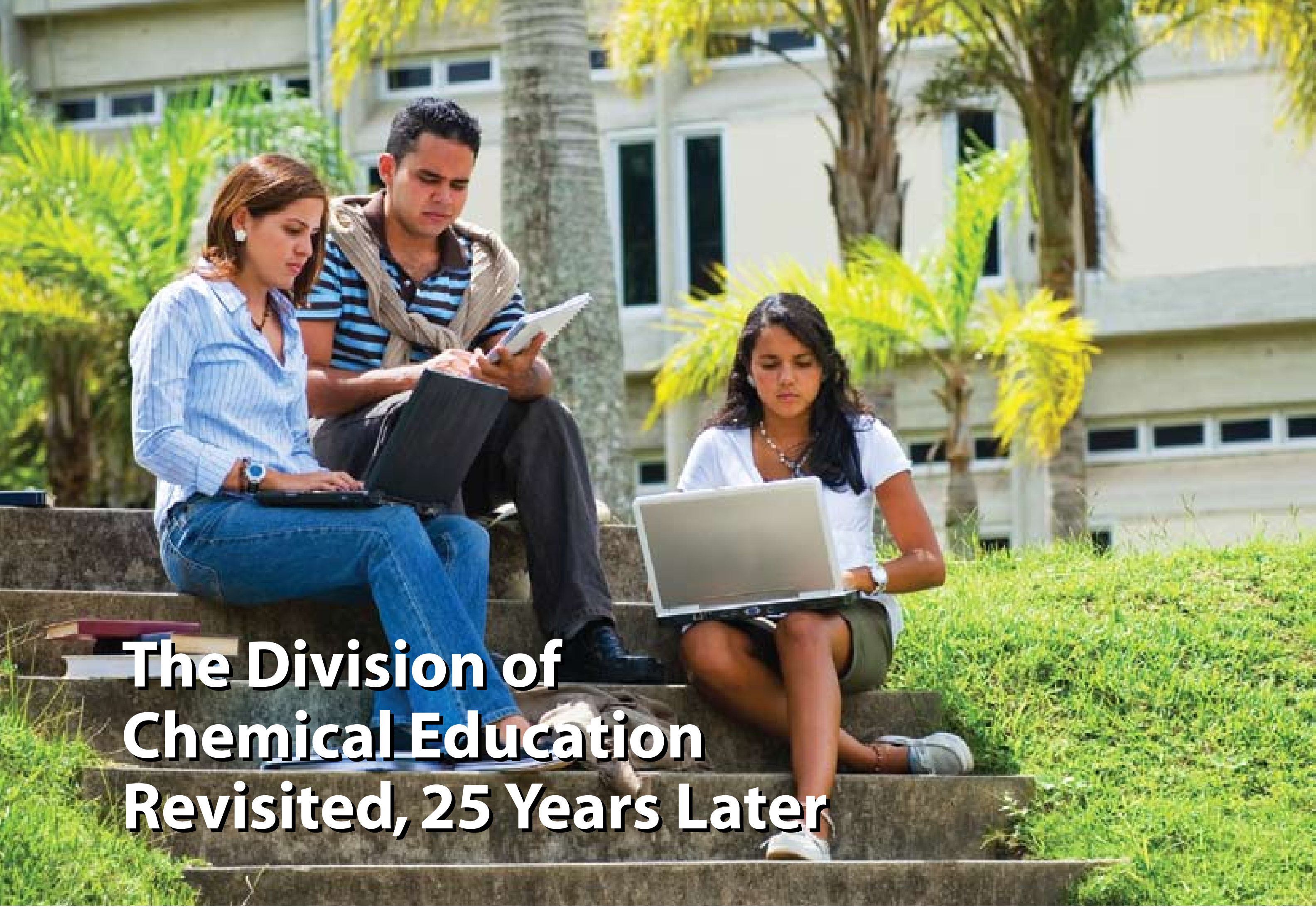

The Division of Chemical Education Revisited, 25 Years Later

By George M. Bodner and Marcy H. Towns

This paper examines what has happened over a period of 25 years since a separate Division of Chemical Education was created within the Department of Chemistry at Purdue University. It argues that the faith in the chemical education graduate program that was demonstrated when the division was created was well-placed, and that chemical education has been shown to be a legitimate area of scholarly inquiry. The chemical education program provides a useful model for other discipline-specific, content-based education research programs such as the School of Engineering Education at Purdue, which recently experienced its fifth anniversary.

