Addressing the Millennial Student in Undergraduate Chemistry
Addressing the millennial student in undergraduate chemistry / Gretchen E. Potts, editor, The University of Tennessee at Chattanooga, Chattanooga, Tennessee, Christopher R. Dockery, editor, Kennesaw State University, Kennesaw, Georgia.
   pages cm. -- (ACS symposium series ; 1180)
Includes bibliographical references and index.
1. Chemistry--Study and teaching (Higher) I. Potts, Gretchen E., editor. II. Dockery, Christopher R., editor.
QD453.3.A33 2014
540.71'1--dc23
2014040640


Copyright © 2014 American Chemical Society

Distributed in print by Oxford University Press

All Rights Reserved. Reprographic copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Act is allowed for internal use only, provided that a per-chapter fee of $40.25 plus $0.75 per page is paid to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. Republication or reproduction for sale of pages in this book is permitted only under license from ACS. Direct these and other permission requests to ACS Copyright Office, Publications Division, 1155 16th Street, N.W., Washington, DC 20036.

The citation of trade names and/or names of manufacturers in this publication is not to be construed as an endorsement or as approval by ACS of the commercial products or services referenced herein; nor should the mere reference herein to any drawing, specification, chemical process, or other data be regarded as a license or as a conveyance of any right or permission to the holder, reader, or any other person or corporation, to manufacture, reproduce, use, or sell any patented invention or copyrighted work that may in any way be related thereto. Registered names, trademarks, etc., used in this publication, even without specific indication thereof, are not to be considered unprotected by law.

PRINTED IN THE UNITED STATES OF AMERICA
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
Editors’ Biographies

Christopher R. Dockery

Dr. Christopher R. Dockery is the Assistant Department Chair, Director of the Master of Science in Chemical Sciences, and Associate Professor of Chemistry at Kennesaw State University. He has established a diverse forensic analytical research group where he has supervised 42 undergraduates and one graduate student in research. His interests cover a broad range of topics in forensic and analytical chemistry that have produced numerous publications and presentations at national and regional meetings, many with student co-authors. His projects have included an analysis of drugs of abuse, forensic analysis of dyed textile fibers, and the development of novel teaching experiments in addition to his primary research on the analysis of gunshot residues by laser-induced breakdown spectroscopy. He routinely teaches Peer Leading in Chemistry and has supervised PLTL for general chemistry 1 and 2.

Gretchen E. Potts

Dr. Gretchen E. Potts is the Director of Integrated Studies and UC Foundation Associate Professor of Chemistry at the University of Tennessee at Chattanooga. For the last 12 years, she has led an active research program supervising 21 students on diverse projects. Her research interests include forensic chemistry, environmental analytical chemistry, and bioremediation. She has given presentations on her research at the Pittsburgh Conference and National ACS. She has also presented workshops on flipping the classroom to UTC faculty, as she commonly “flips” her general chemistry and instrumental lab classrooms. She recently represented UTC at AAC&U’s 2014 Summer Institute on High Impact Practices and Student Success.
Chapter 1

Millennial Students and Undergraduate Chemistry

C. R. Dockery*¹ and G. E. Potts²

¹Department of Chemistry and Biochemistry, Kennesaw State University, 370 Paulding Ave #1203, Kennesaw, Georgia 30144
²Department of Chemistry, The University of Tennessee at Chattanooga, 615 McCallie Ave #2252, Chattanooga, Tennessee 37403
*E-mail: cdockery@kennesaw.edu

Millennials lead highly structured and scheduled lives where they are pushed to achieve academic and professional successes and serve the greater good of the community. Advances in technology have created 24/7 connectivity, constant multitasking, and short attention spans. However, the reliance of many educators on conventional teaching methods has failed to engage this generation. What innovative strategies are being explored to highlight millennial tendencies to thrive on technology and juggle assignments? How do we reach millennial students in deep conversations while promoting critical thinking? This book and introductory chapter explores inventive pedagogies in chemistry classrooms that build upon the millennial students’ strengths and interests.

