The Discipline That Is Transforming Higher Ed

The computer-science boom is straining colleges. But it could save some, too.

Harry Campbell for The Chronicle

By Alexander C. Kafka | April 15, 2020 ✔ PREMIUM

On a Tuesday afternoon last spring, Daniel Zhang, a junior at the University of California at Berkeley, showed up to lead his first two-hour lab section in a computer-architecture course. A teaching assistant, he expected to find maybe 25 students needing his help. Instead he was met by some 200 frenzied faces, a quarter of the lecture course's enrollment.

The pattern continued. "There would be a line of people stretched around the corner through the corridors waiting to get checked off," he says, "as well as people sitting on the floors inside the lab itself."

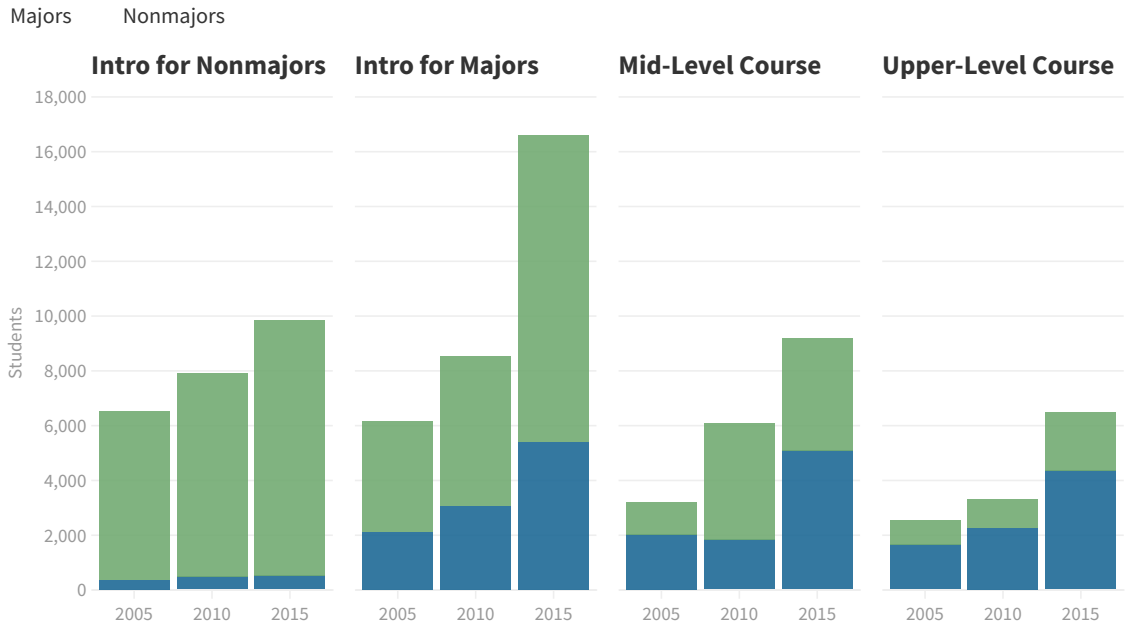
"I started really getting the sense that this is insane."

Insane, maybe, but similar scenes play out in colleges across the country. Zhang is one of an army of undergraduate and graduate-student TAs who help thousands of Berkeley computer-science students navigate the hugely popular and hypercompetitive major. The number of computer-science majors there increased from 1,116 in 2009 to 3,387 in 2019. Nationally, since 2007, as some fields in the humanities and social sciences have withered, the number of computer-science majors has more than quadrupled.

Even that vastly understates the enrollment pressures, because departments face huge additional demand from nonmajors. This spring at Berkeley, 3,847 students are majoring in related data-science fields, and 705 students in unrelated majors are enrolled in three lower-division computer-science courses.

Not Just for Majors

The number of students enrolled in computer-science courses who aren't majoring in the discipline has steadily increased over the years, particularly in courses primarily for majors.



Source: Computing Research Association Enrollment Survey, "Generation CS: Computer Science Undergraduate Enrollments Surge Since 2006 " • Note: Data reflects students in computing courses at doctoral and nondoctoral-granting departments.

"It's just a phenomenal level of growth that is unprecedented in our discipline," says Stuart Zweben, a professor emeritus of computer science at Ohio State University who has led key studies of enrollment in the field. His research suggests that nationally, more than 300,000 undergraduates are enrolled in, or preparing for, computer-science majors. Students in related fields — among them cybersecurity, bioinformatics, robotics, and computer animation — lean on courses offered by computer-science departments. To get a sense of scale, visualize a couple of moderately large cities populated by nothing but computer-science students.

