Let's Revive the Study of Fluids

Ben J. Korgen

Physics has a long and illustrious history. It could have a brilliant future, but in the past several years, university physics departments have experienced problems. Students report that upper-division physics courses are unnecessarily difficult, and they question the social relevance of physics. Physics attracts a lower percentage of women and ethnic minorities than most other fields. Undergraduate enrollments of physics majors are declining in most US universities.

In some ways, physics is a victim of its own successes. Past research by physicists allows today's physicists to push tantalizingly close to the ultimate boundaries of understanding. As a result, many academic physicists may find research much more interesting than teaching. The progress and promise of physics also can lead to a type of arrogance that fails to inspire others.

So much is already known in physics that attempting to digest significant portions of that knowledge can tax the minds of modern-day students—who have virtually the same mental capacities, time, and energy as the students of centuries past who faced a much smaller body of knowledge.

While physics faculty became increasingly concerned about the undergraduate physics curriculum, new discoveries accelerated our awareness of the importance of fluids. Can people with vested interests in fluids and people with vested interests in physics departments gain anything from each other? To answer this question, I will first explore certain dependencies.

The subjects of physical oceanography, dynamic meteorology, and solid-earth geophysics are all applications of physics. All three subjects depend on fluid dynamics, and both physical oceanography and dynamic meteorology are almost totally dependent on fluid dynamics. I use physical oceanography as an illustrative tool, although dynamic meteorology or solid-earth geophysics could serve the same purpose.

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What is physical oceanography?

At one time, physical oceanography was a descriptive enterprise. Today, it is a form of classical physics dedicated to increasing our understanding of physical processes in the oceans. Its practitioners are classical physicists who affiliate with the culture of oceanography. This culture exists because of needs for:

- Specialized vessels, docking facilities, buoys, instruments, and associated equipment
- Consideration of the oceans as unified systems in which the four branches of oceanography (physical, chemical, geological, and biological) are interdependent
- Convenient channels of communication for scientists who work in any or all of the four branches of oceanography.

Physical oceanography research focuses on scales of motion ranging from millimeters (the diameters of the smallest turbulent eddies) to thousands of kilometers (the horizontal dimensions of the ocean basins).

The following phenomena force physical oceanographers to make air–sea interactions and other boundary conditions integral facets of their work:

- A continuous exchange of gases takes place at the air–sea interface
- Winds drive surface waves and currents
- Evaporation and precipitation determine the salinity of sea water, which acts in concert with variations in temperature distributions to drive density circulations
- Bottom topograpy directs, accelerates, and decelerates near-bottom currents
- Shear gradients generate turbulence near land boundaries and at boundaries between adjacent water masses
- Near-bottom currents moving over soft bottoms cause sea water to migrate between sediment grains.

Physical oceanography specialties include air–sea interaction, upper-ocean processes, cascading and bottom water formation, general circulation, paleocirculation, waves, tides, tsunamis, seiches, currents, meanders, eddies and rings, shear, turbulence and mixing, water-column microstructure, nearshore processes, optics, and acoustics.

Some physicists in ocean optics or acoustics consider themselves as physical oceanographers, others as traditional physicists. Still others affiliate with subcultures and consider themselves as optical oceanographers, acoustical oceanographers, underwater sound physicists, or underwater sound engineers.

The importance of physical oceanography derives partly from the importance of the oceans. Photosynthesis in the oceans generates most of the oxygen we breathe and most of Earth's living biomass. Sea-floor sediments contain the world's least-disturbed records of the fallout from past events in the oceans, in the atmosphere, and on land. Evaporation from the oceans provides most of the precipitation that allows life to exist on land.

However, physical oceanography also has an impact beyond its role in ocean physics because biological, chemical, and geological processes in the oceans depend more heavily on physical processes than physical processes depend on them.

Patchiness—that is, unevenness in the geographical extent to which organisms can exist—depends primarily on physical processes that recycle nutrients and bring them into the sunlit surface waters where photosynthesis can take place. Seawater chemistry depends on biological productivity, which depends on physical processes. Geological processes such as the erosion, transport, and deposition of sediments depend on physical processes driven by waves, ocean currents, and turbulence.

