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So These Numbers Really Mean Something? A Role Playing Scenario-Based Approach to the Undergraduate Instrumental Analysis Laboratory

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A number of pedagogical methods have been used to enhance learning in the laboratory setting. These include problem-based learning (e.g., *1−5*), cooperative learning (e.g.,*(6, 7)*), service learning (e.g., *8−11*), and role-playing (e.g., *12−16*). These methods reinforce course content and also enhance communication, critical thinking, and problem-solving skills. Historically, analytical chemistry laboratories have focused on students obtaining the "right answer". In our experience teaching both quantitative analysis and instrumental analysis laboratory courses, we have found that students were more concerned with obtaining the right answer than critically thinking about the significance of the number. In an effort to help students develop critical-thinking skills in the context of analytical chemistry, we have instituted a major pedagogical change in the second-year instrumental analysis laboratory. This change first occurred in the fall 2005 semester and we have just completed the fourth year of this implementation. We have chosen to explore a multifaceted approach that combines many of the favorable components of the aforementioned learning techniques.

Our goals in organizing the laboratory include (i) group or cooperative learning; (ii) real-world sample analysis; (iii) role-playing from multiple points of the employment spectrum; (iv) exposure to multiple methods of scientific presentation including written, oral, and poster formats; and (v) development of a teaching method that could be easily adopted from standard analytical laboratories without significant laboratory development. Additionally, we have made it our strict policy that instructors or teaching assistants never tell the students the "right" answer. It is our view that in their future careers as scientists they will need to rely on their own laboratory skills and data to judge the "rightness" of an answer; there will never be an instance when they are presented with the right answer.

Course Design

The instrumental analysis laboratory course is offered to chemistry majors and is typically taken by second-year students, although upper-level students are often also enrolled. The laboratory consists of a four-hour laboratory and a one-hour recitation each week. A three-hour instrumental analysis classroom lecture course is a corequisite. Our newly designed laboratory curriculum consists of four three-week experiments, each dealing with a unique application of instrumental analysis exposing the students to approximately nine analytical instruments. We have designed laboratory-based, role-playing scenarios focused on more routine topics of pharmaceutical, forensic, environmental, and food chemistry, as well as specialized topics including gemology and art conservation that are rotated each semester.

Each laboratory experiment is prefaced with the "scenario" that will guide the students' experimental design and data interpretation. At the beginning of the semester, each laboratory section (approximately 10−12 students) is divided into three groups. The students remain with these partners throughout the semester. In each scenario, the three groups assume roles of an accusing group, a defending group, and a governmental agency. Students do not have assigned roles within the group, such as supervisors, analysts, technicians, and so forth (as has been the approach of others, e.g., *14*). It is our experience that, with the large amount of outside-of-laboratory work that accompanies these scenarios, those who may assume a leadership role in the laboratory may not lead in data analysis, presentation preparation, or literature research. It is also our experience that each student finds a way to contribute to the group endeavor.

One week following the conclusion of the laboratory scenario, each group presents the results of the analysis, as well as their interpretation of what should be done regarding the original accusation. The accusing group is required to give a poster presentation. The defending group is required to give an oral presentation. The governmental agency is required to write a formal report. For the ensuing two laboratories, the groups rotate roles. Because we have weekly recitation time, by week 9 of the 13 week laboratory, each student has the opportunity to play each role (accusing, defending and governmental) and to present their results in all three formats (Table 1). Thus, for the fourth scenario, we require that each lab section give a 20 min oral presentation. We have chosen this presentation format to further strengthen the students' scientific public speaking skills. Although the fourth scenario involves some degree of controversy where an accusation is leveled that requires analytical measurements to prove or disprove the claim, the lab sections are free to choose a role to assume during the presentation, based upon their measurement results. For instance, a section may find their results support the accusation leveled, and thus would act as an accusatory group during the presentation.

