Looking back, looking forward: reflections on my teaching career and the ABCs of education and professional development column

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It has been an honor to serve since 2013 on the editorial team for the column on education and professional development in *Analytical and Bioanalytical Chemistry (ABC)*. With my retirement from academia, it seemed appropriate to step down as editor and allow someone with a new perspective to fill that role. I appreciate the opportunity to reflect on some aspects of my teaching career and the column, especially as it coincides with the special issue commemorating the 20th anniversary of *ABC*.

Personal journey

I started my faculty position at Bates College, a small, undergraduate four-year institution, in 1981. One attraction of the job at Bates was that I would be the only analytical chemist in the department, which meant that I had the freedom to design the analytical courses however I wanted. In the first several years, between trying to establish a productive research program and maintaining suitable teaching evaluations necessary for securing tenure, I did not do much innovative teaching in my courses. An outside observer would have readily classified the courses as traditional offerings in quantitative and instrumental analysis. In addition to exclusively lecturing in both, the lab with the first course was mostly titrations and gravimetric analysis with only a couple of experiments involving instrumentation. The lab with the second course involved students rotating through weekly experiments on the various instruments we had in the department.

Having secured tenure, I had a full-year sabbatical leave in 1988–1989, which provided me the first meaningful opportunity

to reflect on my teaching. With regard to the laboratories, one realization was that the experience I provided my students was nothing like the work of practicing analytical chemists. In all cases, I gave my students a sample, which was usually totally soluble in water, and a recipe to follow. They never had to define a problem, identify a suitable analysis method, consider how to collect samples, or evaluate how to work up the samples. Students were only experiencing a small component of the analytical process.

I was also troubled by aspects of student performance for the classroom component of my courses, especially with chemical equilibrium. Bates is a highly selective institution; students enter with exemplary high school records. The chemistry majors who took my courses had done well in the prerequisite general chemistry course. Yet, each year, several students did miserably on exams on chemical equilibrium. In class, it seemed that these students understood how to carry out equilibrium calculations, yet on the exam, with the questions presented or phrased in a different way, it was clear that they did not and had scores well below the cutoff for a failing grade.

Another observation I had related to the learning that occurred with students working in my research lab. Most of my research students had already taken one or both of my analytical classes, yet they often had little retention of course topics that were important to their research projects. However, the same students could explain a concept learned while conducting research (e.g., broadening of NMR peaks arising from uncertainty or exchange effects) months after having it explained to them once. It seemed that students in my research lab were learning new information in a context that was important to them, which improved their retention.

Changing my instructional labs to create a context for learning and have the students function similarly to practicing analytical chemists was easy. Beginning in 1990, I replaced the one-week experiments with semester-long, small-group (2–3 students per group) projects. Students were given a problem (e.g., analyze the amino acid content of milk) and then set free to complete the analysis. They had to do a thorough literature search and then

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evaluate methods of analysis, sampling, sample preparation, and validating their results. Each group had to submit a proposal five weeks into the term. I worked with each group during this period to help them navigate the literature, as there were many new topics that arose (e.g., the use of internal standards or matrix spikes), especially in the first course. Once the proposal was approved, students could then undertake the experimental work. Inevitably, over the 30 years, we did these projects, every group encountered some unexpected problem or outcome that required troubleshooting on their part.

In my experience, these unexpected problems were often the most valuable part of the project. Sometimes, the problem was caused by students making an obvious mistake that was often the result of their inexperience. Because the mistake cost them time and slowed down what they might accomplish on the project, I observed that afterward, students were more careful in checking calculations and other aspects of their procedure prior to conducting lab work. Often, problems resulted because the literature article on which the students had based their experimental procedure was vague or omitted some important point. Also, there were situations where everything had been followed exactly as specified in an article, but the expected results were not obtained. In the latter two situations, it meant students went back to find new literature with alternative procedures, called technical support from the instrument manufacturer, and/or emailed the author of the literature article and asked for help. Using primary literature, modifying procedures when the first set did not work, interpreting data to realize that there was a problem, making judgements based on available information and evidence, and troubleshooting instrumental problems first before reaching out to instructional staff for help supported several important learning outcomes for the projects.