Impact

Undergraduate physics majors at universities study classical physics topics (such as thermodynamics, mechanics, and optics) that are required if they choose to enter graduate programs in physical oceanography. University physics departments are the most important source of incoming graduate students in physical oceanography.

Most incoming graduate students in physical oceanography have limited, deficient, or nonexistent backgrounds in fluid dynamics, so they need to do undergraduate remedial work.

To make optimal contributions to physical oceanography, physics departments should offer a fluid dynamics option for undergraduate majors, including an introductory fluid dynamics course requiring as prerequisites upper-division status and mathematics through differential equations, and an advanced fluid dynamics course requiring as prerequisites the introductory course and advanced mathematics for physicists. Both fluid dynamics courses should offer appropriate research experience. Physics departments could also raise awareness of graduate school and career paths in physical oceanography.

Physical oceanography offers a wealth of examples and motivational opportunities that could be used by professors in teaching undergraduate physics courses. Students are likely to find the vortices generated by the conning tower of a moving submarine, the creation and destruction of beaches, and the physics of surfing to be interesting and relevant to contemporary life.

Traditional physics provides important conceptual underpinnings for all branches of science, engineering, and medicine. It provides the best source of people who enter graduate programs in physical oceanography, dynamic meteorology, and solid-earth geophysics, each of which is socially relevant. These direct and indirect contributions suggest that traditional physics is among the most socially relevant fields on the planet. Many students do not see physics that way, however, largely because the seminal character of physics masks its social relevance.

If physics departments expanded their offerings in fluid dynamics, they would increase their contributions to social relevance through their efforts in fluid dynamics itself and by strengthening graduate programs dependent on fluid dynamics. By doing so, the same departments would also gain in the visibility of their contributions to society.

Most physics departments have paid little attention to fluids. Nevertheless, individual scientists have pursued forms of research that would fit best within the realm of classical physics. For example, England's Irish-born Osborne Reynolds (1842–1912) and Germany's Ludwig Prandtl (1875–1953) created flow visualization methods that evolved into the present-day collection of at least 25 different flow visualization techniques.[1] In doing so, Reynolds and Prandtl facilitated some of the most important discoveries in modern fluid dynamics. They opened a door through which physics departments could follow their lead by elevating fluid dynamics to a standard, universally accepted specialty within classical physics.

To sample the extent to which present-day university physics departments have made a commitment in fluid dynamics, I surveyed the course offerings of 55 US university physics departments using the virtual library provided by College Source Online. (For course descriptions, see the website of College Source Online, http://www.cgf.org/home.asp.) I chose those physics departments that are the largest or best known, or that are close to oceanographic institutions. Of those departments, none offered an undergraduate fluid dynamics option. None offered the two or more upper-division courses that might buttress such an option. Seven offered one upper-division fluid dynamics course.

Those seven departments have entered the door opened by Reynolds and Prandtl. They also have opened the same door a bit wider, which suggests that their actions might represent a wise step forward.

The small percentage of physics departments making a commitment in fluid dynamics suggests the presence of opportunities. Within these opportunities, physics departments must find new ways to address the problems I mentioned earlier. For example, fluid dynamics courses exhibit modest levels of abstraction and uncertainty, and they possess the highest possible potentials for exploiting the visualization of processes. These characteristics should allow physics faculty members to teach fluid dynamics courses without making them unnecessarily difficult.

A ray of sunshine pointed in this direction has been provided by Jerry Gollub (PHYSICS TODAY, December 2003, page 10), a professor of physics at Haverford College. He has experimented with integrating fluid dynamics into physics curricula, has achieved encouraging results, and offers suggestions that could be used elsewhere.

By expanding into fluid dynamics and benefiting from the experiences of physicists like Gollub, physics departments could experience the kind of synergy needed to ensure that stable or increased physics major enrollments become almost universal.

Reference

1. B. J. Korgen, *Marine Technology Society Journal* **37**, 23 (2003). ■