The popularity would seem like manna from admissions heaven, but it also creates problems. Most departments can't recruit nearly enough faculty members, because of budget constraints and competition from industry. The scramble to gain entry into the

capped-enrollment programs puts low-income, underrepresented-minority, and female students at a disadvantage. And the increasing tilt toward tech curricula creates frictions with other disciplines.

But in the face of a Covid-19-induced recession and the enrollment cliff forecast for 2025, the boom also creates intellectual and business opportunities for colleges. Adequately funded, computer-science programs could be an even more powerful recruitment draw than they already are. Increasingly sophisticated cross-fertilization with other fields could transform waning majors from competitors into allies. And in a society increasingly based on machine learning, a nuanced understanding of automation's potential, as well as its limits, could better prepare graduates for careers not just in STEM but also in the social sciences and the humanities.

The challenge, says Katherine S. Newman, interim chancellor of the University of Massachusetts at Boston, will be to include a diverse pool of students in "what is probably the most profound intellectual revolution of our time."

Students and professors alike say that the initial appeal of computer science most often is the prospect of a lucrative career. Not only can top graduates from elite programs get entry-level software-engineering or similar jobs with six-figure salaries, signing bonuses, and superb benefits, but along the way they can lasso summer internships paying $7,000 or $8,000 a month, with housing allowances ranging from $6,000 to $9,000, says Ed Lazowska, a professor in the Paul G. Allen School of Computer Science & Engineering at the University of Washington.

Career opportunities aside, on an intellectual level computer science has become fundamental to almost every aspect of society. "You want to know why the sky is blue and how a light bulb works," says Robert Sedgewick, a professor and founding chair of computer science at Princeton University. "You should know how the internet works, too."

The Covid-19 crisis has only underscored how essential computer technology is. The discipline touches nearly every aspect of the response — epidemiological tracking, molecular modeling in vaccine research, 3D printing of medical supplies, shifts to online work and classes. Online teaching tools pioneered by necessity in computer science may now, however flawed, point the way for distance-learning innovations in other fields. And data tracking and measurement of the results of those teaching methods will help to evaluate and refine them.

"Even if you never write a line of code," says Sedgewick, computer science "is a way of logical thinking that will serve you well in addressing a variety of situations."

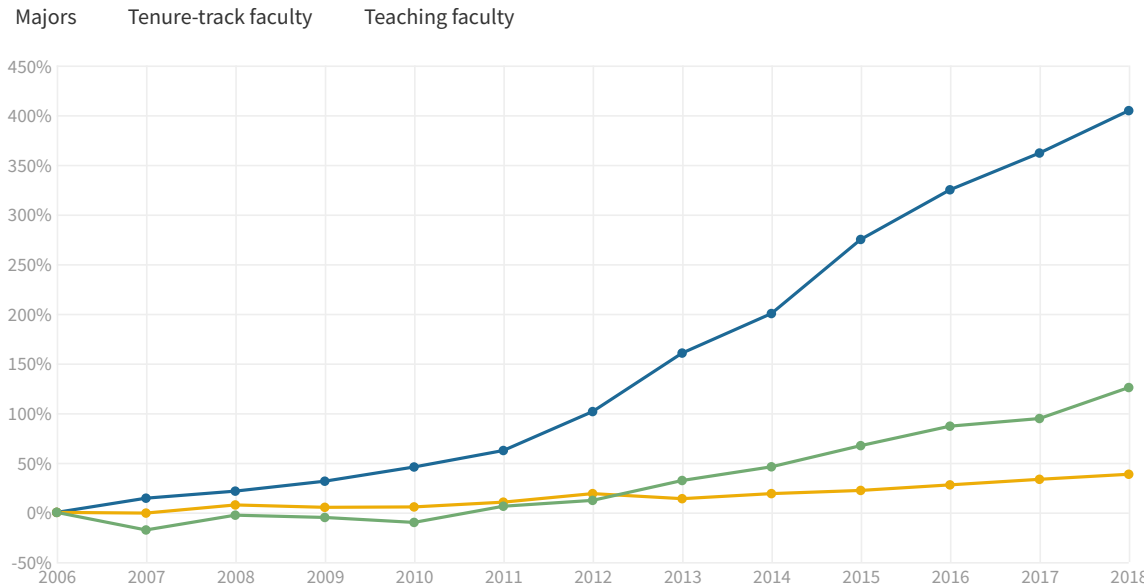
Most scholars in the field, and many outside it, believe computer science should be part of every student's education, like expository writing or a math, statistics, or foreign-language course. When demand is so high that some colleges hold lotteries for enrollment in these classes, the notion of a "requirement" seems almost beside the point. Students are increasingly requiring it of themselves. But an intro course, at least, should be available to all, Sedgewick says.

