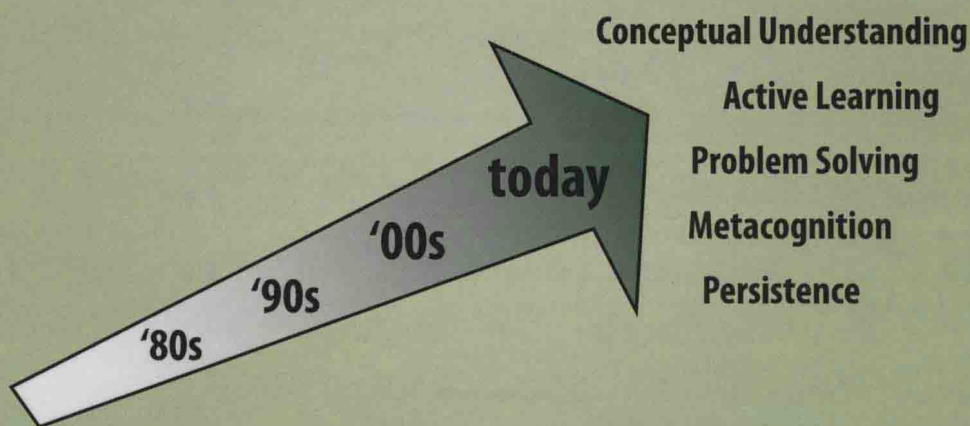


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Trajectories of Chemistry Education Innovation and Reform



EDITED BY

Thomas Holme, Melanie M. Cooper, and
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Trajectories of Chemistry Education Innovation and Reform

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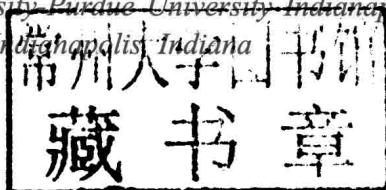
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**Trajectories of Chemistry
Education Innovation
and Reform**

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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Introductory Chapters

Chapter 1

Importance of Considering Longitudinal Trajectories in Education Reform Efforts

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This chapter introduces the collection of articles in this book with an emphasis on why it is important to consider the way that educational research and reform efforts change over time. The importance of considering a longitudinal view of education reform is emphasized in two ways. First, the context of this work relative to current literature is considered. Second, the idea of a greater focus on the longer-term trajectories of reform efforts is considered in terms of suggestions for the future of chemistry education.

Introduction

The Symposium Series of books from the American Chemical Society (ACS) serves as a repository of important trends in chemical science and education. This collection provides, in essence, a set of snapshots of the field and helps establish matters of sufficient importance to merit discussion, by highlighting the topics of specific symposia held at ACS scientific meetings. This particular volume fits within this paradigm well. It arises from a symposium held to acknowledge and celebrate the efforts of Dr. Susan Hixson as a program officer in the Division of Undergraduate Education at the National Science Foundation (NSF), on the

occasion of her retirement from this position. Funding for projects in science or science education has inherent importance for any of a variety of reasons, but this symposium was not rooted in the economics, but rather in the sense of the continuity of leadership throughout an array of changes in how reform was approached by the NSF. In a practical sense, what the continuity of the permanent program officers provides is a means by which reform efforts can grow incrementally, even while specific funding initiatives come and go. This symposium, therefore, provided a moment to look at the trajectories of reform, and it served as the generating moment for this volume.

The broad concept of educational reform in science and particularly within chemistry is a pervasive one in the United States and has been for decades (1–4). Nonetheless, the ability to enact large scale change, based on theories and evidence of efficacy has been modest at best. This collection of articles offers the suggestion that the fragmented nature of many reform efforts represents one critical reason for the modest success. By gathering a group of articles that describe reform endeavors that have been sustained over some length of time, we have sought to start to exemplify the importance of continuity in funding for both reform efforts and the concomitant assessment of the outcomes of these reforms.

Beyond the evidence associated with the existence of this collection of articles, it is also possible to consider the concept of trajectories of reform efforts within the context of understanding how either science or education change. We will describe several such ways to consider this body of work in the next section and then highlight the connection of the articles to each other and to this literature. Finally, we will summarize our impressions of the possible mechanisms for moving from the points on the trajectories noted here to the future.

Models and Theories of Change in Science and Education

The confluence of educational practice and science practice as it emerges in college chemistry courses plays an important role in understanding what changes may be possible in the teaching of chemistry. Studies associated with change in higher education can often identify structural factors within academia that serve to limit the prospects for reform (5–8), and there is little evidence that single studies disseminating new curriculum or practices have a major impact on practice (9). This collection of studies is almost unique in that it takes a historical view of change, over the past twenty years or so, and provides evidence for how change might be accomplished, at various grain sizes, and in a range of settings. Even so, these large grain views of higher education tend to not account explicitly for specific characteristics of particular disciplines, in this case chemistry. Even when compared with other science disciplines, the classroom practice of chemistry is subtly different (10). As noted in a recent report on Discipline Based Education Research (DBER) (11), these differences accentuate the motivation for educational research being conducted within the confines of specific disciplines.

