Teaching traditional physics in a rapidly changing world

A physics education is the gateway to competence in technology, chemistry, medicine, engineering, environmental science, and even business. However, the dominant public perception is that physics is tedious, abstract, and fundamentally irrelevant. Many university students view physics as difficult or unpleasant and so choose not to pursue degrees in it.

Taking into consideration the available works in physics education research (see, for example, the article by Edward Redish and Richard Steinberg, PHYSICS TODAY, January 1999, page 24), I offer here some thoughts on teaching upper-level physics subjects for physics majors in our rapidly changing world.

Students' interest and motivation are vital components in their ability to learn. Traditionally, students majoring in physics took jobs in the physical sciences or continued their postgraduate studies. Nowadays, reasons for studying physics are diverse, and students are apt to use different learning approaches. In a study of students' approaches to learning, John Biggs presented two examples: the deep approach and the surface approach.[1] Students using the deep approach expressed positive feelings of interest, challenge, and mastery. Motivation to learn is also important, and the best sort of motivation arises from intrinsic interest or fascination. It is therefore crucial for instructors to do all they can to stimulate students' interest in the subject matter.

I currently teach two physics courses: Statistical Mechanics (Thermal Physics) and Electromagnetism. Both are core subjects for physics majors and are generally believed to be difficult—for example, the textbook I use in one of my classes at the University of Wollongong contains more than 1300 equations in the seven chapters covered. To stimulate students' interest in those traditional subjects, I use various approaches in delivering my lectures.

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Highlighting major discoveries. As an example, in the first lecture of my Thermal Physics class, I list 15 Nobel Physics Prizes, from Johannes van der Waals's 1910 prize for his equation of state for gases and liquids, to Werner Heisenberg's 1932 prize for his creation of quantum mechanics, to the 2001 prize to Eric Cornell, Wolfgang Ketterle, and Carl Wieman for their achievement of Bose–Einstein condensation. All are related to the main topics of thermal physics and serve as lead-ins to my lectures. By discussing those achievements, demonstrating their effects, and adding interesting personal details about the physicists, I hope to increase students' curiosity and hence to arouse their interest.

Introducing recent discoveries. The latest achievements in physics are published frequently in *Nature*, *Science*, and other journals. On every Friday of the term, I use the first five minutes of the lecture to talk about recently published results related to thermal physics. For example, a paper on the Fermi surface of a quantum gas[2] was used to discuss both the Fermi–Dirac distribution and the Fermi gas. With that paper, I helped students make connections between the latest research and the topics in the class. After the lecture, two students expressed interest in the solid-state physics group at the university.

As I mentioned earlier, electromagnetism is a mathematics-heavy subject. The equations are long and complex. For instance, when the vector potential was first introduced, it was purely mathematical, with no physical meaning. Recent research has demonstrated that the vector potential does have physical meaning. My recent research results even demonstrated an equivalent potential for noncharged particles.[3] When I told my current students that two honors students had worked with me on that project, a few asked if I would take more students the following year.

Linking to everyday life. A wide range of everyday devices—from a magnetic resonance imager to the price scanner at the grocery store to smart phones—depend critically on discoveries in physics.

It is well known that learning is more effective and robust when linked to real-life experiences. For every topic in Thermal Physics, I prepare at least one example that links to everyday life. For instance, the last section of the course, on semiconductor statistics, describes fundamental characteristics of semiconductors and the simplest semiconductor structure, the p–n junction, by using the Fermi–Dirac distribution of electrons.

I start the first lecture of that topic by asking students what the electric conductivity of a semiconductor would be if it were cooled down to absolute zero. Most answer that it would become a superconductor. They learned previously that the electric conductivity of a metal will increase when the temperature is reduced, and even superconductivity could be achieved if the temperature was low enough. However, the correct answer is the opposite: A semiconductor becomes an insulator at zero temperature—if you put your mobile phone in a low-temperature freezer, it will stop working. During the lectures, I derive the expressions for electron and hole concentrations and introduce the statistical models. The temperature dependence of the carrier concentrations

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clearly shows the conducting properties of a semiconductor at various conditions. By the last lecture in that section, the students understand the principle.

Using new technologies. With the ever-increasing availability of online education resources, including open courseware, online courses, and discussion forums, choosing the best resources is becoming a new challenge for instructors. However, electronic resources provide new tools and opportunities to increase students' conceptual understanding.

I have adopted a lot of electronic resources in teaching both Thermal Physics and Electromagnetism. For example, Bose–Einstein condensation and superfluidity are subtle processes that can be hard to understand, and few laboratory teams have achieved those results experimentally. Videos played in the classroom allow students to watch the phase transition when liquid helium-4 is cooled to a temperature of 2.17 K and becomes a superfluid.

References

1. J. B. Biggs, *Student Approaches to Learning and Studying*, Australian Council for Educational Research (1987).
2. K. Aikawa et al., *Science* **345**, 1484 (2014).
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A universal law of procrastination

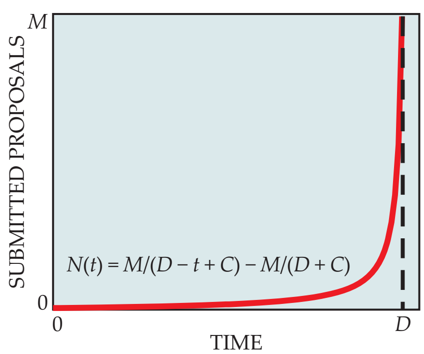
Throughout our lives we all are under pressure to deliver on deadlines. Yet we often have a substantial time window in which to complete the given tasks—for example, term papers, book chapters, tax returns. When during such a window do we deliver? And to what extent do we procrastinate?

Increasing pressure forces us to finalize tasks. The closer we are to the deadline, the higher the pressure. To quantify things a bit, we could assume that deadline pressure is inversely proportional to remaining time. Such scaling behavior is well known in physics; for example, it describes how the electrostatic potential energy of a point charge depends on distance from the charge, or how the gravitational potential energy of a system of masses scales with distance between the masses.

The scales look like $1/r$, where r can be distance, remaining time, or some other factor. The corresponding mathematical function is a hyperbola. To give an example of the scaling using arbitrary and dimensionless units, if a deadline is 100 days away, the pressure to meet it is just 0.01. But if the deadline is tomorrow, the pressure shoots up to 1.

As it turns out, that scaling may be universal when it comes to human behavior and perhaps reflects a universal law of procrastination (ULP). Cornelius König and Martin Kleinmann reported a hyperbolic "deadline rush" for a small set of fewer than 30 students preparing for exams over a 21-day period.[1]

As a program director at NSF, I was impressed by the tremendous increase in the number of proposals routinely submitted right before deadline as compared with those turned in earlier in the submission window. In analyzing large data sets from 10 annual submission



PROPOSED MODIFIED HYPERBOLIC function reflecting a universal law of procrastination. The red line represents the full form of the law, which illustrates the hyperbolic scaling, $N(t)$ is the number of submissions received by day t, M is the final number of proposals submitted, and D is the number of days in the submission window. According to the universal law of procrastination, $N(t) = M/(D - t + C) - M/(D + C)$, where $C = \frac{1}{2}(\sqrt{D}\cdot\sqrt{4 + D} - D)$ helps improve the fit for small values of t. The second term in the right-hand side of the equation ensures that $N(t) = 0$ at $t = 0$. Asymptote (not shown) is located at $t = D + C$.