Introduction: The Changing University Environment

Those who teach in undergraduate chemistry programs face an ever-changing environment. While most public universities are still assessing students using the traditional grades, twenty-six states now assess university-success using retention figures and graduation rates, shifting to a performance funding model touted by Complete College (I). In Tennessee, for example, public universities compete for a pool performance funding and though not fully funded, a successful year can increase state funding a few percent, which could translate to a million dollars in
support (2). This also means that in a very competitive year, a university could lose out on a million dollar of support.

Due to declining economics, we face reduced support for an increased classroom size. With the increase in classroom size, we ask “Is a traditional lecture the most effective method for communicating chemistry?” Perhaps not. Researchers at University of Washington are currently analyzing active learning methods across the disciplinary literature. After analyzing 225 studies, results published in PNAS reveal that passive learning comes in a far second (3). Student retention in the classroom increased with active learning, which is perhaps more relevant to the performance funding of the Complete College model.

But, if we apply active learning in our classrooms and labs, whom are we reaching? Currently, professors can find vast generational diversity in the classroom. Of course, the majority of our students are classified as the Millennial generation, born after 1981 (4). However, we also encounter students classified as GenX (born 1961-1981), Boomers (born 1960-1973) and even a few students who represent the Silent generation (born 1925-1942). Who do we address with the new active learning pedagogies? Is it possible to reach all of these populations of students with one style of teaching? How does one best deliver content to facilitate active learning and critical thinking? To help answer these questions we will dig deeper into the nature of the millennial student.

The Millennial Student

The millennial generation has been defined in several contexts and given several names, but the Pew Research Center describes them as the generation that has “come of age in the new millennium” (5). The expansion of the internet and technological innovation have both shaped this generation like none before. They are confident, self-expressive, informal, diverse, and close to their parents. Their connection to social media outpaces all other peer groups and as a result they function in “immediate realities” (5, 6). In his book “The Dumbest Generation”, Mark Bauerlien argues that technology provides students access to media and news from across the globe, but that they focus interactions locally and are uninterested in the bigger picture (6). Our millennial students expect 24/7 service and availability and are recklessly distracted by this “wonderful” technology. We face an uphill battle in reaching and engaging them.

Possibly the potential or amount of millennial engagement could be projected by a professor’s millennial-character. The Pew Research Center hosts a quiz, “How Millennial Are You?” (7). After answering 14 questions, you will learn how you compare to the respondents of the national survey, including those comparable to your age. The editors, born in 1973 and 1978, independently completed the quiz and scored 58 and 84 respectively. If you simply filled the classroom with professors who scored close to 100 on this quiz, would it solve the current problems with student learning? It would be an interesting study to undertake, but most likely it would not cross the divide of student engagement. Understanding a student’s generation should help with classroom management and could facilitate
some engaged-learning, but ultimately fundamental changes in content delivery will need to be implemented in order to engage this techno-savvy generation.

This is not a new problem; the oldest millennial was 34 years old at the time of this publication and there have been numerous pleas trying to convince the “sage to leave the stage” (8). It is now widely accepted that traditional lecture is not engaging millennial students (3). Why then are we reluctant to put down the chalk and close the PowerPoint? Are the articles in the Journal of Chemical Education and resources presented in this book simply preaching to the choir? In the opinion of the editors, the most challenging roadblock to reform pedagogy is the significant mission creep and drastically increased research expectations placed on faculty at primarily undergraduate institutions. Other significant roadblocks to broad adoption of reform pedagogy stems from the lack of funding and increasing class sizes which result in a shift of instruction of general chemistry and other service courses to part time and non-tenure track faculty.

With instant access to information, millennial students are often “learning on demand” and can find specific content using online resources faster than searching the textbook (if they even have a textbook anymore). They don’t want to wait for the faculty to cover the slide in class, or ask the faculty in office hours or by electronic communication. Unfortunately, many syllabi specifically prohibit the use of electronic devices during the lecture period. Simply put, the traditional lecture hall is far from their natural habitat. If that is the case, then what strategies can we use to reach them?

