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Misconduct at the Lab? A Performance Task Case Study for Teaching Data Analysis and Critical Thinking

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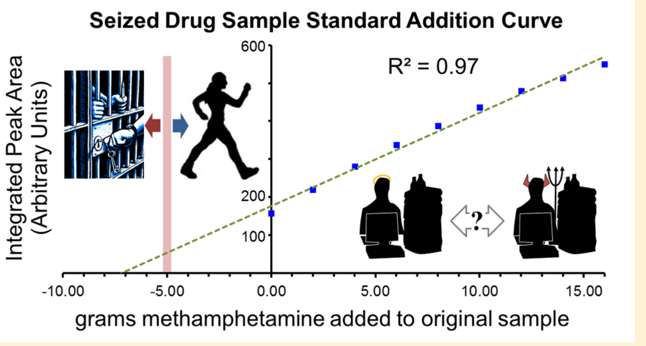
Supporting Information



ABSTRACT: A distractor-rich performance task case study was developed to teach undergraduate analytical chemistry students about standard addition while reinforcing their grasp of data analysis and quality control principles. The performance task presents students with an e-mail from a fictional district attorney that asks them to investigate allegations of data falsification in a crime lab and determine whether fabricated, falsified, or faulty analyses may have impacted one particular court case. It also asks students to suggest changes to the lab's quality assurance practices. Correct analysis of the task scenario requires students to recognize that the accused analyst systematically overestimated analyte levels when they incorrectly assumed that their standard addition data fell within the linear region of their method's signal-response curve. The task is also designed to help students to grow in their professional awareness as chemists, critical thinking, and communication skills. This is because students are expected to apply their understanding of data analysis concepts and typical signal−response curve behavior to a complex problem; develop an understanding of how standard addition works from the analyst's trial testimony; avoid numerous distractors embedded in the documents that detail the scenario; and present their findings in a written report. Because these features of the task require students to decide how much to focus on possible motives instead of analysis of the analytical data, they raise questions about the degree to which chemists should comment on nontechnical matters when speaking as a chemical professional. Since the prompt deliberately avoids specifying the length and other characteristics of the report, the students must make choices about how to present their findings. Consequently, the assignment concludes with instructor-led discussion and self-evaluation exercises aimed at helping students learn to assess and prioritize information, use statistics to assess analytical data, draw warranted conclusions, and communicate those conclusions appropriately.

KEYWORDS: *Second-Year Undergraduate, Analytical Chemistry, Problem Solving/Decision Making, Communication/Writing, Forensic Chemistry, Quantitative Analysis, Instrumental Methods*

The time when the sociologist Auguste Comte could claim that mathematical analysis runs counter to "the spirit of chemistry"[1] is long past. Data analysis is integral to virtually all areas of chemical practice, and instruction in data analysis is infused throughout the undergraduate chemistry curriculum. It is particularly prominent in the analytical chemistry sequence, where students are introduced statistical and quality assurance methods for assessing and validating data. Ideally, the goal of this instruction should not just be to provide students with knowledge of these topics, but also to develop the habits of mind needed to assess data, detect anomalies, draw warranted conclusions, and, if necessary, act on them—in short, to help students think like professional scientists.

Unfortunately, there are some indications that traditional lecture, memorization, and algorithmic problem-solving approaches to chemical education actually impede students' ability to engage in scientific reasoning.[2] The need for more critical thinking instruction is currently being addressed through active learning efforts like those of the POGIL project[3] and the National Center for Case Study Teaching in Science[4] and has been the subject of various worksheet-based,[5] open-ended laboratory,[6] Mathematica notebook,[7] inquiry-guided instruction,[8] and problem-based exercises;[9] a proposal asking students to evaluate scientific claims made on the Internet;[10] and efforts to formally train chemistry students in logical reasoning.[11]

One tool that has been of particular recent interest is a type of case study that is sometimes described as an authentic performance task. These have recently become popular in K−12 education, in part because they are used by the Collegiate Learning Assessment (CLA and CLA+) tests to measure critical thinking and writing skills.[12] Authentic performance tasks are distractor-rich elaborate case studies that ask students to use authentic or simulated real-world documents like e-mails, lab notebook data, and articles to develop an understanding of a complex problem, apply disciplinary content to address that problem, and communicate the results professionally.[13]

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Because performance task case studies involve the higher-order cognitive abilities in Anderson and Krathwohl's revised Bloom's taxonomy of learning,[14] they are intended to supplement, not replace, other instruction. Several of the cases presented before in this *Journal* might be classified as performance tasks.[15]

This paper describes another authentic performance task entitled "Misconduct in the Lab?" (Supporting Information) that is designed for use with undergraduate analytical chemistry students. The intent, scope, and other deign rationale are first presented, followed by its implementation in the classroom and its reception by students.