At Princeton, about 70 percent of undergraduates take Sedgewick's introductory course, "Computer Science: An Interdisciplinary Approach." The proportion used to be around 80 percent, he says, but now a growing number of students place out after taking good high-school or online courses. Forty percent of the undergraduates take Sedgewick's course on algorithms, and 25 percent of all Princeton students major or earn a certificate in computer science.

But, he says, "many colleges do not even aspire to reach those levels."

Growth in Majors Outpaces Growth in Faculty Members

Since 2006, when the most recent enrollment surge in computer science began, the growth in the average number of faculty members in computer-science departments has lagged behind the growth in the average number of majors per department.



Source: Computing Research Association Taulbee Survey, 2018 • Taulbee survey data reflects departments in North America that grant Ph.D.s in computer science, computer engineering, or information.

In part, that's because there aren't nearly enough faculty members to keep up with demand. Among universities responding to a Computer Research Association survey in 2016 of Ph.D.-granting institutions, from 2006 to 2015 the number of computer-science majors increased

almost fourfold (from an average of 192 students to 753) while growth in tenure-line faculty grew by only 22 percent (from an average 23 to 28).

The enrollment surge has continued since then, says Craig E. Wills, who heads the computer-science department at Worcester Polytechnic Institute and tracks hiring in the field. Over the past three years, however, new tenure-track positions for computer-science faculty peaked and have remained steady.

Faculty salaries can't compete with industry pay, which can be several times higher and is often accompanied by excellent benefits. So great is the need for faculty members, says Dan Garcia, a teaching professor in Berkeley's computer-science department, that some colleges are filling full-time teaching positions with candidates who have a four-year bachelor's degree and a one-year master's.

The sparse faculty ranks are supplemented by armies of teaching assistants. Berkeley's computer-science classes and combined electrical-engineering and computer-science courses together employ 444 TAs. In decades past, Garcia says, he'd try to learn the names of all of his students, but now he has trouble learning the names of all of his teaching assistants. Instructors have become more like generals now, he says, overseeing, for a single course, dozens of TAs. The scale is such that the assistants have become specialists, with niche skills in creating tests, grading, running labs, or tutoring.

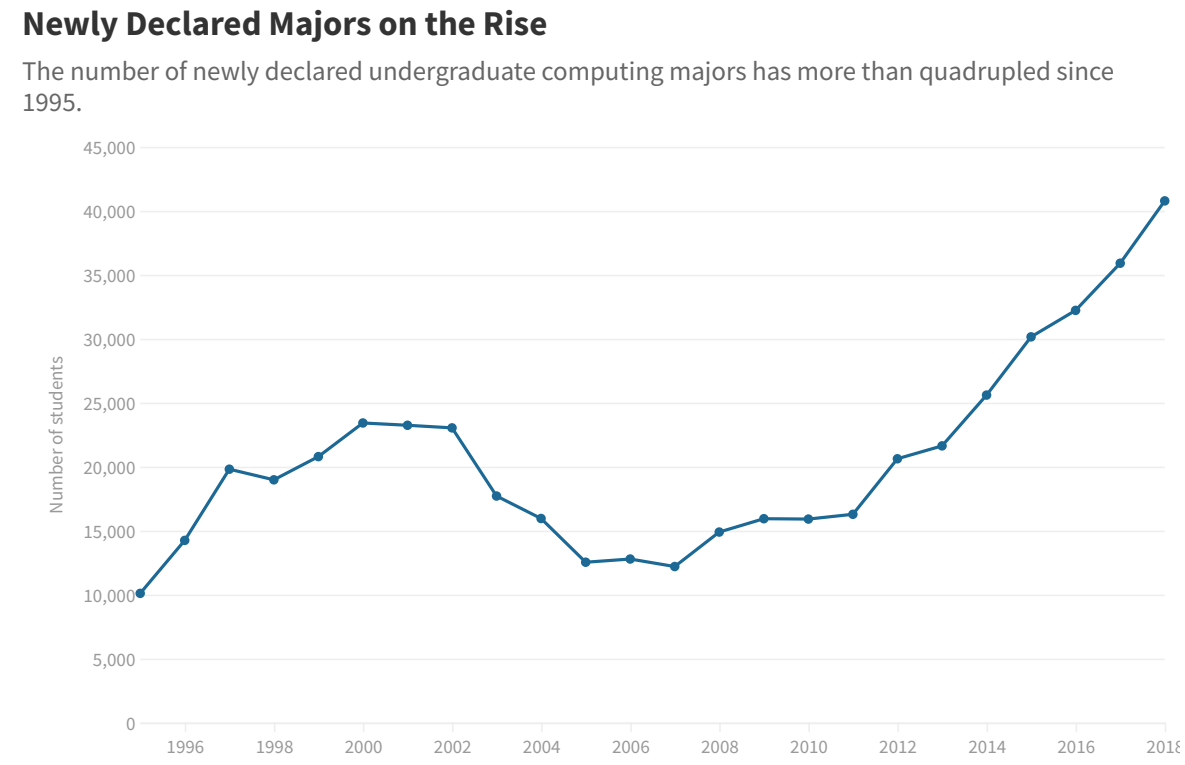
These battalions cost millions of dollars. Unions argue that colleges are getting off cheap — too cheap. An arbitrator in January ruled that Berkeley must stop employing TAs for less than the 10-hour weekly threshold at which they would contractually receive partial tuition reimbursement and other benefits. The ruling also awarded them a collective $5 million in back pay. Some TAs, at least the undergraduates, worry that such rulings will force departments — and not just at Berkeley — to shrink their TA programs, denying students valuable teaching experience.