Reform Pedagogies

It is clear that simply “covering the syllabus and lecturing do not provide a supportive framework to encourage critical thinking skills” (9). At most institutions, recitation serves as a review period “in which students critique homework problems and complete a weekly quiz” yet “properly instructing students on how to solve problems algorithmically, does not empower them with conceptual chemistry knowledge” (9). To address this, reform pedagogies have slowly crept into the chemistry curriculum as pilot programs and research platforms. A general search for research articles on reform pedagogy in the Journal of Chemical Education yields numerous finds, including 43 articles on guided inquiry, 29 articles on peer leading, and 22 articles on the flipped classroom yet the word “millennial” is noticeable missing from these pages (10). Rath, et al note that students completing chemistry courses utilizing reform pedagogies such as supplemental instruction and peer leading “generally perform better in the supported classes, in subsequent courses in the sequence, and have higher retention rates in the major” (11). Anecdotal gains in retention may be linked to an increased sense of community experienced by students in supported classrooms.

Supplemental Instruction (SI) was developed at the University of Missouri-Kansas City in 1973 and is defined by the International Center for Supplemental Instruction (SI) as “an academic assistance program that utilizes peer-assisted study sessions. SI sessions are regularly-scheduled, informal
review sessions in which students compare notes, discuss readings, develop organizational tools, and predict test items. Students learn how to integrate course content and study skills while working together. The sessions are facilitated by “SI leaders”, students who have previously done well in the course and who attend all class lectures, take notes, and act as model students” (12). The stated purpose of SI is to increase retention and student grades within targeted historically difficult courses and to increase graduation rates. The successes of SI in achieving these goals have been well documented and SI has been offered internationally at an estimated 1,500 institutions impacting hundreds of thousands of students each year (13).

Peer-Led Team Learning (PLTL) is an active learning reform pedagogy designed to engage students in group discussion of content knowledge. Students are not expected to arrive at concept invention, rather open dialog among peers while reinforcing concepts. As such, most applications of PLTL supplement only part of the traditional lecture period, or occur in recitation or supplemental sessions. Peer or workshop leaders are undergraduate “student(s) with good communication and people skills who have done well in the course previously” and are “there to actively engage students with the materials and with each other” (14). Typically, students are not provided with an answer key and the sessions are graded for participation only. Students are therefore encouraged to talk about the problem freely, without fear of losing points for arriving at the wrong answer. In one editor’s personal observations, a measure of success in a peer-led session is walking into a classroom to hear students actively engaged in conversation about chemistry. Independent research on retention progression and graduation rates using PLTL at two different institutions show students in PLTL general chemistry classes are less likely to withdraw than their non-peer-led counterparts (15, 16). Additionally, Lewis shows PLTL classes “featured a statistically significant improvement of 15% in the pass rate for the classes, compared to conventional, lecture only classes” while maintaining “a comparable score on a comprehensive ACS final exam”.

Flipped learning was first introduced by Bergmann and Sams in an attempt to help absent high school science students catch-up on missed material (17). The result is a pedagogical movement that engages students in active learning in the classroom and moves direct instruction into the student domain. Though “flipping” takes many forms, the key is engaging students and removing all forms of passive learning from the classroom (18). Perhaps flipped learning is the key to engaging the millennial generation. These students have been connected to technology since birth and struggle to be attentive for long periods of time. A flipped classroom environment could provide the alternate learning style which might best accommodate the millennial student.

In the flipped classroom, the professor does have a more hands-on role with the students and therefore in a much better space to gage student learning. The professor can then increase or decrease the rate of instruction based on this immediate feedback (19). Outside of the classroom, students may watch a pre-recorded lecture, videos from the internet, or even be directed to read in the lecture text. The onus is on the student to prepare for the active learning that will take place in the classroom. Student comments on flipped settings are
varied. Considering the diversity in the classroom, you will always have students who will want to learn in a traditional setting. Some students have also voiced a concern that the professor does not put as much effort into the active-learning environment. What the student doesn’t realize is that the change from passive to active learning in the classroom is not easy and actually requires more work from the professor. The time and effort to make the change can also be a big enough stumbling block that many professors busy with research do not move from the traditional lecture format (20).