About 25 years ago, a paper appeared in the *Journal of College Science Teaching* (*JCST*; Bodner and Herron 1984) that reported the formation of a Division of Chemical Education within the Department of Chemistry at Purdue University. This new division was generated to supplement the long-established divisions of analytical, inorganic, organic, physical chemistry, and biochemistry at Purdue. That paper noted that "In creating a division of chemical education, the chemistry department showed a certain amount of faith that chemical education is an area of scholarship worthy of the status afforded established branches of chemistry" (p. 179). We believe that this faith has been shown to be well-placed and that chemical education has become a legitimate scholarly enterprise that deserves to be considered an equal partner among the various branches of the chemical sciences. The goal of this paper is to report to the community of science educators what has happened in the years since the division's inception, with the expectation that this information will serve as a useful reference for other, similarly intentioned divisions at other schools or in related disciplines.

What is the Division of Chemical Education?

The term *chemical education* can mean different things to different people. Chemical educators have been involved in creating new approaches to teaching chemistry at many levels, from high-school through upper-level graduate courses. They have also contributed extensively to the development of curriculum materials, whether in the form of complete textbooks or individual lab experiments or activities. Some are involved in pre-service teacher training and/or run in-service workshops for middle-school or high-school teachers. In recent years, however, chemical educators have become increasingly and deeply engaged in the scholarly investigation of the efficacy of educational approaches, both formal and informal, at all levels of the chemical enterprise (Bodner and Weaver 2008).

The chemical education program at Purdue was initially created to focus on the training of graduate students to become K–12 teachers or college/university faculty in the chemical sciences. Because this program has focused on graduate students identified as chemists, it has been actively involved in promoting discipline-specific, content-based research on the teaching and learning of chemistry that leads to MS and/or PhD degrees in chemical education.

When the chemical education graduate program at Purdue was first created, only two tenured faculty members (the authors of the original *JCST* paper) were associated with this program. Each of the students in this nascent division was expected to earn an MS degree in one of the traditional divisions of chemistry. They then moved into the chemical education program to work toward a doctoral degree that was conferred from Purdue University's School of Education.

At present, the division consists of five tenured faculty and approximately 35 graduate students working toward MS and/or PhD degrees in chemical education. The majority of our PhDs graduate from the Department of Chemistry. As in earlier days, some of our chemical education PhD students come to us after they have earned an MS in one of the traditional research groups. Sometimes, however, the flow has occurred in the other direction; students who began with an MS in chemical education have completed their PhD in a research group in one of the traditional branches of the chemical disciplines.

Perhaps the most important outcome for a successful program is the placement of its graduates. Graduates of Purdue's Division of Chemical Education have accepted faculty positions in chemistry departments at research-oriented institutions such as Clemson, Delaware, Iowa State, and Purdue. Other students have gone on to successful careers in comprehensive colleges and universities such as Akron; Cleveland State; Illinois State; Texas Tech; and the University of Puerto Rico, Mayaguez. Still others have gone to predominantly undergraduate institutions such as Grand Valley State, Lander, Mankato State, and Southern Illinois University Edwardsville.

Research interests and ongoing investigations within the division include learning theory, problem solving, improving the teaching/learning of advanced chemistry courses, distributed cognition, learning with technology, alternative pedagogies, alternative modes of assessment, misconceptions in chemistry, computer-based instruction in chemistry, developing instructional materials, assessing instructional technology, cooperative learning, laboratory-based learning, and online cooperative learning.

Growth of chemical education research

One way to study the development of a discipline is through an analysis of papers or presentations in the field. At the time of our division's inception, the few research studies in chemical education were reported primarily at meetings of science educators. Most often, these endeavors were presented at conferences sponsored by the National Association for Research in Science Teaching (NARST). Although the National Science Teachers Association (NSTA) has a long history of active conferences, most of NSTA's work has centered on K–12 education in the sciences. Content-specific research in education is perhaps most appropriately disseminated through content-centered meetings, and the American Chemical Society (ACS) conferences are the center of the vast majority of presentations for active researchers within any of the traditional branches of chemical research. In 1984, a half-day symposium on research in chemical education that featured a total of six papers was included for the first time at an ACS meeting. Today, a chemical education research (CER) symposium is automatically scheduled for every ACS meeting, and an average of perhaps 50 CER papers are given at ACS meetings each year.

