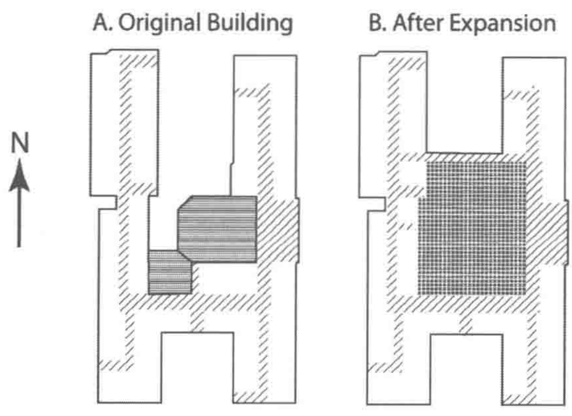

Figure 3. A. The outline of the Chemistry Building prior to expansion in 2005. Hallways and stairwells are shown by the hash marked paths. A medium and large auditorium are indicated by the darker shaded area. B. During the expansion, the central auditoria and attached structures were removed, and a new central core was constructed, indicated by the darker shaded area.

The majority of the new space in the central core was allocated to support the teaching mission, with a large fraction allocated to instructional laboratories. Outdated laboratory space, 13,526 ft^2, was replaced by 19,923 ft^2 of new and efficient laboratory space. Phase 1b was initiated in 2005 and completed in December 2007. On-time completion was critical so that operations could be shifted to the new laboratories over winter break, and the next phase could begin on schedule. At multiple times during constructions, careful coordination was needed to ensure that student, Department and University needs were simultaneously met.

Introduction of the Case Study Instructional Concept

Although it is easy to get lost in the myriad details related to physical structures and costs, the true value of the new instructional laboratory space is its use to enhance the education of 1500-1800 students each semester. It is for this reason that we now focus on the pedagogical restructuring of our general chemistry courses that preceded the physical laboratory restructuring. For optimal function, the curriculum and the instructional spaces that support that curriculum should target common goals. Further, specific goals should adhere to a larger conceptual framework formed by knowledge of best practices and guided by theories of how to promote learning and development of problem solving skills.

In 1996, there was a significant effort by the Chemistry Department to move the laboratory experience beyond a traditional approach of explicit step-by-step instructions that directed students to verify chemical principles and practice basic laboratory techniques. The traditional methods were largely acknowledged to be less-than-optimal for student learning (*15*). By 1998, new experiments were implemented in which the laboratory activities were cast in a larger problem-based context that blended components of lab skills development, guided inquiry, and open-ended problem solving as appropriate for each topic (*16*). In addition, workstations that included computers, computer interfaces with probes, and USB-interfaced spectrometers were introduced to facilitate measurement and provide students with hands-on experiences with modern measurement and analysis methods. Further, it was recognized that projected video display from teaching assistant computers was important in communicating and sharing student results in the lab area during the new laboratory activities. Although this initiative increased student interest, engaged students in higher- order thinking, and used more modern measurement methods, the Department concluded that the extent of success was limited by the structure of the curriculum, which isolated the laboratory into its own separate course.

At that time, General Chemistry was a one-year course, three semester hours (s.h.) each semester, with three 50-minute lectures per week and one 50-minute discussion section. A related one-semester laboratory course (2 s.h.) was delivered as one 50-minute lecture and 170 minutes of laboratory work each week. The laboratory course was taken by students enrolled in the second-semester lecture course, but for various reasons, many students did not take the courses simultaneously. One of the assumed advantages of this course design was that students had already completed one semester of chemistry and were thought to