While the DBER report concludes that the different areas of DBER are loosely connected disciplines with closer ties to their parent disciplines than to each other, the conclusions and recommendations are all applicable to chemistry.

For example, it is widely documented that many college students hold incorrect beliefs that are difficult to “overcome”, particularly for concepts that involve very small or very large spatial or temporal scales. Clearly, this concern is particularly problematic for chemistry, since a robust understanding of molecular level interactions and processes is necessary. This, coupled with another finding from the DBER report, that serious impediments to learning emerge from difficulties with disciplinary specific representations such as chemical structures, means that there are specific difficulties in chemistry that instructors and curriculum developers must be aware of. The report suggests that these difficulties require integrating proven strategies for general instruction (such as socially mediated learning) with targeted instruction aimed at helping students overcome these specific challenges to learning.

The DBER report also suggests that future studies on to best facilitate the translation of DBER into practice. The extent of education research dissemination requires more nuanced, multi faceted investigations than are currently available, but as of now there is little evidence of widespread adoption of evidence-based approaches to teaching and learning at the college level. However, productive change is more likely if efforts are “1) consistent with research on motivating adult learners, 2) include a deliberate focus on changing faculty conceptions about teaching and learning, 3) recognize the cultural and organizational norms of the department and institution, and 4) work to address those norms that pose barriers to change in teaching practice (11).”

One way to consider the nature of chemistry education reform efforts is to view the potential barriers to change as contradicting claims on educational resources (12). In principle, with infinite, or much larger resources, the barriers to change would be less – perhaps even minimal. When cast in this light, a theme that emerges in looking at reform efforts over longer time-scales is that halting change stems from the time it takes to make sense out of conflicting data. A key example of this type of challenge arises fairly often, when measures of student learning, particularly content tests, do not show large gains after a teaching innovation has been implemented. One possible explanation for this observation is that such tests do not necessarily measure what the innovation was meant to promote. Without sustained research, however, it is difficult to definitively know the cause.

Another aspect of educational change that merits consideration is the cultural background in which it occurs. Considerable efforts have been made over the years to understand the nature of cultural capital in science education (13). For example, it has been argued (14) that for most students, the science classroom represents a sub-culture that is quite distinct from their daily experience (with family or peers, for instance) and one result is that many students routinely compartmentalize the science knowledge (15–17). The challenge of simultaneously supporting content-based strategies for education reform with other cognitive strategies or socio-cultural strategies remains an important one to consider. Arguably, the only way these aspects can be considered is with longer-term work as represented in the idea of trajectories in this volume.

Another confounding component of educational reform efforts lies in the nature of replicated studies (18). The premise that replication of the results of

an educational research study in a new context will lead to a new, or improved, understanding of student learning in either context is not always obvious. Identical results in different contexts, for example, would seem rather suspicious, but if learning gains for students are lower in the new context is the value of the original research lessened? This type of question clearly cannot be addressed by single instance education reform efforts. Questions such as these argue forcefully the importance of considering trajectories that reform efforts acquire as they move forward, and this volume accentuates several such instances within chemistry education reform.

Summary of Studies in This Volume

The studies presented in this volume are organized into four sections. The introductory section includes this paper and an additional paper authored by Hixson titled, “Trends in NSF-Supported Undergraduate Chemistry Education, 1992-2012” (Chapter 2). This paper connects strongly to the motivation of the ACS Symposium that represents the origin of this project because it summarizes the grant funding trajectory of the National Science Foundation as it related to chemistry education for the past 20 years.

The next section of the volume includes four papers that are generally related to the trajectory taken to accomplish curricular reform efforts. In part because the number of students involved in the course, these papers reflect the relatively high concentration of work at the General Chemistry level. The first paper, “Research on Learning in the Chemistry Laboratory: A Trajectory Connecting Student Outcomes to Thinking Processes” (Chapter 3) by Rickey and Tien, describes the development and impact of a teaching strategy called MORE (Model – Observe – Reflect – Explain) that employs guided discovery methods to improve student understanding and retention of chemistry concepts. The next paper is “Twenty Years of Learning in the Cooperative General Chemistry Laboratory” (Chapter 4) by Cooper and Sandi-Urena. This paper provides a historical account of a reform of general chemistry labs at one institution and the research efforts that emerged over the years, as the authors developed expertise and an understanding of how laboratory activities might affect outcomes for both the students and the graduate teaching assistants.

The third paper in this section describes a number of strategies, in terms of content and in terms of teaching strategies, that were used to reform a specific course over time. The paper “A Trajectory of Reform in General Chemistry for Engineering Students” (Chapter 5) by Holme and Caruthers has a focus on the idea that service courses like General Chemistry have constraints and opportunities associated with the student clientele of the course. The final paper in this section, “Developing a Content Map and Alignment Process for the Undergraduate Curriculum in Chemistry” (Chapter 6) by Zenisky and Murphy, includes significant information about general chemistry, but also extends to the rest of the undergraduate chemistry major. This paper emphasizes a way to vet efforts in chemistry among many stakeholders, essentially establishing a trajectory

within a broader community of educational researchers and practitioners over time.

