One Hundred Years Later, Introductory Labs Are Poised for Change

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Ashley R. Carter

One Hundred Years Later, Introductory Labs Are Poised for Change

Ashley R. Carter, Amherst College, Amherst, MA

Introductory lab courses have been a staple of the physics curriculum for over 100 years. Yet these courses are now poised for change as recent research shows that they do not meet a frequent goal of enhancing student understanding of lecture content.[1] In thinking about how to move forward, a look back at experiment courses in history seems wise. Here, I take a quick look at our historical record and describe three interesting experiment courses from different time periods: Adolphe Ganot's demonstration-style experiment course of the mid-1800s, Fredrich Kohlrausch's research-grade experiment course in the late 1800s, and Newton Henry Black's concept-exercise experiment course of the early 1900s. In looking back at these three courses, I find that instructors throughout history have had to face the same questions we do today. Specifically, what is the role of the introductory lab course in teaching experimental or theoretical concepts, and how much preparation, instruction, authenticity, and complexity are required? It seems that even if the introductory lab course is poised for change, that change may not be meaningful unless we answer these questions.

Ganot's demonstration-style experiment course

Adolphe Ganot was a French prep school teacher with 20 years of experience before he published the famous *Traité élémentaire de physique* in 1851.[2,3] The text was an instant success with eight editions in eight years and translations in 10 languages.[4] It also reached a broad audience, from secondary school students and engineers to non-students.[4] What I find interesting about the *Traité* is that it reminds me of a laboratory manual mixed with a textbook. It contains descriptions of both theoretical concepts (e.g., the law of refraction) and experimental procedures (e.g., how to measure the index of refraction of a gas). The experimental procedures are often accompanied by professional drawings of the equipment, experimental data, or descriptions of how to take the measurements.[3] In addition, these experiments "were kept in glass-fronted cupboards" in the lecture hall and were "performed by the teacher in front of the students"[4] as demonstrations.

The popularity and longevity of the *Traité* suggest that this demonstration-style experiment course got many things right. It was an authentic course, since Ganot continually updated the book with new developments in physics that he read in French periodicals.[4] For example, the experiments of Fizeau and Foucault (1845-1850) were published in the 1856 edition of the *Traité*.[3] It was also simple to execute, requiring only a single demonstration apparatus. Finally, according to historian Josep Simon, educators praised Ganot's "teaching of science through demonstration, experimental manipulation and observation."

However, this demonstration-style experiment course was not perfect. Ganot worried about the suitability of particular sections for less prepared students and placed these more complex sections in smaller type-font.[3] He also worried about the amount of time spent on experimental vs. mathematical topics, even creating a book in 1859 without any math at all.[5] Finally, other instructors complained that students in courses like Ganot's were only spectators of the demonstrations[6] and needed to increase the "adroitness" of their fingers.[7]

Today's instructors would agree with this last sentiment. In 2014, the American Association of Physics Teachers (AAPT) recommended six learning outcomes for the laboratory,[8] including modeling experiments, designing experiments, and developing technical skills. To achieve these learning outcomes, institutions will need hands-on experiments.

In looking back at this course, there are advantages and disadvantages in teaching students using only demonstration-style experiments. The advantage is the small price tag, the simplicity, the focus on physics concepts, and the ability to teach many students at once. The disadvantage is that the students do not learn experimental skills. To address this concern, Fredrich Kohlrausch used a different type of course.

Kohlrausch's research-grade experiment course

Fredrich Kohlrausch was a prominent experimentalist at Gottingen that published the well-known lab manual *Leitfaden der Praktischen Physik*.[9] In the preface to the second edition of 1872, he wrote that we needed a "preschool for the experimental" where future physicists could familiarize themselves with "scientific tools" and workers could gain "practical execution."[9] To gain scientific tools and practical execution, the manual contained one- to two-page descriptions of experimental measurements, complete with the apparatus, theory, and typical data for students to reproduce. This moved students out of the lecture hall and into a lab facility. In addition, many experiments were based on recent research. For example, in the 1884 edition[10] of the *Leitfaden* there are experiments on the Wheatstone bridge of 1843, Lord Kelvin's galvanometer of 1858, and Lippmann's capillary electrometer of 1873. This created an authentic, hands-on experiment course.