Those engaged in the teaching of chemistry have traditionally gathered at conferences such as the Biennial Conference on Chemical Education (BCCE), which has existed for more than 40 years, but for a great deal of that time, presentations at the BCCE focused on the practical matters of teaching and professional development. In the summer of 1984, however, a daylong chemical education research symposium was added to the program at the 8th BCCE hosted at the University of Connecticut. Ten years later, at the 13th BCCE at Bucknell University, the chemical education research symposium lasted two days. Twenty years after that first half-day symposium, at the 18th BCCE at Iowa State in 2004, there were six half-day sessions devoted to chemical education research, with 35 papers from 20 different institutions. Presentations clearly involving chemical education research also appeared within 10 of the other conference symposia.

At one time, papers on chemical education research were published in the *Journal of Research in Science Teaching*, or possibly *Science Education*. Although the *Journal of Chemical Education* has a long and distinguished history, few of the papers published in the early years of that journal included a fully developed research protocol. Eventually, a research in chemical education column was added to this journal. Today papers involving active and effective research into chemical education appear in each of these journals, as well as in *JCST*'s Research and Teaching column, *The Chemical Educator*, *Chemical Education Research and Practice* (published by the Royal Society of Chemistry as a continuation of a journal once known as *University Chemistry Education*), *Biochemistry and Molecular Biology Education* (published by the American Society for Biochemistry and Molecular Biology), and other journals as well.

Content-based education research

The graduate students in our program who receive PhDs from the Department of Chemistry fulfill all of the requirements for that degree. This includes the successful completion of appropriate graduate-level coursework in the established areas of chemistry (organic, inorganic, physical, analytical or biochemistry); passing a series of cumulative exams in one of these traditional subdisciplines; and successful development, presentation, and defense of an original research proposal, in addition to the completion and successful defense of their PhD dissertation. A list of the research topics undertaken by the graduate students associated with the chemical education program at Purdue who have graduated in the last 30 years can be found in Table 1. For clarity, these have been organized into eight general themes: laboratory-based instruction, teachers' understanding, students' understanding, problem solving, alternative modes of instruction, computer-based instruction, research in advanced-level courses, and content-based research in other disciplines. If one includes PhDs awarded by faculty in the Department of Chemistry at Purdue in the years before the chemical education was formally established, more than 60 PhD degrees have been awarded at Purdue in this emerging field.

Some of the work on which these degrees are based could have been done in a traditional science education program by graduate students with a strong undergraduate background in chemistry. However, the creation of a Division of Chemical Education within a large, research-oriented Department of Chemistry has facilitated the growth of effective, collaborative research on the teaching and learning of chemistry in advanced courses. This work requires both extensive graduate-level training of the investigator in one or more traditional areas of chemistry and access to practicing chemists and faculty members who are willing to collaborate on research of this nature (Bodner and Weaver 2008). Brief descriptions of several recent studies carried out at Purdue might best illustrate what can be achieved through collaborative, team-based, discipline-specific, content-based research. The following examples illustrate some of the contributions that have stemmed from work in only one group within the chemical education program at Purdue. Similar stories, with similarly powerful outcomes, can be found in each of the research groups active within the chemical education division.

David Gardner had majored in physics as an undergraduate. He came to graduate school in the Department of Chemistry at Purdue and wrote an MS thesis in solid-state chemistry (Gardner 2000) before he started work toward his PhD in chemical education. His dissertation (Gardner 2002) focused on the experiences of students learning quantum mechanics. The work involved extensive classroom observations as well as both traditional qualitative interviews and more loosely organized tutor sessions/interviews with students enrolled in either a quantum mechanics course for junior physics majors, the second half of a physical chemistry course for chemistry majors, or a one-semester introduction to quantum mechanics taken by students from chemical engineering.

The nature of this study required an interviewer with sufficient content knowledge to act as a tutor in quantum mechanics and to analyze the data that eventually produced insight into the phenomenon known as a "problem-solving mindset" that many chemistry students bring to quantum mechanics courses (Gardner and Bodner 2007). Both the analysis of the data collected in this study and the validity of its conclusions were significantly aided by the presence on the dissertation committee of four faculty who not only taught physical chemistry but were actively involved in research within this content domain.

During the course of her PhD work, MaryKay Orgill had the opportunity to teach half of the lectures in both a junior-level biochemistry course and a graduate-level course on biotechnology. She was therefore in an excellent position to complete a study of the use

TABLE 1

PhD dissertation topics.