■ ACTIVITY DESIGN

The "Misconduct in the Lab?" performance task was designed for use in undergraduate analytical chemistry courses and assumes students are familiar with basic data analysis concepts such as descriptive statistics, Student's *t*, regression, and typical signal−response curve behavior.

The fictional task presents students with an email from a district attorney asking them to investigate allegations of misconduct at a crime lab. Specifically, they are asked to determine whether the alleged misconduct occurred, whether a specific court case was affected, and whether the lab should alter its operating procedures. The crime lab setting was chosen to provide a readily understandable context for the task and to leverage student interest in forensic science and forensic scientist misconduct.[16] A secondary goal was to reference the task in later course discussions about research ethics, scientific misconduct, and scientific management (see the case teaching notes in the Supporting Information).[16,17]

Students were asked to present their findings to the district attorney in a written report. This output was chosen to probe how effectively students produced a concise and well-argued report that met the needs of the district attorney. Nevertheless, the task's technical communication aims were left implicit in the prompt so as to better assess students' awareness of their audience's needs and willingness to craft a report that met them.

The questions students are expected to address were selected to evaluate how effectively and rigorously students engaged the task. For instance, when determining whether the faulty analysis affected the specific case, students can judge that the true amount of methamphetamine in the seized sample was likely less than 5 g using the average ratio of actual to reported methamphetamine in the quality assurance (QA) samples. However, this argument should be bolstered by reanalysis of standard addition data, using a polynomial fit or a linear fit to the low-concentration linear portion of the curve. Both lead to the same conclusion, although only the latter is consistent with the expected linear behavior of low-concentration signal−response data.

The task documents were also designed to probe student's ability to evaluate data. Only a portion of the lab notebook printouts, independent lab analytical reports, e-mail correspondence, trial transcript, investigator reports, and newspaper article, is germane to the problem and much of the rest tempts students to draw inferences tangential to (or even opposed to) those suggested by the lab notebook and QA data. The newspaper and investigator reports in particular subtly encourage students to focus on the suspect and accuser's motives. The chemical professional's code of conduct[18] does not explicitly prohibit chemists' from considering such questions. However, the scenario raises the question of whether and how far chemists should venture outside the limits of their professional expertise and qualifications, especially when this is done at the expense of more technical elements of a problem.

The task is designed to be used in conjunction with a post-assignment discussion. A task rubric (Supporting Information) was designed to help students self-assess their own work and provide talking points for an in-class discussion; thus, even though the rubric assigns a numerical score, it is not intended to serve as a means for assigning student grades. The rubric consists of two parts, a flowchart and grid rubric. The flowchart is used to assess how well the student identified key data, prioritized key analyses, and addressed the prompt's questions. The grid rubric is used to help students reflect on whether they approached the case professionally and whether their report communicated their findings effectively.

■ IMPLEMENTATION

The assignment was introduced in a 5 min class discussion held just after students had completed learning about statistics, quality control, and typical signal response curve behavior. The class was told the assignment was designed to help them think critically about data analysis concepts and then asked to complete the performance task as an individual homework assignment that would be due 2 days later. The students were explicitly asked not to discuss the assignment with each other but instead to wait for a postassignment class discussion that would help them reflect on how effectively they addressed the task.