Another active learning pedagogy is inquiry-based learning, which was originally developed in the sciences in the early 1980s (21). This pedagogy encourages students to employ the scientific method, including the development of a hypothesis, to work through new concepts and develop theories (22). It encourages critical thinking and discourages direct memorization of material. Also known as problem based learning (PBL), this pedagogy is popular in laboratory settings and in the classroom (23–29).

A specific form of inquiry-based learning used in chemistry classrooms and laboratories is termed POGIL, Process Oriented Guided Inquiry Learning. POGIL applies problem based learning but focuses on group learning in a collaborative effort and relies significantly on reflection and critical thinking. The professor works as a facilitator, encouraging students in the critical thinking process and traditional lecture is abandoned. Students are allotted jobs in the group, including manager, recorder, reflector, technician and presenter (30). This style of active learning does fit the some of the characteristics of the millennial student, but for those prefer a tradition style, this method causes more distress. The research, however, shows it is effective. When compared to traditional lecture, students are overwhelmingly positive (31). More importantly, researchers measured progress in student learning, critical thinking and a reduction in attrition. As companies are looking for new employee who can think critically and work in team environments, perhaps POGIL is preparing the millennial generation for this new job market where skills are more important than the academic major (32). Unfortunately, due to limited resources and increasing class sizes widespread adoptions of these reform pedagogies in typical undergraduate chemistry curricula are the exception.

Undergraduate Chemistry Curriculum

As these new pedagogies are established to accommodate our changing classrooms, chemistry departments depend on the American Chemical Society Committee on Professional Training (ACS-CPT) to define the goals and learning outcomes for undergraduate chemistry programs in the United States. Established in 1936, the goals of the Committee are three-fold,

- to conduct and enhance an approval procedure for bachelor’s degree programs in chemistry,
- to promote effective practices and innovations in chemistry education, and
to promote broad participation in chemistry to enrich the profession with the talents of a diverse group of individuals (33).

The current CPT guidelines for approving undergraduate chemistry programs are dated Spring 2008, but the Committee will be releasing a revision in Summer 2014 (34). According to 2010 data from the US Department of Education published in the Digest of Education Statistics, there are over 2800 four-year Title IV colleges and universities in the United States (35). As of this July 1, 2014, there are 676 ACS-approved undergraduate chemistry programs. The ACS-CPT approval process is rigorous and well-respected.

In 2010, ACS-CPT published a report to guide departments in the development of excellent programs of undergraduate chemistry (36). In the document, ACS-CPT indicates that the curriculum and student learning should contain foundation courses, in-depth courses and hands-on laboratory experiences with modern instrumentation. Additionally, students should have opportunities for literature searching, computational chemistry and research. More interestingly though, the Committee deemed it important to state that the pedagogy should “excite students about chemistry”, in addition to being challenging, engaging and “taught in a manner that accommodates a variety of all learning styles” (36). Are these comments on pedagogy addressing the millennial student without speaking directly to the obvious shift in the population of classroom students? The contributing authors of this symposium series will present herein exciting additions to reform pedagogy in undergraduate chemistry.

Review of Chapters

The work presented herein is not meant to be an exhaustive list of reform pedagogies, rather, our contributing authors present updates and reflections as practitioners who have adopted reform pedagogies and presented at recent national and/or regional ACS meetings, primarily the 65th Southeastern Regional Meeting of the American Chemical Society in Atlanta, GA, November 12-16, 2013. Each chapter works to address the unique challenges of teaching millennial students by engaging students in innovative, active learning strategies and/or increasing professor accessibility to the next generation.

K. D. Kloeppep from Mercer University (GA) describes millennial students as team-oriented learners who prefer non-traditional lecture methods, yet convincing them to participate productively in class can be challenging. Participation strategies focused on group work and peer interactions were developed and implemented into assessment, projects, and class discussions. Incorporating intentional participation opportunities that complement the strengths of millennials improved engagement and learning.