A Scenario Example

As an example, for the pharmaceutical chemistry scenario (see supporting information), the accusing group is a consumer advocacy group that is making an accusation that a pharmaceutical

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Table 1. Example Project Schedule for One Semester

Date	Scenario Topic	Instrumental Methods	Rotation Among Groups: Accusatory (poster)	Defense (oral)	Government Agency (report)
9/28	Pharmaceutical	AA, UV−Vis, HPLC	Group 1	Group 2	Group 3
10/26	Environmental	AA, GC−MS, GC−ECD	Group 2	Group 3	Group 1
11/9	Forensics	GC−MS, LC−MS, fluorescence	Group 3	Group 1	Group 2
12/7	Art Conservation	IR, SEM, microscopy	Oral presentation by each section on last recitation day		

company has purposefully included less iron in a multivitamin than is reported on the label in an effort to cut costs and increase company profits. The defense group represents the pharmaceutical company being accused and the governmental group represents the U.S. Food and Drug Administration. Each group is presented with the same scenario information, samples, and analytical protocols and is expected to complete the lab in the allotted time. The samples are over-the-counter vitamin tablets; however, the instructors have relabeled the bottles and changed the reported values. For example, the correct label for the tablets purchased for the lab experiment states that the iron tablets contain "27 mg of Fe as iron sulfate heptahydrate". The relabeled bottle states "28.8 mg of Fe as iron sulfate hexahydrate". Had Fe been incorporated into the tablets as the hexahydrate, the label as rewritten would in fact be the correct mass of Fe per tablet. Assuming students accurately measure the mass of Fe during the experiment, they will obtain a value lower (27 mg) than that reported on the bottle (28.8 mg). Students then need to put forth hypotheses for why their measured values differ from the reported value. In some cases, diligent students doing outside research have been able to determine that iron can be included in different forms and correctly concluded the label had the incorrect water of hydration listed that resulted in an incorrect calculation of the amount of iron in the tablet.

The laboratory experiments that students conduct are typical protocols found in standard analytical texts such as Harris *(17)* or Skoog, Holler, and Crouch *(18)*. Thus, little modification of existing laboratories is required to implement this approach in the curriculum. Simply printing new labels each semester allows the instructors to vary which group will be considered "at fault" each semester. Additional example scenarios that we have used for food, environmental, and forensic chemistry laboratories can be found in the supporting information section. The food chemistry scenario involves the quantitation of cholesterol and vitamin E in organic versus nonorganic eggs and pyoverdine (a fluorescent compound present in bacterially spoiled eggs) in an effort to examine the claim that the organic eggs are more nutritious and stay fresher than nonorganic eggs. The environmental chemistry scenario investigates metal and organic pollutant levels in soil samples from a property that is for sale, but may require environmental remediation if sufficient pollution of the site is identified. The forensic chemistry scenario investigates levels of quinine in urine of a tonic water drinker (with comparison to literature values reported in those who do and do not drink tonic water) and identification of illicit drug residues in urine. It should be noted that urine samples for this scenario were produced using commercially available (Flinn Scientific) artificial urine.

This redesign of the curriculum has not only allowed us to reinforce the idea that the numbers that students generate "*really do mean something*" and can have substantial implications, but it has brought to light the ethical and moral implications that are related to each real-life scenario. Is the company at fault? What repercussions should follow? How might the guilty company explain their data? Should a guilty party try to explain away incriminating data by, for example, sampling statistics or simply admit guilt and accept the consequences? Although role-playing is not necessarily a new paradigm in education (or even in analytical chemistry, see, e.g., *16*), the ability to implement this type of curricular approach within the context of existing laboratory experiments is a key facet of the approach described here.

In comparison to other laboratory curricula, we have been delighted by the level of enthusiasm that students have shown in this laboratory. Students spend a significant amount of time and effort on outside research that supports their data or claims (or may negate the claims of another group). A healthy level of rivalry among groups invariably arises and this manifests itself in high-quality presentations that have exceeded our original expectations for the course.

Student Assessment

Student assessment for instrumental analysis laboratory has consistently evolved since the original implementation of the curriculum. Students were originally assessed based on the group presentation (40%), peer assessment (40%), and the individual laboratory notebook (20%). Originally, the peer assessment was done in an anonymous fashion and the other lab partners did not know what grade their peers had assigned (they would be told the total points awarded, but not how many points each individual lab partner had awarded them). This often resulted in a number of perfect scores, as the small class size meant most of the students were friends (and thus biased in their assessment of lab performance). On the other hand, in a few cases where difficult group dynamics were present, peer assessment was often completed in a spiteful nature, rather than an impartial evaluation.