The postassignment discussion involved the entire class of 20 students and was held during the first 30 min of the following class period. The discussion involved three stages. The first did not use the rubric and focused on how effectively students analyzed the fictional district attorney's three questions. Since one goal of the discussion was to help students think about their reasoning processes, the students who were least sure about their findings were asked to contribute their thoughts first. The discussion about whether misconduct occurred established that the data indicated the accused analyst was overestimating the amount of methamphetamine present in samples by using a linear fit to model nonlinear data. Further discussion centered on whether faulty analysis constituted evidence of misconduct and whether chemists functioning in a professional capacity should address nontechnical issues like personal motives. The class next discussed whether the analyst's overestimation of methamphetamine levels in a particular sample led to improper charges in the court case. Students were first asked to share which piece of evidence they used to answer this question. This revealed that about half of the students simply accepted the independent lab's reanalysis of the sample, while the other half reanalyzed the original data using a polynomial curve fit. This sparked a discussion about whether it is sufficient to simply disregard misanalyses when there is enough data present to reanalyze the original data. The question of whether the lab's QA procedures should be altered was then addressed by asking the students how the lab was not implementing reasonable quality assurance practices. Students noted that the lab should have been conducting periodic audits of analysts' work and using standards to detect problems before they are allowed to influence court cases. The students were then asked what changes they might make in any existing QA procedures that might be in place. This led some to suggest that the use of residual plots be added to the lab's operating procedures for standard addition analyses and a brief discussion about the advisability of using dilution to conduct analyses in the linear range.

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The second part of the class discussion employed a task rubric to help students self-asses how effectively they approached the assignment. This was done by talking students through the flowchart section of the rubric and discussing how the rubric rewards students for focusing on the prompt questions, employing scientific data, and conducting rigorous analyses. The discussion also led students to see that the flowchart did not reflect the steps most students employed. Most first concluded that the analyst was in error because they overestimated the amount of methamphetamine in the QA standards; they then asked whether the analysts' notebook data provided evidence as to why they were systematically overestimating methamphetamine levels. At this point the students either first noticed the improper linear fit and then determined how it led to systematic error or else first hypothesized that an error in the standard addition curve would explain the discrepancy and then observed that the standard addition data is nonlinear. Students also noted that if the curve included data from the signal—response curve's nonlinear region, it would explain how the amount of methamphetamine could be grossly overestimated.

The final portion of the discussion focused on students' ability to recognize the implicit elements of real world assignments by asking them to evaluate their report's effectiveness using the task rubric's grid section. Students were asked to evaluate how clearly and concisely they reported their main findings, effectively used logic and scientific evidence to support those findings, and crafted their report around the needs of an attorney-reader.

■ STUDENT PERFORMANCE AND RECEPTION

All students recognized that the accused analyst overestimated methamphetamine levels and determined that properly analyzed data do not support a possession with intent charge in the court case under consideration. Ninety percent identified the analysts' improper use of a linear trendline as the problem, although this likely overestimates a typical student response since one student discussed the nonlinearity with a significant fraction of the others. More interesting, therefore, was how these students discussed their findings. Only 6% of those who recognized the analyst's error equated his actions with misconduct; the rest either recognized the possibility of honest error or did not comment on whether misconduct occurred. The answers of those students who failed to identify the problematic linear trendline were also instructive. One focused on the lack of evidence for tampering in the analysts' notebook records and both focused on the suspect or accuser's potential motives. In contrast, only half of students who identified the problematic linear analysis speculated about either the analyst or accuser's motivations.

Students enjoyed the assignment and expressed the desire to do similar assignments more often, although not as a main method of instruction in any course. Typical comments include:

> *I thought that this assignment was a worthwhile use of time. It was interesting and kind of fun to reanalyze the data and figure out what [the accused analyst] did wrong and it was a good way to help us think about quality assurance and how to analyze data.*
>
> *I thought this was [an] interesting assignment and really enjoyed working on it even though I didn't find all of the mistakes.*
>
> *I thought this assignment was really fun and it was cool to see how what we are learning in class applies to real life.*
>
> *I really enjoyed the exercise, especially the part associated with knowing our limits as analytical chemists rather than as a private investigator.*

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00478.

- Performance task assignment (PDF, DOCX)
- A more realistic and difficult version of the performance task (PDF)
- Instructor notes (PDF)
- Grading rubric (PDF)
- Excel spreadsheet file of the simulated standard addition curves for the performance task and various advanced modifications and a list of possible things to notice, for instructors who wish to modify this performance task further: standard addition curve sims (XLSX)
- Advanced data and power law simulation (XLSX)
- Intermediate data sample and polynomial sim (XLSX)

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Notes

The authors declare no competing financial interest.

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