Department heads say they're caught in the middle. The University of Washington's computer-science program employs 590 TAs, 470 of whom are undergraduates. The undergrads earn a stipend that works out to $16 to $20 an hour, says Lazowska. Waiving tuition, he says, would cost roughly $5.7 million, "a staggering number that would more than double our annual TA costs."

As it is, he says, "we are siphoning funds from everywhere" to pay the TAs — unrestricted gifts, vacant staff and faculty positions — a scramble for dollars that is happening at colleges across the country.

"Most of us have been pleading with our deans to grow our programs," says Berkeley's Garcia. "People are just struggling under the weight, and overworked."

Capping enrollments in computer-science majors and classes, as many colleges are doing, is not the answer, many experts argue. In fact, for students' intellectual and professional development, as well as for the sake of diversity, Sedgewick says doing so is "bordering on immoral."



Newman, of UMass Boston, was previously provost and senior vice chancellor on the Amherst campus. Before she left, in 2017, demand for computer science was so high that the university could easily have filled an entire freshman class with nothing but computer-science students. The program was turning away most applicants with grade-point averages below 3.9 (Advanced Placement courses raise the maximum GPA to 4.5). Since then the competition for computer-science spots, there and across the nation, has become only more intense.

That's a problem most departments would be thrilled to have. But it has exacerbated computer science's gender and racial imbalance. Newman, a sociologist, says training in computer science is a ticket to the upper-middle class, much as medical and law school

once were. But it is out of reach for many women and underrepresented minorities.

On average, reports from the National Academy of Sciences and elsewhere show, women account for only about a fifth of computer-science students. And while Asians and Asian-Americans are well represented, African American, Hispanic, and Native American students, collectively, make up roughly just 16 percent. Educators blame, among other factors, disparate preparation and resources at the K-12 level, cultural stereotypes about and within the field, and an imbalance in types of role models.

The percentage of female students has inched up in the past several years, but the percentage of underrepresented minorities hasn't. While the federal government, through the National Science Foundation, has significantly subsidized training in cybersecurity, Newman says, a broader effort is needed.

Some college leaders tell computer-science department heads that continued rapid growth in the programs would be unfair to other disciplines competing for tenure lines, and lab, office, and classroom space. They also worry that the surge is temporary, similar to the enrollment bubble in the mid-1980s after personal computers took off, or the bubble around 2005 after the dot-com boom.

The program directors understand that apprehension — a new tenure line is, after all, a 30- or 40-year commitment — but they think the fears are ill-founded. That's because high tech in the past decade has been woven into every industry.

An influential 2018 report by the National Academy of Sciences cites data from the Bureau of Labor Statistics showing that "employment in computer occupations grew by nearly a factor of 20 between 1975 and 2015," almost twice as fast as bachelor's degrees in the field. Demand will continue to grow, the federal figures suggest. "It doesn't look like a bubble," says Jennifer Hunt, a professor of economics at Rutgers University at New Brunswick who has studied this market.

And program expansion is not a zero-sum game that will happen only at the cost of other programs, says Susanne E. Hambrusch, a professor of computer science at Purdue University who analyzes enrollment trends in the field. Particularly as colleges face a recession triggered by Covid-19, integrating data science into a wide variety of disciplines makes good curricular and business sense, she says. Fifteen years ago, it was mostly software companies and a few financial firms that recruited at computer-science job fairs. Now it's corporations of many types.