However, this experiment course using research-grade experiments had its flaws. One flaw was that teaching experimental prowess rather than theoretical knowledge was a tough sell. James Clerk Maxwell said he always had "to labor to prove the advantage of practical science to the University" when teaching a similar course.[7] In addition, Kohlrausch worried about the level of instruction of the experiments, since "academics" might find the treatment too lax, while "workers" might find the treatment too pedantic.[9] He also worried about the complexity of the research-grade experiments for a general introductory audience. Indeed, others complained that complex experiments were "ineffective" because the "students get lost in the multitude of details and forget the purpose of the experiment."[11]

Perhaps the lesson for today's instructor is that if we want to build a "preschool for the experimental," it needs to be a preschool. Right now, there is a push, mainly in biology, for research to be incorporated into the introductory course.[12] This is because research is a realistic experience that increases "thinking and working like a scientist"[13] and provides "learning gains related to the research process, scientific problems, and lab techniques."[14] However, Kohlrausch's course should serve as a warning against research-grade or complex experiments in the introductory course.

In looking back at this course, there again appear to be advantages and disadvantages that instructors must weigh. The advantage is that students are working on authentic experiments that require them to think about modeling, design, and analysis. The disadvantage is that this type of course is expensive, it is not easily scalable to large numbers of students, and the experiments are too complex. To remove some of this complexity, instructors like Newton Henry Black created the concept-exercise experiment course.

Black's concept-exercise experiment course

Newton Henry Black was the Science Master at Roxbury Latin School in Boston for 24 years before he joined the Harvard faculty in 1924 as an assistant professor of education and eventually physics. He published a textbook with Harvey Davis of Harvard in 1913 for secondary school students and also wrote an accompanying lab manual.[11] In Black's laboratory course, students worked in a laboratory to complete experiments, as in Kohlrausch's course. However, the experiments in Black's course were "very simple and often crude" so that "the average boy or girl, who already has in mind the general outline of the problem, can not only do the experiment but can see the point to it."[11] The manual is also fairly prescriptive, falling into the category of a traditional laboratory course, which is a course that tells students "what to do and how to do it."[1] In addition, Black's course contained theoretical questions or exercises. For example, in the experiment on "The Straight Lever," Black asks, "How does the sum of the moments on the right of the fulcrum compare with the sum of those on the left?" He also asks in a problem at the end of the experiment, "Where must a second girl weighing 80 lb be placed to balance the plank?" Thus, in this concept-exercise experiment course, exercises on the theoretical concepts are weaved into the experimental narrative. The beauty of the course, as Black put it, was that the "elementary work is not primarily physical *measurements*, but *physics*."[11] This thinking has resonated with instructors for decades as many have viewed the laboratory as a vehicle to reinforce lecture content.[1]

However, recent physics education research has shown that traditional laboratories like this one are not meeting this goal of reinforcing lecture content.[1] In addition, the AAPT recommends that we teach experimental skills in the laboratory, not lecture content.[8] Even instructors in the early 1900s were able to point out the flaws of a course with simple, prescriptive experiments. Daniel Rich in his 1923 laboratory manual[15] said to "encourage a few of the better students in each class to depart from the routine occasionally and work up independently some new or different exercise" as "this time may be well spent." Harry Hadley in the preface to his 1916 manual[16] said "that the training is more permanently useful when the student has to solve his own difficulties and to discover principles for himself," but that this was "possible only when the class is small and when more time is available that can usually be given to the subject."

The lesson here is that simple, cookbook experiments that teach theoretical concepts will need to be replaced with courses that allow students to "depart from the routine." The problem is that despite two world wars, the introduction of computers, globalization, and countless advances in physics, the cookbook experiment on "The Straight Lever"[11] could have been used at my institution last semester! That longevity means that this type of course is likely entrenched in our institutions, and replacing it with more independent or open-ended inquiry will be difficult.