Laboratory-based instruction Designing general chemistry laboratory experiments that enhance cognitive development from a Piagetian perspective; the effect of structured writing on achievement, time and accuracy in the general chemistry laboratory; the efficacy of computer-assisted labs; what defines effective chemistry instruction in the laboratory; the student's perspective of the chemistry teaching laboratory; the development and evaluation of a research-based undergraduate laboratory; the effect of authentic research experience and inquiry on teachers and students	**Alternative modes of instruction** A comparison of student-directed and teacher-directed modes of instruction for presentation of density to high school chemistry students; an inquiry into what happens when the lecturer stops lecturing in organic chemistry courses; a longitudinal study of Action Research as the vehicle for curriculum change in analytical chemistry
Teachers' understanding Prospective elementary school teachers' understanding of the particulate nature of matter; how teachers' beliefs about science and science teaching shape their classroom instruction; high school chemistry teachers' perceptions and actions; how science methods course can enrich the pedagogical content knowledge of prospective chemistry teachers; the professional development of graduate teaching assistants in chemistry; high school science teachers' beliefs about the intended and actual impacts of standards-based reforms	**Computer-based instruction** The effect of drill question sequencing on learning and user satisfaction in computer-assisted instruction in molecular geometry; integrating the microcomputer into the high school chemistry classroom; an investigation of the relationship between student cognitive characteristics and the use of hypermedia science tutorials; an investigative look at the experiences of students using the computer in science classrooms; student participation in worldwide web-based curriculum development of general chemistry; investigation of student use of web-based tutorial materials and understanding of chemistry concepts
Students' understanding Use of the learning cycle to promote cognitive development; students' perceptions of academic dishonesty in a chemistry classroom; assessment of the impact chemistry text and figures have on visually impaired students' learning; an investigation of students' degree of concept links as a function of exposure to college chemistry courses; a case study of a female preprofessional major's perspective of learning chemistry; case studies of concept maps from the perspectives of middle-school students; a phenomenographic study of the beliefs and practices of general chemistry students and faculty members regarding knowledge transfer: a phenomenographic study, ontological categorization in chemistry: a basis for conceptual change in chemistry; relating macroscopic observations of melting and mixing to microscopic explanations	**Research in advanced-level courses** A study of undergraduate and graduate students' conceptual understanding of thermodynamics; learning in quantum mechanics; how students use spectrophotometric instruments to create understanding; using spectral analysis to probe the continuum of problem-solving ability among practicing organic chemists; the role of analogies in biochemistry; understanding arrow-pushing formalism from a student's perspective; a cognitive model of second-year organic chemistry students' conceptualizations of mental molecular rotation; how students learn to solve organic synthesis problems
Problem solving Problem-solving behaviors of concrete and formal operational high school chemistry students when solving chemistry problems requiring Piagetian formal reasoning skills; investigation of variables involved in chemistry problem solving; implementing instruction to improve the problem-solving abilities of general chemistry students; the role of beliefs in general chemistry problem solving; the effect of interactive instruction and lectures on the achievements and attitudes of chemistry students; a comparison of low spatial ability students' and high spatial ability students' representation and problem-solving processes on stoichiometry questions; the role of multiple representation systems in problem solving in chemistry; students' understanding of chemical equilibrium as revealed by algorithmic and conceptual problems; a phenomenographic analysis of how chemistry students study for an exam; an investigation of the effective aspects of multiple external representations for students learning chemistry	**Content-based research across disciplines** A critical Action Research approach to curriculum development in a lab-based chemical engineering course; curricular reform in computer-based undergraduate laboratories via Action Research; an investigation of the factors involved in self-efficacy belief modification in the first-year engineering experience; students' conceptions and problem-solving ability in a modeling-based interactive engagement in an introductory physics course; similarities and differences in design across disciplines

of analogies in biochemistry that involved classroom observations, analysis of biochemistry textbooks, and extensive interviews with both students and faculty involved in undergraduate biochemistry courses (Orgill 2003). She found that analogies are useful in promoting understanding, visualization, recall, and motivation in biochemistry students at all levels, and that students appreciate, pay attention to, remember, and use analogies their instructors provide. She found, however, that they would be even more useful if students understood what analogies are and how they can be used to improve understanding of biochemical concepts (Orgill and Bodner 2004, 2006, 2007).