Fixing the problem some of my students had with equilibrium calculations was also quite easy. I put all the problems that I would cover on the board onto worksheets, divided the students into groups of three or four, and let them discuss how to do the problem. Each class period consisted of short increments of small-group work followed by whole-class reporting out and discussion. It was particularly gratifying the first year I used this approach when no one failed any of the equilibrium exams. In 30 years since, it's been a rare occurrence for a student to fail one of my exams. In the first couple of years of small-group work, I still lectured on conceptual material. Eventually, both the students and I realized lecturing was just not as effective as small-group work in promoting learning, and I transitioned conceptual topics to in-class worksheets.

The changes I made to my courses in the early 1990s were done on a hunch; it just seemed that students would learn better in an environment where they were more engaged in the material. Once I started using project-based labs and small-group work in class, that approach felt better to me and my students. I was fortunate to be able to publish an article on my approach in the *Pages of Analytical Chemistry* [1]. Only later did I learn that the

value of these approaches, which can be broadly characterized as active learning, was already documented. It was already known that people learned more by doing something than by watching and listening [2]. It had been noted that students often leave an organized lecture with a false impression of how well they understand the topic, and only later discover it is more complex than they thought [3]. More recent research into the benefits of active learning continues to show increased student performance and retention. Furthermore, the impacts of active learning show even greater benefits for students typically underrepresented in the sciences [4–6]. A comprehensive review of laboratory practices published in 1982 showed that traditional laboratory instruction methods have little measurable effect on the educational achievement of students [7]. Other studies in the mid- to late 1970s found that inquiry-based experiments resulted in higher order cognitive outcomes than conventional instructional laboratory experiments [8–10]. More recent work further supports the value of inquiry-based laboratory experiments [11–13]. Given how long it has been known that active learning is preferable to lecturing and recipe-driven experiments, it is disappointing to me how much instruction still involves traditional methods.

Fortunately, today we have the Active Learning site of the Analytical Sciences Digital Library (ASDL), a repository for peer-reviewed active learning materials for the classroom and laboratory of undergraduate analytical courses [14]. The Active Learning section of ASDL includes a wealth of text resources as well. All materials on ASDL are under the Creative Commons Copyright, so are freely available to anyone throughout the world. Files on the Active Learning site of ASDL are editable so that instructors can modify them to better suit their course goals. Active learning and textual materials available on ASDL include virtually every topical area that is covered in undergraduate analytical courses. A grant from the National Science Foundation supported a professional development program to promote the use of student-centered teaching methods in undergraduate analytical chemistry courses in the USA [15]. We observed that instructors who transitioned to student-centered teaching methods have continued their use because of the many benefits they observe (e.g., improved understanding of concepts, improved communication skills and teamwork, more enjoyable to them and their students because of increased interactions in the classroom and lab).

Educational/professional development column

Although primarily a research journal, *ABC* has long recognized the importance of professional development and education in the field of analytical science. In 2004, John Fetzer, who spent over 20 years as an industrial chemist at Chevron Research before becoming a full-time consultant, became the editor for the series Building a Professional Career. In 2006,

Cynthia Larive, then Professor at the University of California Riverside and now Chancellor of the University of California Santa Cruz, and Reiner Salzer, Professor at the Dresden University of Technology, became the editors for the column ABCs of Teaching of Analytical Science. Recognizing the overlap between education and professional development, the two series were merged into one in 2012.

I had the good fortune of being asked to replace Cindy in 2013 as she pursued other editorial responsibilities. The retirements of Reiner and John in 2018 and 2020, respectively, led to appointments of Martin Vogel, analytical chemist at the University of Munster, and Jill Robinson, Teaching Professor at Indiana University as editors for the series. Wendy Saffell-Clemmer, Lead Scientist and Senior Director of R&D in the Global Pharmaceutical business of Baxter Healthcare, recently replaced me as editor.

Over 100 articles have been published in the education and professional development series. These articles have explored a broad range of topics, some examples of which are listed in Table 1. The breadth of topics covered in the column is impressive and show the extent to which topics on education and professional development are broadly defined. The recent series of articles on teaching in the pandemic shows how the column is responsive to immediate needs by members of the community. The timeliness and value of these pandemic-related articles was evident by the large number of downloads of each soon after their publication.