Princeton's Sedgewick says that once-resentful academics in other departments warmed to computer science when they saw that its courses could be tailored to the needs of their students. That's the approach many programs now take.

The University of Illinois at Urbana-Champaign offers degrees in computer science, math and computer science, statistics and computer science, and a minor in computer science. But it has also established "CS + X" programs in advertising, animal sciences, anthropology, astronomy, chemistry, crop sciences, economics, geography, linguistics, music, and philosophy.

Elsa L. Gunter, a research professor in the computer-science department, says CS + X hybrids don't work when they're dictated from on high. "We want everyone involved to know why it's desirable," she says. The hybrids generally include 11 courses in the computer-science core, at least eight in the X topic, one or two technical electives, and a course or two specifically designed for the combined program.

CS + Philosophy students, for example, might prepare for a profession like intellectual-property law, learning to consider not just the technical but also the ethical aspects of an invention. The combination is organic, Gunter says. "It was philosophy that gave birth to logic that gave birth to the various foundations of computer science."

Colleges' next step should be to flip the order and create "X + CS" programs, says Newman, so "you've got enrollment flowing into that home discipline." That would ease other departments' resentment toward computer science and would relieve, to some extent, demand on overwhelmed computer-science departments.

"There are a lot of students out there who don't want to be computer-science majors but really do want to have data-analysis and tech skills," says Laura Haas, dean of the College of Information and Computer Sciences at the University of Massachusetts at Amherst. In the X + CS programs she and colleagues are creating for those students, "the other department owns the major," while computer science provides tailored technical skills in what might constitute 40 percent of the coursework. In computational linguistics, for example, among the computer-science elements would be machine learning, statistics, and natural-language processing.

Combine the CS and the X in any order you like, though, and problems remain, says Princeton's Sedgewick. In some such hybrid programs, computer science isn't taught by computer-science professors. "We don't tolerate that in other disciplines," he says. Moreover, "developing multiple curricula is just plain inefficient and cannot scale to solve the problem." And many of the hybrid programs don't provide sufficient preparation for advanced courses, like those on algorithms.

What's more, professors in other departments may, at least initially, be skeptical of the role that computer science can play in their fields. In the early 2000s, scholars began to explore humanistic questions with the help of data. Christopher Warren, an associate professor of

English at Carnegie Mellon University, offers some examples: Who knew whom in Shakespeare's England? What life patterns emerge through analyses of 60,000 entries — 72 million words — in the Oxford Dictionary of National Biography?

Early on, some humanists saw research projects along those lines as a techie invasion of the liberal arts. One objection was that applying quantitative approaches to humanistic matters would shortchange ethical considerations. But digital humanists have internalized such concerns, and ethics has become integral to their work, says Warren. Now the digital humanities have become mainstream. He points to his university's minor in "humanities analytics" as an example.

There are still skeptics. Mark Bauerlein, editor of the journal *First Things* and an emeritus professor of English at Emory University, says some humanities scholars "enjoy the energy that comes with an alliance with computer science, but most professors won't. They have neither the equipment nor the disposition to do so."

Whether or not humanists are ready for the technological convergence, it is well under way, says Brian Christian, a visiting scholar at Berkeley and author of the forthcoming book The Alignment Problem: Machine Learning and Human Values. In the past few decades, he says, machine-learning systems have become elemental to technology, and technology has become elemental to society.

He cites a controversial recent California bill, SB 10, which seeks to eliminate cash bail and to use algorithmic software to quantify the risk of a suspect's fleeing or committing an offense while awaiting trial. Christian has studied the algorithms' inherent biases, their inability to recognize outlying factors in suspects' circumstances or behavior. When he watched judges at arraignment hearings, he says, "the impression that I got was very much that no one knew what the score meant or how it was generated."

Or consider dermatologists who rely on computer analyses that show 99-percent confidence that a skin discoloration is not a malignancy. How and when should doctors weigh experience-based judgments against technology's predictions?

Students who are "age 18 or 19 today cannot avoid the fact that their job will put them in contact with machine learning on an almost daily basis," Christian says. Engineers will have to realize that the tools they design must mesh with the messiness of society — and society, in turn, will have to understand the limits of those tools.

"We need everyone fluent in computing and technology," says Berkeley's Garcia, "so that they're not just passive users of it but active creators of it."

"Computing," he says, "is the literacy of the 21st century."

Audrey Williams June created the graphics for this article.

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