
DALE EDWIN MURRAY

# Campus 2.0

*Massive open online courses are transforming higher education — and providing fodder for scientific research.*

BY M. MITCHELL WALDROP

When campus president Wallace Loh walked into Juan Uriagereka's office last August, he got right to the point. "We need courses for this thing — yesterday!"

Uriagereka, associate provost for faculty affairs at the University of Maryland in College Park, knew exactly what his boss meant. Campus administrators around the world had been buzzing for months about massive open online courses, or MOOCs: Internet-based teaching programmes designed to handle thousands of students simultaneously, in part using the tactics of social-networking websites. To

supplement video lectures, much of the learning comes from online comments, questions and discussions. Participants even mark one another's tests.

MOOCs had exploded into the academic consciousness in summer 2011, when a free artificial-intelligence course offered by Stanford University in California attracted 160,000 students from around the world — 23,000 of whom finished it. Now, Coursera in Mountain View, California — one of the three researcher-led start-up companies actively developing MOOCs — was inviting the University of Maryland to submit up to five courses for broadcast on its software platform. Loh wanted in. "He was very clear," says Uriagereka. "We needed to be a part of this."

Similar conversations have been taking place at major universities around the world, as dozens — 74, at the last count — rush to sign up. Science, engineering and technology courses have been in the vanguard of the movement, but offerings in management, humanities and the arts are growing in popularity (see 'MOOCs rising'). "In 25 years of observing higher education, I've never seen anything move this fast," says Mitchell Stevens, a sociologist at Stanford and one of the leaders of an ongoing, campus-wide discussion series known as Education's Digital Future.

The ferment is attributable in part to MOOCs hitting at exactly the right time. Bricks-and-mortar campuses are unlikely to keep up with the demand for advanced education: according to one widely quoted calculation, the world would have to construct more than four new 30,000-student universities per week to accommodate the children who will reach enrolment age by 2025 (see go.nature.com/mjuzhu), let alone the millions of adults looking for further education or career training. Colleges and universities are also under tremendous financial pressure, especially in the United States, where rocketing tuition fees and ever-expanding student debt have resulted in a backlash from politicians, parents and students demanding to know what their money is going towards.

When MOOCs came along, says Chris Dede, who studies educational technologies at Harvard University in Cambridge, Massachusetts, they promised to solve these problems by radically expanding the reach of existing campuses while streamlining the workload for educators — and universities seized on them as the next big thing.

There is reason to hope that this is a positive development, says Roy Pea, who heads a Stanford centre that studies how people use technology. MOOCs, which have incorporated decades of research on how students learn best, could free faculty members from the drudgery of repetitive introductory lectures. What's more, they can record online students' every mouse click, an ability that promises to transform education research by generating data that could improve teaching in the future. "We can have microanalytics on every paper, every test, right down to what media each student prefers," says Pea.

MOOC companies still face challenges, such as dealing with low course-completion rates and proving that they can make profit. And they have a lot of convincing to do among faculty members, says Uriagereka. "Some salivate and can't wait to be a part of it," he says, noting that his university had 20 volunteers for its 5 inaugural MOOCs. "Others say, 'Wait a minute. How do we preserve quality? How do we connect with students?'"

## LARGE-SCALE PEDAGOGY

MOOCs are largely a product of one corridor in the Stanford computer-science department, where the offices of Andrew Ng, Daphne Koller and Sebastian Thrun are just a few steps apart. But they are also the fruit of research dating back to at least the 1990s, when the explosive worldwide growth of the Internet inspired a multitude of efforts to exploit it for education. Campus administrators tended to regard such projects as a sideshow — the higher-education financial crunch was not quite as serious back then — so most experiments were the work of committed individuals, departments or research centres. But with the relentless advance of technologies such as broadband, social networking and smart phones, researchers' interest continued to grow.