A new peer evaluation system has been implemented with initial results that are much more positive. Peer evaluations are now done in an open group discussion with full consent of an individual's evaluation by all group members. Students decide, as a group, a pseudofinancial bonus (or penalty) to be awarded to each individual based on their performance during a particular laboratory scenario. A maximum remuneration is assigned by the instructor (e.g., \$800 of "salary" for each group member) and each bonus or penalty awarded (to a maximum of \$200) must be explained in detail and justified. For example, exemplary leadership and contacting outside experts in the field to discuss real-world implications have constituted acceptable reasons for awarding a bonus, whereas fulfillment of typical laboratory analysis duties would not be accepted by the instructor as the basis for awarding a bonus. The students complete written forms detailing each member's bonus or penalty and the reasons for each decision. Each group member is then required to sign the form stating that they agree with the group's decision, so that they can be held accountable for their performance. At the end of the semester, the total bonus or penalty quantity for each student is then translated to a percentage of the total grade. The relative percentage of the total grade that the peer evaluation constitutes is less (20%) than the original peer evaluations implemented in the first year (40%). This approach has alleviated some of the group dynamic problems that resulted from the previous anonymous evaluation process. Students are forced to engage in conflict management and avoid involving instructors at the first sign of disagreement.

Group evaluation by instructors (constituting 50% of the course grade) is based on a grading rubric that is specific to each type of presentation (see supporting information). Separate rubrics are given to the students for the oral, poster, and written presentations. All presentation formats are primarily graded on the quality of the data produced, accuracy, precision, interpretation, error analysis, and correct use of statistics. The quality of the data is evaluated based upon their measured result and the derived confidence interval of that measurement. No feedback is provided as to how close they were to the true measurement, but rather the onus is put upon the student groups to perform replicate measurements using multiple independent methods with analytical standards to increase their confidence in the measured value. Because students are more accustomed to the typical laboratory approach of being rewarded or penalized based on their reported value, not receiving that feedback can be frustrating; however, we feel this approach mimics what a scientist faces in reality. Additional consideration is given to presentation organization and style, as outlined in the grading rubric (see supporting information).

The final portion of the laboratory grade is based on individual student performance based on laboratory notebook quality (20%) and good lab practices (10%). These grades are assigned independent of the group's performance.

Course Assessment

In an effort to assess student response to the role-playing scenario-based method, we conducted surveys of each class at the end of the past four, semester-long courses (see supporting information). Ideally, to compare this curriculum change to traditional instrumental laboratory experiences, the same survey would need to have been given to class participants prior to 2005. Unfortunately, the authors made the change immediately upon their arrival at Villanova University. Thus, we have only taught the course this way and comparison to the previous curriculum is unavailable. Upon the basis of the survey results and open-ended responses, we have accumulated significant anecdotal evidence that indicates students find this laboratory course more enjoyable than other laboratory courses they have taken. Students noted that the best features of the laboratory were the opportunities to be creative on presentations, independence in the laboratory, improved research abilities, practical applications of the experiments, the fun of role-playing, and freedom to try new experimental protocols rather than rely on a "cookbook" of experiments and techniques. Negative comments included that some students felt the grading was ambiguous (due in part to the fact that we do not tell them the "right" answer), finding time to meet outside of class was difficult, and group dynamics could be challenging.

Implementation

One can envision modifications to the specifics of this approach based upon the time allotments for laboratory and recitation. For instance, if a separate recitation is not available, some laboratory time must be used for presentation purposes and the fourth scenario could be shortened or omitted and other instrumental techniques added to the remaining three scenarios.

The benefits of implementing a scenario-based instrumentation laboratory curriculum include increased student enthusiasm, development of critical-thinking skills, development of scientific communication skills, and fostering group learning environments. Scenarios can be developed that involve already developed experiments and instrumental techniques. Instructors just need to present some "real-world" context to which the measurements apply. Gradual incorporation of role-playing scenarios is also a possibility, depending on the nature of the existing laboratory curriculum. This versatility in course design and implementation is also a benefit to the role-playing, scenario-based approach to instrumental analysis.

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Supporting Information Available

Example laboratory scenarios, course guidelines, grading rubrics, and course evaluation. This material is available via the Internet at http://pubs.acs.org.

