Research and practice in chemical education in advanced courses

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For many years, chemical education research was done by individuals involved in pre-service teacher training and in-service teacher workshops. As a result, it often focused on the problems faced by elementary- and secondary-school students encountering chemistry topics for the first time. Because a large fraction of the students enrolled in chemistry courses at the tertiary level can be found in first-year courses, it is not surprising that as research expanded to studies of college and university students, it began by looking at the experiences of students in introductory courses. Recent years have seen a significant increase in the number of research studies that focus on students in upper-level courses at the undergraduate and graduate level. This is an important development because of the different cognitive and pedagogical challenges that are encountered in 'advanced' courses. This special issue of CERP is therefore devoted to studies that have the potential of producing changes in the way upper-level courses are taught that are equivalent to the changes that research on the teaching and learning of chemistry by high-school and introductory level students has had on the way courses for these students are being taught.

Keywords: organic chemisry, biochemistry, physical chemistry, chemical education research

Introduction

A fundamental change has occurred in research on the teaching and learning of chemistry over a period of twenty-five years. A significant fraction of the early work (*e.g.* Gorodetsky and Hoz, 1980; Gabel and Sherwood, 1984; Gabel *et al*, 1984; Yarroch, 1985) focused almost exclusively on high-school students. With time, the number of papers that dealt with research on college-age students increased (*e.g.* Bodner and McMillen, 1986; Herron and Greenbowe, 1986; Carter, et al., 1987; Nurrenbern and Pickering, 1987; Sawrey, 1990; Nakhleh, 1993; Phelps, 1996). Most of this work, however, concentrated on students enrolled in the first-year general chemistry course. Papers eventually appeared that described work with students enrolled in organic chemistry courses at the undergraduate (*e.g.* Pribyl and Bodner, 1987; Johnson, 1990) and graduate level (Bowen and Bodner, 1991). Journals that published research in science education at that time were less receptive, however, to this type of work than to studies that focused on first-year or pre-college issues.

Ultimately, work on research related to more advanced undergraduate courses began to appear (*e.g.* Moore and Schwenz, 1992; Zielinski, 1995; Towns and Grant, 1997; Towns *et al.*, 1998; Pentecost and James, 2000). While such research is published regularly today, its frequency is still much lower than for work related to first-year courses. Table 1 shows the results of a search using the ERIC database (Educational Resources Information Center) for articles for the years 1995 and 2005 in which the word 'chemistry' appears in the title. The first row for each year shows the total number of articles for that year sorted by the academic level on which the paper focused. The second row for each year excludes articles that are not 'educational research' in the broadest sense of the word. The first column includes papers that address cognitive issues of learning that are not related to a particular level. The second, third and fourth columns report the number of articles that focus on pre-college students or teachers, first-year undergraduate students, and students enrolled in advanced courses, respectively. The last column reports the percentage of the total number of articles that focused on advanced courses. Because the data in Table 1 represent nothing more than a snapshot at two ends of a decade, we will not over-interpret the numbers. It is worth noting, however, that the percentage of articles that report studies based on advanced courses is not high, even in recent years.

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Research on organic chemistry and biochemistry

There has never been a shortage of papers that describe new approaches to the teaching of subjects such as organic chemistry (e.g., Bradley *et al*., 2002; Tien *et al*., 2002). Until recently, however, the number of papers that detailed the results of research on the learning of organic chemistry has been relatively small. A few years ago, research based on the analysis of students' explanations of their answers to exam questions (Bodner and Domin, 2000) was used to suggest a fundamental difference between what instructors write on the blackboard when they give lectures on organic chemistry and what their students write in the lecture notes they take. The instructor writes symbols that represent a physical reality, whereas students often write letters and numbers and lines that are not symbols because they have no physical meaning for the students. A similar phenomenon has been seen in a study of graduate students (Bhattacharyya and Bodner, 2005), which concluded that the curved arrows used in the arrow-

Table 1 Analysis of ERIC citations in 1995 and 2995

year	type of article	Academic level on which article focuses				% advanced
		chemistry in general	pre-college students and/or teachers	1st year undergraduate	advanced	
1995	All	9	19	21	11	18%
	Research	8	13	16	8	18%
2005	All	22	25	23	29	29%
	Research	9	20	16	3	6%

pushing formalism are not 'symbols' for the graduate students because "... *they did not symbolize anything in the students' minds*."