Ng got involved in 2007 because he wanted to bring Stanford-quality teaching to "the people who would never be able to come to Stanford", he says. Following a path blazed by the open-source software movement, and by earlier open-source education initiatives, he started a project to post online free lecture videos and handouts for ten of Stanford's most popular engineering courses. His approach was fairly crude, he admits: just record the lectures, put them online and hope for the best. But to his astonishment, strangers started coming up to him and saying, "Are you Professor Ng? I've been taking machine learning with you!" He began to grasp how far online courses could reach, and started working on a scaled-up version of his system. "When one professor can teach 50,000 people," he says, "it alters the economics of education."

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One of the many people he talked to about his work was Koller, who began developing her own online-education system in 2009. Whereas Ng looked outwards, Koller wanted to look inwards and reform Stanford's teaching on-campus. She particularly wanted to promote 'flipping', a decade-old innovation in which students listen to lectures at home and do their 'homework' in class with their teachers, focusing on the most difficult aspects or discussing a concept's wider implications. This lets the instructors concentrate on the parts of teaching most of them enjoy — interacting with the students — and relieves them of the repetitive lecturing that they often dislike.

Koller also wanted to incorporate insights from the many studies showing that passively listening to a lecture is a terrible way to learn (F. I. M. Craik and R. S. Lockhart *J. Verb. Learn. Verb. Behav.* **11,** 671–684; 1972). Following an approach pioneered by other online developers over the previous decade, Koller broke each video into 8–10-minute segments separated by pauses in which students have to answer questions or solve a problem. The idea was to get them to think about what they had learned; the deeper their engagement, studies showed, the better their retention.

Finally, to encourage greater interaction among the students themselves, Koller took a cue from social-networking sites such as Facebook and gave her system an online discussion forum. As Ng explains, the idea was to extend what happens in a face-to-face study group: "Students sit with their best friends, they work on problems together, they critique each others' solutions — lots of pedagogical studies show that these more interactive modes of student engagement result in better student learning."

Koller and Ng eventually realized that they could achieve both their goals — outreach and on-campus reform — by pooling their efforts. In late 2010, they started work on a software platform that would support discussion forums, video feeds and all the other basic services of an online course, so that an instructor only had to provide the content. But making social interaction work on a large scale turned out to be a research project of its own, says Ng. For example, standard online discussion forums are a fine way to bring communities together — for 100 or so users. "With 100,000 it gets more complicated," he says. Hundreds of students might end up asking the same question. So the developers implemented a real-time search algorithm that would display related questions and potential answers before a student could finish typing. Ng and Koller also let students vote items up or down, much like on the link-sharing website Reddit, so that the most insightful questions would rise to the top rather than being lost in the chatter.

The two researchers even set the system up so that students could mark one another's homework for essay questions, which computers

can't yet handle. Not only is such a system essential to scaling up learning, says Koller, but it also turns out to be a valuable learning experience. And experiments have shown that if the criteria are spelled out clearly, grades given by the students correlate strongly with those given by the teacher (R. Robinson *Am. Biol. Teach.* **63,** 474–480; 2001).

By early 2011, Ng and Koller were planning to demonstrate the platform on campus, and other faculty members were paying attention. Among them was Thrun, a robotics researcher who was splitting his time between Stanford and Google in Mountain View, where he worked on the development of driverless cars.

It was Thrun's idea to go big, using a platform of his own based in part on Ng and Koller's ideas. He says that he was scheduled to teach an artificial-intelligence course that autumn, along with Peter Norvig, Google's director of research, "and I thought it was a social responsibility to take it online, so we could reach more than the 200 students we would get at Stanford". But even he hadn't imagined how big it would get. This was the course that registered 160,000 people from 195 countries after just one public announcement, a post to an artificial-intelligence mailing list. "It shocked everybody," he says.

In response, Ng took his machine-learning course public using the platform he and Koller had developed, while department chair Jennifer Widom did the same with a database course. Each attracted roughly 100,000 students. With those numbers, venture-capital funding quickly followed.