J. P. Lee from the University of Tennessee at Chattanooga describes his experiences as an Assistant Professor within the first three years of teaching inorganic chemistry within a research active undergraduate program. The intent is to give a brief overview of what has been incorporated in the classroom early in his career to set precedent and rigor while fulfilling his desire to develop a symbiotic
relationship between teaching and maintaining an active undergraduate research program. Emphasis is placed on the incorporation of group learning activities in upper level (i.e., Junior/Senior) inorganic chemistry classes in order to keep students actively engaged, and serves as an introduction for the incorporation of chemical literature as a tool to spark further interest in inorganic chemistry.

Scott E. Lewis from the University of South Florida presents the practical aspects for initiating, growing, and sustaining peer-led team learning (PLTL) in the General Chemistry class. In particular this chapter will focus on the necessity for team building and administrative support, and the supporting role of education research.

Lucille Benedict and James R. Ford from the University of Southern Maine discuss a flipped classroom model in a large lecture chemistry course. This model consists of a structured course website for content delivery, online quizzes and homework, and a large emphasis on group work and problem solving during lecture and recitation times. These course changes had a major impact on student success and retention in the general chemistry course at the University of Southern Maine. The D,F,W rates significantly dropped while the number of students passing the course significantly increased. Student responses to an end of semester survey revealed that many of the students found the course structure extremely beneficial to their learning and helped to alleviate many of the pressures (anxiety, and under-developed math and study skills) of the course.

Melissa S. Reeves (Tuskegee University, AL) and Robert M. Whitnell (Guilford College, NC) report on the development of computational chemistry laboratory experiments in the Process-Oriented Guided Inquiry Learning (POGIL) method, from the POGIL Physical Chemistry Laboratory Project (POGIL-PCL). In the POGIL-PCL framework, experiments are conducted in collaborative teams, focusing on multiple learning cycles with progressive complexity, pooling data among the entire class, and analyzing data peer-to-peer in the lab under the instructor’s guidance. This structure changes the lab from a data collection site with analysis done later in solitude to a richer environment where students are partners in their own learning, fostering independent thinking, teamwork, and communication skills.

Chavonda J. Mills, Julia K. Metzker, and Rosalie A. Richards present Undergraduate Research (UR) as the cornerstone of the chemistry program at Georgia College, Georgia’s Public Liberal Arts University. In a recent revision of the chemistry program’s student learning goals, faculty identified UR as a high impact pedagogy for the millennial student and developed a roadmap for the integration of UR into the curriculum. Yet, despite success in developing a robust UR program, chemistry faculty encountered several challenges in sustaining the UR program and maintaining student interest. To address these challenges, they established a parallel series of cost-effective faculty and student activities, and a robust faculty evaluation system that values UR and a comprehensive study of student perceptions of UR.

C. L. Weaver, E. C. Duran, and J. A. Nikles from the University of Alabama at Birmingham share a progressive approach used to improve writing in the first semester organic lab course. Initially individual, scaffolded writing assignments combined with online peer review were implemented, succeeded by group
writing assignments using a writing cycle. Preliminary results from the first three semesters are presented.

Luciano E. H. Violante, Daniel A. Nunez, Susan M. Ryan, and W. Tandy Grubbs from Stetson University (FL) integrate 3D printing in the chemistry curriculum, inspiring millennial students to be creative innovators. There are certainly positive characteristics associated with the millennial generation that should be kept in mind as educators tailor effective learning strategies for students of chemistry. Millennials typically possess a higher technological proficiency and a greater enthusiasm for using the latest digital gadgetry in comparison to their predecessors. In this chapter, Grubbs et al. illustrate one way to take advantage of this technological edge by incorporating 3D printing activities into the curricula. Several student-driven projects are described, ranging from the creation of simple ball-and-stick models of common chemical structures to the fabrication of more realistic, space-filling models of proteins and quantum-optimized molecular complexes.

Meagan K. Mann from Austin Peay State University (TN) covers methods and techniques available to increase accessibility to professors in the broad demographic of students found in the millennial classroom. Included are ways for professors to communicate remotely with students through instant messaging services, social media, desktop streaming, and web conferencing systems.