In looking back at this course, there are advantages and disadvantages. The advantage is that the course is hands-on, and that the cost and scalability are not as prohibitive as the research-grade experiment course. The disadvantage is that the experiments are not adding value to the theoretical skills taught in lecture, nor do they give students the independence they need to learn experimental skills. Thus, traditional lab courses, like Black's course, are poised for change. What will that change look like?

Future introductory lab course

In looking at past experiment courses, what have we learned for the future? Ganot's demonstration-style experiment course teaches us that students need hands-on instruction. Kohlrausch's research-grade experiment course teaches us that students need to be scaffolded into a laboratory experience. And finally, Black's concept-exercise experiment course teaches us that students need independent exploration.

Upon this review, is there a path forward for the introductory lab course? I am hopeful that the physics education research community will lead the way through collaborative research and assessment.[17] After all, instructors have worried about the same questions since the inception of the experimental course. What is the balance between experimental and theoretical (or computational) topics? How do we serve both "workers" and "academics"? And, how do we balance complexity and efficiency? It is time we answered some of these questions. My money is on paths that use open-ended exploration and simple equipment to allow for student design and redesign. But, whatever the answer is, after 100 years, the introductory lab is finally poised for change.

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References

1. Natasha G. Holmes and Carl E. Wieman, "Introductory physics labs: We can do better," *Phys. Today* **71** (1), 38–45 (2018).
2. A. Ganot, *Traité élémentaire de physique expérimentale et appli-*

quée, ... par A. Ganot (Chez l'auteur, 1851).
3. A. Ganot, *Traité élémentaire de physique expérimentale et appliquée et de météorologie avec un recueil nombreux de problèmes* (Chez l'auteur, 1856).
4. P. R. C. X. Guillem-Llobat, J. Simon, and N. H. T. Lanuza-Navarro, *Beyond Borders: Fresh Perspectives in History of Science* (Cambridge Scholars, 2009).
5. A. Ganot, *Cours de physique, purement expérimentale et sans mathématiques* (Chez l'auteur-éditeur, 1859).
6. M. E. Crowell, *A Manual of Experiments in Physics for Teachers: Adapted to the Crowell Physical Apparatus* (Columbia School Supply Company, 1901).
7. J. C. Maxwell and W. D. Niven, *The Scientific Papers of James Clerk Maxwell* (University Press, 1890).
8. J. Kozminski et al., "AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum" (AAPT, College Park, MD, 2014).
9. F. W. G. Kohlrausch, *Leitfaden der praktischen Physik* (B. G. Teubner, 1872).
10. F. W. G. Kohlrausch, *Leitfaden der praktischen Physick mit einem Anhange das elektrische und magnetische absolute maass-system* (B. G. Teubner, 1884).
11. N. H. Black, *A Laboratory Manual in Physics to Accompany Black and Davis' Practical Physics* (Macmillan, 1913).
12. Melinda Harrison, David Dunbar, Lisa Ratmansky, Kimberly Boyd, and David Lopatto, "Classroom-based science research at the introductory level: Changes in career choices and attitude," *CBE Life Sci. Educ.* **10** (3), 279–286 (2011).
13. Elaine Seymour, Anne-Barrie Hunter, Sandra L Laursen, and Tracee DeAntoni, "Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study," *Sci. Educ.* **88** (4), 493–534 (2004).
14. David Lopatto, "Undergraduate research experiences support science career decisions and active learning," *CBE Life Sci. Educ.* **6** (4), 297–306 (2007).
15. D. L. Rich, *Physics Laboratory Manual* (G. Wahr, 1923).
16. H. E. Hadley, *A Manual of Practical Physics* (Macmillan and Company, Ltd., 1916).
17. Benjamin Zwickl, "AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum: Implications for Assessment," *Forum on Education Spring 2016 Newsletter* (2016).

Ashley R. Carter *is associate professor of physics at Amherst College. Her current scholarship focuses on the mechanics of cells and biomolecules.*
Department of Physics, Amherst College, Amherst, MA 01002; acarter@amherst.edu