Table 1 Example topics covered in the education and professional development column

- Ways to network
- Value of networking
- Ways to enhance one's marketability when seeking employment or a career change
- Causes of and strategies for avoiding conflicts and toxicity in an industrial or academic workplace
- Succeeding at key career stages in academia
 - Navigating the early years of a faculty position
 - Improving one's odds of getting tenure or promoted
- Active learning teaching pedagogies
 - Flipped classrooms
 - Small-group work in classes
 - Project-based labs
 - Group component of exams
 - Use of the primary literature
 - Use of simulations
- What we know about how people learn
- Advice on common practices in our field
 - More effective poster presentations
 - More effective oral presentations
- Approaches, perspectives, or methods used within different countries or regions of the world
- Using active-learning and hands-on lab experiences in remote instruction

Future directions

I have retired so I no longer have to ponder future iterations of my analytical courses. If I were to continue teaching, I would need to address how to refine my courses in response to the impact of the instrument shown in Fig. 1. It is interesting how frequently that instrument has been put to use by students undertaking projects in my courses. When considering the retention order of compounds on a gas chromatogram, our need to know the boiling points of several compounds was quickly available via an Internet query on a cell phone. Another group struggling with an unexpected problem when performing a fluorescence measurement pulled up a literature article on a phone and we quickly examined the key part to determine a plan for moving forward. Unlike when I was an undergraduate student, the reality today is that most of the information and course content we cover in analytical chemistry is available instantaneously to anyone with Internet access. Of more importance than memorizing information is knowing how to find reliable information on a topic and then how to apply that information to the problem at hand.

I have been at many meetings with faculty members or other professionals when some information was needed to continue a discussion, and someone quickly looked it up on their phone. Given that reality, a question to ask is whether it makes sense to have any exam questions that only require the recall of information that can be quickly obtained using a phone. Another might be whether we ought to allow students to use the Internet while taking exams. I have done many a home repair with the aid of an Internet video. Perhaps our students should be watching Internet videos when they need to carry out a new technique in the lab. This does not mean that I am advocating that analytical chemistry courses be devoid of content. Content is necessary to create a basis for developing other skills necessary for professional growth. I served for eight years on the American Chemical Society's (ACS) Committee on Professional Training, the

Fig. 1 The instrument that should cause us to reflect on how we teach

committee that oversees the ACS approval program for undergraduate chemistry degrees. Materials provided for analytical courses I reviewed were overwhelmingly designed around a content-coverage model. Development of the professional skills needed to function as an analytical chemist was usually not the primary focus. Recognizing these other skills as being most important could free analytical chemistry instructors from feeling that we must cover most topics contained in our textbooks.

As for the future of the *ABC* column, the goal will be to continue to publish articles on a broad array of education and professional development topics. Articles that help instructors imagine ways to make their courses more effective are encouraged. Articles that articulate skills that employers desire in analytical chemists and help those in academia design curricula that better develop those skills are welcome. Articles on activities aimed at improving the relationship between people in academia and industries to improve course content and experiences are of interest. I served for three years on the ACS's Graduate Education Advisory Board (GEAB). A topic raised by the student members of GEAB involved how graduate school provided an excellent understanding of what a career as a faculty member entailed, but a poor to non-existent understanding of other career paths that Ph.D. chemists pursue. Articles on programs or opportunities that advisors or graduate programs have developed to prepare students more broadly for careers someone might pursue with a Ph.D. are of interest. Most people will undergo transitions throughout their career that will require or emphasize a different skill set. An obvious example is going from a position where one mostly takes directions from a supervisor to a supervisory position with responsibility for overseeing others. Articles that speak to the needs and traits that lead to excellence in different roles, or describe programs designed to instill the skills needed to excel in different types of positions, are welcome. One beauty of the column is that there is no expected style or format for contributions. Provocative opinion pieces that challenge the status quo or otherwise cause us to examine our practices and behavior have been some of the most widely read articles in the column and will continue to be encouraged.

Data on the number of views of articles indicates that the education and professional development column has been valued by readers of *ABC*. I have every expectation that the current and future editors and the readership of *ABC* will continue using and valuing the column as a venue for promoting the education and professional development of analytical chemists. I look forward to reading future installments of the column in my new role of retired editor.

Declarations

Conflict of interest The author declares no competing interests.

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