Thrun announced his company Udacity in January 2012. Arguing that most professors don't have a clue about how to exploit the online medium, he and his colleagues elected to develop their courses in-house, working with education experts to make the pedagogy as effective as possible.

Ng and Koller announced Coursera in April 2012, and took the opposite tack. They partnered with big-name universities — Stanford and three others, to start — and let them provide the content while Coursera provided the hosting and software platform.

Anant Agarwal, former head of the computer science and artificial-intelligence laboratory at MIT, had been experimenting with online learning for a decade, developing an electric-circuit simulation package called WebSim that tried to give online students an effective substitute for hands-on laboratory experience. In December 2011, inspired by goings on at Stanford, he launched MITx: an independent, not-for-profit company that would offer massive online courses from MIT on an open-source basis. It became edX in May 2012, when Harvard joined.

At the same time, the term MOOCs, which had been circulating quietly in educational circles since it was coined in 2008, took off. Media accounts boomed, and company principals were soon giving talks at the popular Technology, Entertainment and Design (TED) conferences and the annual meeting of the World Economic Forum in Davos, Switzerland. As Koller told one interviewer: "I can't believe my life!"

**270,000**

Students enrolled in Udacity's Introduction to Computer Science MOOC

**200,000**

US university first-years intending to major in computer science

## LEARNING CURVE

The MOOC companies can point to plenty of success stories. For example, the 7,200 students who completed Agarwal's electric-circuits MOOC in spring 2012 included an 81-year-old man, a single mother with two children, and a 15-year-old prodigy from Mongolia who got a perfect score on the final exam. Udacity's Introduction to Computer Science MOOC, currently its most popular, has enrolled more than 270,000 students.

But MOOCs have also had some teething problems. "Many people have no idea what they're in for when they commit to put a course online," says John Mitchell, a computer scientist and Stanford's first vice-provost of online learning. "Restructuring even one lecture into short, self-contained segments takes a fair amount of thinking." So does coming up with good, compelling questions to engage the students between the segments. Then there is the push for high-quality production, he says. "It takes many hours to produce one hour of quality video."

More worrisome are the MOOCs' dismal completion rates, which rarely rise above 15%. Completion has been a problem for distance learning ever since the first correspondence courses in the nineteenth century, says Dede. Only a small fraction of students have the drive and the perseverance to learn on their own, he says, and most people need help: "social support from their fellow students to help them keep going, and intellectual support from their professors and fellow students to help them figure out the material". At the moment, says Dede, the MOOC companies' peer-to-peer communication tools don't do nearly enough to provide that kind of help. "They're just kind of hoping that people will figure out from the bottom up how to support each other," he says.

The companies acknowledge that completion rates are a concern and that their platforms are still works in progress. "My aspiration isn't to reach the 1% of the world that is self-motivating," says Thrun, "it's to reach the other 99%." The companies are already working on enhanced social tools such as live video and text chat, for example.

And to observers such as David Krakauer, that is as it should be. "There are two ways to make something new," says Krakauer, a biologist who directs the Institute for Discovery at the University of Wisconsin–Madison. "You can design something that's perfect on paper, and then try to build it. Or you can start with a system that's rubbish, experiment and build a better one with feedback. That's the Silicon Valley style — but it's also the scientific way."

## SILICON VALLEY STYLE

A Silicon Valley sensibility permeates the three big MOOC firms. For example, they all subscribe to the open-source ideal. "Charging for content would be a tragedy," says Ng. But they also see plenty of opportunities to make money using the 'freemium' model followed by Google and many other technology companies: give away the basic product to draw users, and then charge for premium add-ons.

One obvious add-on might be certification, says Ng. "You would get a certificate that verifies you took the course for a small fee like US$10–$30" — a potentially substantial revenue stream when enrolments are in six figures. In the future, the companies might also offer full university course credits for a fee; they are already working with accreditation agencies to arrange that.