References


In Addressing the Millennial Student in Undergraduate Chemistry; Dockery, et al.;
20. Cassuto, L. Can We Create a Culture That Values Good Teaching?: We like to talk about the value of pedagogy, but we never seem to get around to rewarding it. The Chronicle of Higher Education; May 27, 2014.
25. Knutson, K.; Smith, J.; Nichols, P.; Wallert, M. A.; Provost, J. J. Bringing the excitement and motivation of research to students; Using inquiry and


34. Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor’s Degree Programs; American Chemical Society, Committee on Professional Training: Washington, DC, 2008.


Chapter 2

Give Them Something To Talk About: Participation Strategies That Improve Student Learning and Engagement

K. D. Kloepper*

Department of Chemistry, Mercer University, 1400 Coleman Ave., Macon, Georgia 31207
*E-mail: kloeppe_kd@mercer.edu

Millennial students are team-oriented and prefer non-traditional lecture methods, yet convincing the current generation of undergraduates to participate productively in class can be challenging. Common traits for Millennials include a preference for structure and an interest in building peer networks. Participation strategies utilizing structured teamwork were developed and implemented in analytical chemistry classes through modified discussions and assessment. Students spent out-of-class time on projects and attending specific seminars, both of which benefited in-class participation. Incorporating intentional participation opportunities that complement the strengths of Millennials improved their engagement and learning. These participation approaches can be adapted for large lecture classes, non-majors courses, and other chemistry disciplines.

Introduction

Many chemistry instructors have experienced at least one of the following all-too-familiar scenarios:
• Scenario #1: You carefully prepare a lecture with interesting examples that you are certain will keep your students on the edge of their seats. At the end of your lecture, you pose an open-ended question for discussion but are only met with blank stares. Did they even follow your lecture?

• Scenario #2: Your exam includes questions that you are sure give students a fair opportunity to demonstrate what they have learned. You provide feedback that includes suggestions for improvement. When you hand the exams back, you see students quickly flip to the grade as they leave the room. At the next class meeting, you want students to talk about the material they missed, but they have nothing to contribute.

• Scenario #3: You develop a thoughtful assignment that requires students to work through a tricky class topic. There is significant work required out of class, but when you ask the class to discuss project progress, students are hesitant to volunteer.

• Scenario #4: You ask students to read a journal article before class that you have selected specifically because it matches student interests and aligns well with course content. When you start the in-class discussion, eyes avoid you and no hands go up.

How can an active classroom be created if students are reluctant to participate? Research suggests that that active participation in class promotes learning more than lecture alone (1–4), so how do you get today’s students, the so-called Millennials, talking? Modifying teaching strategies to better align with the strengths of today’s students may be the answer.

Millennials often are characterized by their immersion in technology, and others have reported on technology-based pedagogies for chemistry courses, with examples including social networking (5–7), student-generated videos (8), clickers (9, 10), “Google jockeys (11),” virtual laboratories (12), online discussions (13, 14), and modified wikis (15, 16). Another approach is to develop teaching strategies that take advantage of generational strengths and preferences (17). Howe and Strauss identified seven core traits of Millennials: special, sheltered, pressured, optimistic, rule-following, team-oriented, and high-achieving (18). While the media often focuses on negative aspects of these traits, these generalized characteristics can actually be beneficial in the classroom, particularly the latter three. Designing structured course activities that require teamwork and higher-order thinking may increase the motivation of today’s college students.

Here, efforts by the author to improve the participation of Millennials in analytical chemistry classes are described. There are many aspects of a chemistry class where participation can be incorporated and adjusted to appeal to college students, including in group work, class discussions, assessment, and out-of-class events. Specific examples of how these modes have been used in sophomore-year Quantitative Analysis and the upper-level course Instrumental Analysis are provided. Suggestions for applying these participation-inducing activities to other courses, especially larger classes, are given.
Classroom Participation

Overview

In scenario #1, discussion stalled when students were prompted only at the end of lecture, while scenario #2 describes a failed attempt to get students talking about exam performance. Both situations could be improved by providing more structure to the discussions and tapping into students’ affinity for teamwork. Millennials have more familiarity with group work in educational settings than previous generations of college students because of frequent high school group work (19), and potential employers place increasing emphasis on collaborative work environments (20). Intentionally incorporating peer interactions into classroom activities and assessment gives students more opportunities to participate, which increases the likelihood of productive discussions.