For more than 20 years, researchers in chemical education at Purdue have been trying to understand why so many well-prepared, hard-working students struggle with organic chemistry (Pribyl and Bodner 1987). In recent years, they have probed the cognitive structures that facilitate the mental rotation of a two-dimensional representation of the structure of an organic molecule (Bodner and Briggs 2005), and studied the factors that influence the ability of practicing organic chemists to solve problems that involve determining the structure of an organic compound from ^{1}H NMR and IR spectra (Cartrette and Bodner 2009). Particular attention has been paid to understanding what the arrow-pushing formalism that is used by practicing organic chemists to convey the mechanism of a chemical reaction means to undergraduates (Anderson and Bodner 2008; Ferguson and Bodner 2008) and graduate students (Bhattacharyya and Bodner 2005).

This work on the teaching and learning of organic chemistry has been facilitated by the fact that Bhattacharyya, Cartrette, and Ferguson had all completed MS theses in synthetic organic chemistry before they began their work in chemical education and that Briggs had been a practicing chemist in industry before returning to graduate school.

New directions in content-based educational research at Purdue

It may be of interest to note that a major shift has recently begun in colleges of engineering in the United States that involves the development of research on the teaching and learning of engineering as another example of discipline-specific, content-based educational research. The magnitude of the change in engineering education is best illustrated by noting that the *Journal of Engineering Education* was transformed after more than 90 years of existence as a repository of articles that described the "practice" of teaching applied to a particular course at a given institution into "an archival record of scholarly research in engineering education" (Lohmann 2003, p. 1; Lohmann 2005).

In much the same way that Purdue University took an active role in the development of chemical education research at the tertiary level, Purdue has demonstrated a growing commitment to research in engineering education through the creation of a graduate program in engineering education (Haghighi 2005). Within the College of Engineering at Purdue, the new School of Engineering Education was given status equal to that of traditional programs in the disciplines of aeronautical, agricultural, biomedical, chemical, civil, construction, electrical, industrial, materials, mechanical, and nuclear engineering.

When discussions of the creation of a graduate program in engineering education began, there were five engineering faculty at Purdue whose primary interests were in research-based engineering education. By the beginning of the fall semester of the 2007–2008 academic year, there were 24 faculty with a full-time or part-time appointment in the new School of Engineering Education. It is interesting to note that one of these individuals is the dean of the College of Engineering. In addition, faculty centered in other schools at Purdue held joint or courtesy appointments in this program. One of the authors of this paper (Bodner) is among this latter group. Currently, 20 students are working toward graduate degrees in this new program.

Conclusion

Neither chemical education nor engineering education is a new field of endeavor. The *Journal of Chemical Education* is in its 85th year, and chemical education is one of the largest divisions in the American Chemical Society, with more than 5,000 members. As noted earlier, the *Journal of Engineering Education* has been published for almost 100 years, and the American Society of Engineering Education recently held its 115th annual conference and exposition. What has changed in the last few years is the definition of the terms *chemical educator* and *engineering educator*. We noted 25 years ago that the term *chemical educator* "can no longer be used exclusively to mean 'those who teach chemistry'" (Bodner and Herron 1984, p. 179). The term *chemical educator* increasingly encompasses those who engage in active and disciplined research into the learning and teaching of chemistry at all levels. We would like to suggest that a similar change is occurring in the meaning of the term *engineering educator* (see Hutchison et al. 2006; Hutchison, Follman, and Bodner 2008).

In our paper published 25 years ago in *JCST* announcing the creation of the Division of Chemical Education at Purdue, we noted "Only time will reveal whether what we have done represents a significant step in the growth and development of chemical education or merely an unimportant administrative reorganization in a single institution" (Bodner and Herron 1984, p. 179). The best evidence that content-based educational research programs in chemistry now transcend the boundaries of a single institution can be found by noting that PhD programs in chemistry education exist at Akron, Arizona, Arizona State, Clemson, Colorado State, Connecticut, Georgia, Iowa State, Kansas, Massachusetts—Boston, Miami, Montana, New Hampshire, North Carolina State, North Texas, Northern Colorado, Oklahoma, Purdue, South Dakota State, South Florida, Texas, Texas Tech, and UNLV (CER Resources 2010).

It is our hope that this considerable success will encourage our colleagues in other science and related disciplines to develop and nurture similar programs. ■

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