One of the early experiments with graduate students (Bowen and Bodner, 1991) noted that they rarely, if ever, worried about the viability of the organic syntheses they were proposing from the perspective of what actually occurs in the laboratory. Subsequent work (Bhattacharyya *et al*., 2004) has suggested that graduate students approach organic synthesis as if it was a paper-and-pencil exercise that has little (if any) connection to their experience in the laboratory.

A series of papers on the teaching and learning of organic chemistry appeared at the turn of the century that studied factors that influence student performance in organic chemistry courses (Black and Deci, 2000), ways of measuring conceptual change in organic chemistry (Nash, et al., 2000), the use of knowledge space theory to map students thought patterns (Taagepera and Noori, 2000), the validity of the Johnstone-ElBanna model of problem solving when applied to organic synthesis problems (Tsaparlis and Angelopoulos, 2000), and gender differences in both cognitive and noncognitive factors related to achievement in organic chemistry (Turner and Lindsay, 2000). More recent work has involved studies of distance-education as an alternative approach to teaching organic chemistry (Kurtz and Holden, 2001), students' understanding of hydrogen bonding (Henderleiter *et al*., 2001), the application of the Structure of Observed Learning Outcomes (SOLO) taxonomy for evaluating student learning in the two-semester organic sequence (Hodges and Harvey, 2003), and the use of model-eliciting activities to probe the mental models of organic chemistry graduate students (Bhattacharyya, 2006).

Although the journal *Biochemistry and Molecular Biology Education* is in its 36th year of publication, the vast majority of the papers in that journal focus on approaches to the teaching of biochemistry (*e.g.*, Minderhout and Loertsche, 2007). Research on the learning of biochemistry has included studies of student difficulties with the interpretation of textbook diagrams (Schönborn *et al*., 2002), student understanding of the concept of pH (Watters and Watters, 2006), and a series of papers on the use of analogies by instructors in biochemistry classes (Orgill and Bodner, 2004), by authors in textbooks (Orgill and Bodner, 2006), and by biochemistry students (Orgill and Bodner, 2007).

Research on analytical, inorganic and physical chemistry

A primary stumbling block in the learning and teaching of physical chemistry is the traditional reliance on advanced mathematics as the primary means to both explain concepts and solve problems in physical chemistry. It has been recognized that students could succeed in this course by having very good mathematics skills (Hahn and Polik, 2004) and logical thinking skills (Nicoll and Francisco, 2001), without necessarily understanding the chemical concepts nor, in fact, needing to think very much at all about the chemical concepts. Therefore, much of the work in physical chemistry research has looked at ways to enhance students' understanding of the chemical concepts and to create conceptual links between physical chemistry and other chemistry knowledge that students have (Towns *et al*., 1998; Jennings *et al*., 2007). To this end, many researchers have also explored teaching approaches specific to physical chemistry that will provide increased engagement in the learning process (*e.g.* Zielinski, 1995; Deckert *et al.*, 1998; Pentecost and James, 2000; Hinde and Kovak, 2001). A qualitative research study of undergraduate chemistry and physics students enrolled in introductory quantum mechanics courses (Gardner and Bodner, 2007) noted that many of the problems students encounter when learning quantum mechanics are not the result of a misunderstanding of the concepts being taught; they are the result of employing non-productive strategies while studying and doing homework.

The results of studies of teaching and learning in inorganic and analytical chemistry have recently begun to appear. Particular attention has been paid to student responses to computer-based learning environments that simulate classical quantitative and qualitative analysis (Josephsen and Kristensen, 2006) and the use of study packs supported by on-line formative assessment to replace lectures in an inorganic chemistry module (Williams *et al*., 2008).

Conclusion

Inasmuch as *Chemistry Education Research and Practice* has played an important role in reporting research on the teaching and learning of chemistry at the tertiary level in courses beyond general chemistry, we proposed the theme of *Research and Practice in Chemical Education in Advanced Courses* when asked to edit a special issue of this journal. The call for papers asked for contributions that dealt with the learning of chemistry in advanced or upper level courses for either undergraduate or graduate students across the spectrum of majors that enroll in these courses. It also asked for papers that described the incorporation of non-traditional modes of instruction and inquiry-based instruction in advanced or upper-level courses. The result was a series of eleven papers that focus, primarily, on organic chemistry and biochemistry. Some of these papers examine the problems students encounter when they enroll in organic and biochemistry courses; others deal with instructional techniques that can help address these problems. We sincerely hope that this issue provides the impetus for more researchers to examine the unique problems that arise in the upper-level courses taken by both chemistry majors and non-majors.

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