Group Work

There are many types of group work that have been incorporated into chemistry courses, with three common active-learning pedagogies including peer-led team learning (21–23), problem-based learning (24–26), and process-oriented guided inquiry (POGIL) (27, 28). While there are differences between these approaches, they all share a common intended outcome of engaging students through active learning (29). Group work done during class has the dual benefit of providing students with opportunities to learn from one another while also having the instructor present as a guide, when and if the need arises. In-class group work models for students how to form appropriate study groups, and this can facilitate the formation of study groups outside of class.

Using alternative classroom techniques to traditional lecture promotes student involvement in learning, but waiting to do a group activity after a long span of lecture time, as described in the first scenario, may not be as effective as interspersing more frequent group activities (30). However, using group activities to cover course content often requires more time than lecture delivery alone.

The author has developed a participation strategy for Millennials that uses technical videos found on YouTube (unpublished). Despite students’ immersion in technology, they still can struggle with appropriate use of internet resources for educational purposes (31, 32). Although videos provide visual reinforcement of concepts, students may have difficulty with fully learning from narration and visual content unless guidance is provided to integrate the new material with previous knowledge (33). The video participation strategy positions short YouTube clips as the starting point for discussions and aids students in learning from both the auditory and visual components of the videos. Associated in-class work is structured to require students to summarize video content before integrating it with previously-learned information. Videos produced by scientific societies, individuals, and instrument companies all are rich sources of information appropriate for chemistry courses, but to maximize student participation and learning, care should be taken to select video clips that minimize extraneous information.
For example, when starting the section on mass spectrometry, the class viewed an introductory video produced by the Royal Society of Chemistry (34). The video includes explanations of the instrumentation, basic theory, and sample data. Students have some experience from previous courses with the instrument’s operation and data interpretation, but they have not learned about the function of the instrument in detail. After watching the video, students are given prompts to help discuss different aspects of the video. Questions follow the order of information presented in the video and focus on the most important points such as the function and purpose of each component of the mass spectrometer. As part of the discussion, students draw the block diagram, which shows the main components of the instrument, on the board. Alternatively, students could work through handouts of the questions in small groups and then discuss the answers as a class.

The author also has utilized a number of different group activities in Instrumental Analysis and Quantitative Analysis at Mercer University. Analytical chemistry POGIL (ANA-POGIL) exercises have been used in both courses, and POGIL exercises are available for a range of disciplines and levels of courses (35). ANA-POGIL activities can be used to introduce a new topic or reinforce previously-learned material. Although many available exercises are intended to take full class sessions, longer activities can be divided into smaller pieces if traditional lecture is still being used. The guided inquiry nature of POGIL exercises is intended to introduce new material to students, but the activities can also be used to reinforce already-taught topics. For example, the author follows a 20-minute lecture on an overview of chromatography with the first pages of an ANA-POGIL activity about chromatography data. This excerpt takes students approximately 10 minutes to complete, and as students work through the questions, the instructor interacts with each group, listening for common errors or points of confusion. Answers are discussed as a full class, which provides the instructor with additional opportunities to correct student misconceptions about the material.

These activities also have been used by the author in larger lecture classes. ANA-POGIL activities have been used in the 70-person Quantitative Analysis course to introduce concepts. When working with a larger class, the author typically uses groups of three, as the classroom has immovable benches. Group activities are kept to 10 minutes and then gone over as a group. Typically in the 10 minutes the instructor still has time to interact with each group, just to a lesser extent than with smaller classes (<20 students).

**Collaborative Quizzes and Exams**

The second scenario, which describes a situation where students disregarded instructor feedback, touches on a common struggle: what do we as instructors want students to get out of exams? Quizzes and exams assess student learning and can inform both the student and instructor on individual progress and understanding. The timed, written format of tests, however, can over-emphasize memorization and limit the ability of the instructor to assess critical thinking (36). To improve the outcome for scenario #2, the students needed some motivation to look over the