The third section of papers advances the theme of considering reform in chemistry education by enhancing teaching methods and tools available for the effort. The first paper in this section, “PLTL: Tracking the Trajectory from Face-to-Face to Online Environments” (Chapter 7) by Varma-Nelson and Banks, emphasizes a specific segment of a trajectory in the use of Peer Led Team Learning (PLTL). In this case, the emphasis is on porting a successful innovation in the traditional classroom environment and describing the trajectory that allows this method to move to a new, electronic format. The second paper in this section, “Working To Build a Chemical Education Practice” (Chapter 8) by Wink, Fetzer Gisalsou, and Ellefson, emphasizes how different settings for educational reform can nonetheless lead to commonalities in the development of both teachers and curricula over time.

The third paper in this section, “The Evolution of Calibrated Peer Review” (Chapter 9) by Russell, follows a long-term development of a specific teaching tool (CPR) that allows instructors to incorporate writing into even large courses. The ways in which this tool developed and how the developers changed the system in response to an expanding user base are key themes of this chapter. The fourth article in this section, “A Chronology of Assessment in Chemistry Education” (Chapter 10) by Bretz, takes a long-term view of how curricular reform efforts collect and make sense out of data about efficacy. The acceleration of the role of assessment during the past 20 years of reform efforts represents an important aspect of this topic.

The final section of the volume emphasizes the role of institution-wide reform efforts and the importance of reform over multiple institutions. The first paper in this section, “Lessons Learned from Collaborations in Chemistry Assessment across Universities: Challenges in Transfer and Scale” (Chapter 11) by Paek and Holme, looks at a specific collaborative effort to leverage several individual projects into a larger vehicle for change. The emphasis of this project on assessment meshes with the final chapter of the previous section. The second paper in this section, “Undergraduate Research with Community College Students: Models and Impacts” (Chapter 12) by Higgins, focuses on two key aspects of student learning. First, the power of undergraduate research is emphasized. Second, the role of two-year colleges is also a key factor in the projects described here. With the large number of students who take chemistry in these schools, this emphasis is particularly important.

The third paper in this section, “Preparing the Future STEM Faculty: The Center for the Integration of Research, Teaching, and Learning” (Chapter 13) by Mathieu, takes essentially a dual-trajectory approach. The first trajectory describes how a multiple-institution effort can be initiated and sustained. The second trajectory is that long-term sustainability of education reform efforts depends strongly on teaching the future professoriate, and this project works directly in this area. The fourth and final chapter in this section and in the book is “Improving STEM Student Success and Beyond: One STEP at a Time” (Chapter 14) by Scharburg. This chapter takes a long-term look at how reform efforts that

are initiated in a single department or college within an institution can spread over time and improve student outcomes in a wider array of programs at that school.

Moving Forward in Chemistry Education Reform

What is clear from this collection of reports on trajectories to reform is that reform is possible, but that it takes time, resources, and an awareness of the specific difficulties that chemistry learner's face. At the same time, it is important to be aware that there are large gaps in the research. As yet, we know very little about how specific reform efforts affect different populations of students. For example, few studies are disaggregated by sex, socioeconomic background, race/ethnicity, or ability. We know little about how students at different stages of their academic careers are affected by changes, or how difficulties first identified in introductory courses "play out" as students move through a curriculum. Are innovations designed to have an impact on students in one learning environment effective for students in a different environment? Some studies have found that teaching strategies or methods show improved outcomes in various environments (19), but even then, more studies are needed to identify factors that encourage successful cross-cutting effects and those that hinder such effects. We have few longitudinal studies that investigate how change affects a learning environment and outcomes over time, and how these changes affect retention in STEM disciplines. Despite current enthusiasms for online learning, we do not have convincing studies on the differences between face-to-face environments and online environments, and what that means for chemistry education reform. More generally, we need more studies about reform in general. What is the role of the reward system? How can we change institutional and departmental cultures so that evidence based teaching and learning becomes the norm?

Our assessment methods and techniques must improve and address new outcomes, as we begin to understand that learning chemistry means more than chemistry disciplinary knowledge, but also includes the development of science practices such as the use and construction of models, and the development of explanations and arguments. If we believe that there is more to learning in the laboratory, for instance, than replicating exercises and confirming data, then we must focus on developing ways to assess the outcomes we value.

If the collection of articles in this volume tells us anything, it is that addressing key questions such as these will take time and concerted efforts. The challenge of sustaining reform can only be met by affording the time to consider the needs and interests of a range of stakeholders. Thus, taking time to take stock of trajectories of reform represents a crucial exercise in shaping meaningful reform efforts for the future. We hope this collection of articles provides an example of why this introspection is worthwhile. There is little doubt that the over-arching goal of all the projects noted here, improving the ability of students to learn chemistry, is vital for any number of reasons. This fact makes it worth following reform efforts over time and characterizing the paths taken and the lessons learned.