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Editorial

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Evidence for the Importance of Laboratory Courses

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ABSTRACT: Laboratory courses are an ever-present form of teaching in chemistry, despite little evidence for their impact upon student learning. The chemistry community is challenged to consider the evidence basis for laboratory teaching commensurate with the significant investment of cost and time to provide this instruction.

KEYWORDS: *Laboratory Instruction, General Public*

During its first year in publication, this *Journal* printed the findings from what may well be the oldest known report of chemistry education research. In a paper titled "The Advantages of Laboratory Work in the Study of Elementary Chemistry",[1] Bowers wrote that "the need of laboratory work is to train observation... because memory work is emphasized too much and scientific observation not enough." He argued, however, that this is the "most insignificant claim" one could make about the value of learning in the chemistry laboratory, instead arguing for the importance of learning information that can be used in further study. He created an exam of 20 questions, 10 about content taught only from the textbook and 10 about content that students had been taught both in the textbook and in the laboratory. He administered this exam to students who had completed first-year university laboratory and examined the accuracy of students' responses based on the number of years since they had completed their laboratory work at the university. All students scored better on content taught in both the textbook and the laboratory compared to content taught solely in the textbook, and the exam scores increased as more years had passed since a student had completed first-year university laboratory. Bowers's conclusion? Laboratory experiments lead to more learning than the textbook alone.

While Bowers's experimental design and statistical analyses would not meet the criteria for publishing chemistry education research papers in today's *Journal*,[2] Bowers's conclusion still resonates today among chemists as a statement so obvious, a conclusion so sound, that we need no evidence to support the assertion that all students studying university chemistry not only need, but also learn from, hands-on laboratory experiences. The American Chemical Society Committee on Professional Training (CPT) stipulates that its approval of bachelor's degrees in chemistry requires 400 h of laboratory experience above and beyond first-year, introductory university chemistry. Furthermore, these hours may not be virtual or simulated experiences. The CPT explains that laboratory experiences provide "a particularly attractive opportunity for inquiry-driven and open-ended investigations that promote independent thinking, critical thinking and reasoning, and a perspective of chemistry as a scientific process of discovery."[3]

However, in 1982, Hofstein and Lunetta issued a report decrying the lack of evidence for student learning in the laboratory (ref 4, p 212):

> *Researchers have not comprehensively examined the effects of laboratory instruction on student learning and growth in contrast to other modes of instruction, and there is insufficient data to confirm or reject convincingly many of the statements that have been made about the importance and effects of laboratory teaching.*

When these same authors returned to examine additional evidence for the value of laboratory teaching two decades later, they once again pointed to sparse data regarding student learning in the laboratory.[5]

Given the significant expectations to provide laboratory experiences for students, not to mention the financial costs of doing so, the question must be asked: Why do chemists continue to ignore the lack of evidence regarding this ubiquitous form of teaching? Reid and Shah explain that "very little justification is normally given... it is assumed to be necessary and important"[6] despite the fact that research has failed to demonstrate any relationship between students' experiences in the laboratory and their learning.[7] Additional critiques have suggested that, without evidence of learning to justify the substantial financial investment required to create these specialized teaching spaces,[8] not to mention the cost of consumable chemicals and waste disposal, "the most important issue in the context of laboratory classes is whether there needs to be a laboratory program at all."[9]

Even recent reports from the National Research Council (NRC) do little to suggest that gathering evidence about the quantity and quality of learning in the undergraduate teaching laboratory is a priority. The newly released report *Indicators for Monitoring Undergraduate STEM Education*[10] makes but two mentions of laboratory learning, in both instances invoking the 2012 NRC report on discipline-based education research that "laboratory experiences that incorporate realistic scientific practices and the use of technology" have been shown to be effective.[11] While *America's Lab Report* does ask the important question of what laboratory experiences contribute to science learning, the report is limited to laboratory teaching in secondary schools.[12] *Undergraduate Research Experiences for STEM Students* reports an analysis of some laboratory teaching, but undergraduate research experience as a pedagogy in the teaching laboratory is certainly an exception, and not the rule.[13]

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Certainly, chemistry faculty continue to design new chemistry experiments for undergraduates to reflect the ever-growing content of our discipline. This *Journal* published more than 100 new undergraduate chemistry experiments in the past year alone. Innovations in laboratory pedagogy and curriculum continue with reports on virtual instruments and digital badges to improve students' proficiency with instrumentation and equipment in the laboratory.[14−16] A few measurement tools have been developed to characterize meaningful learning in the laboratory,[17] instructional practices of graduate teaching assistants,[18] and the degree of inquiry afforded students in laboratory experiments.[19] Recently, Pullen and colleagues published a report detailing the results of a competency-based assessment model for the first-year undergraduate chemistry laboratory.[20] Laboratory pedagogies such as MORE (Model−Observe−Reflect−Explain),[21] the Science Writing Heuristic,[22] and Argument-Driven Inquiry[23] have long existed and generated evidence of student learning but have not been widely adopted.

Why should chemists require evidence of student learning in the undergraduate chemistry teaching laboratory? Because not all who shape and influence higher education share the same value proposition. Teaching laboratories are labor intensive (prep staff, instructional faculty, graduate teaching assistants) and costly (specialized classroom space, breakable equipment, instrumentation, consumable chemicals that cannot be reused each semester, waste disposal costs, salaries and tuition of graduate student instructors...). And these costs only increase as we move from introductory laboratory courses for the masses to specialized laboratory courses for the (relatively) small number of chemistry majors.

University budgets are under increasing strain, and administrators are keen to reduce instructional costs without sacrificing the quality of student learning. Courses, disciplines, and pedagogy that can point to evidence of high-quality student learning will fare better than colleagues in departments whose teaching lacks such an evidence basis. What evidence does your department have that the significant investment of space, time, personnel, and resources is essential for your students to learn chemistry? What arguments and data would your department amass to defend laboratory instruction if your university administration decided that virtual laboratories and simulations would be a far less expensive pedagogy that does not compromise student learning? Chemists can no longer afford to believe that the importance of teaching laboratories is a truth we hold to be self-evident. As scientists we must support our research claims with evidence. Our claims about student learning require this same standard.

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Notes

Views expressed in this editorial are those of the author and not necessarily the views of the ACS.

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