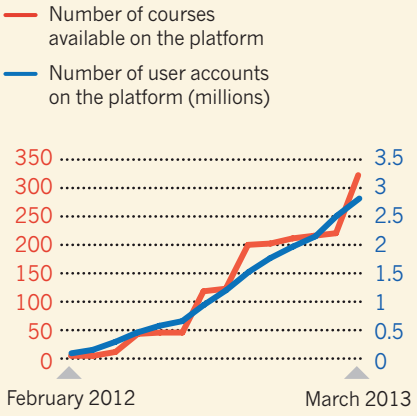
Other possibilities include profiting from in-course mentoring services, career counselling — and charging universities for licensing. In October 2012, for example, edX licensed a circuit-theory MOOC designed by Agarwal to San Jose State University in California, where it was used as the online component of a flipped classroom experience. In return for the licensing fee, "the professors can offer the course on campus, tweak the course however they please, get access to students' grades and online activity, and all the analytics a teacher would want to see", says Agarwal. In this particular experiment, he adds, the San Jose course's usual 40% failure rate fell to 9%.

Analytics are another example of the Silicon Valley style, potentially allowing the MOOC companies to do for education what Internet giants such as Google or Amazon have done for marketing. In Coursera's case, says Koller, the platform monitors the students' every mouse click — "quiz submissions, forum posts, when and where a student pauses a lecture video, or rewinds, or moves to 1.5 speed".

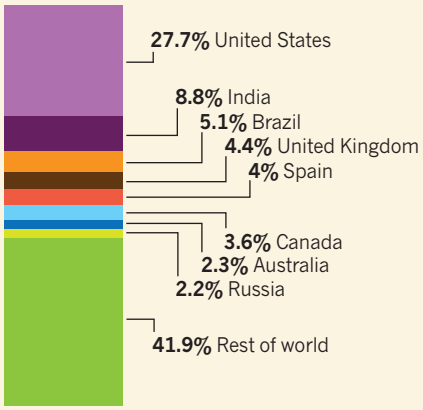
# MOOCs rising

Over little more than a year, Coursera in Mountain View, California — the largest of three companies developing and hosting massive open online courses (MOOCs) — has introduced 328 different courses from 62 universities in 17 countries (left). The platform's 2.9 million registered users come from more than 220 countries (centre). And courses span subjects as diverse as pre-calculus, equine nutrition and introductory jazz improvisation (right).

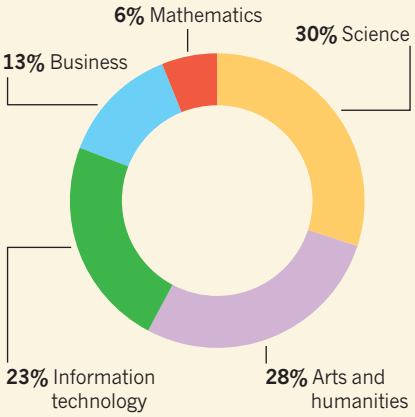
## Supply and demand




## Student origins




## Courses offered




The company is constantly using these data as feedback, says Koller, both for refining the platform's user interface and for improving the course content. If 90% of the students start stumbling over the review exercises for a certain lecture, for example, then maybe it is time to revise that lecture.

"But anything we do is just the tip of the iceberg," says Koller. When data from individual students are multiplied by tens or hundreds of thousands of students per course, they reach a scale big enough to launch a whole new field of learning informatics — "big-data science for education", Pea calls it.

Learning informatics could provide an unprecedented level of feedback for colleges and universities, says Stevens: "We haven't measured learning in higher education very often, very consistently or very well — ever." Academics have endlessly studied factors that are associated with university enrolment and success, such as race, parental income and school achievement. They have also studied what happens after graduation: the higher earnings and other benefits that college confers, on average, over a lifetime.

"What we don't know is how college performs this magic," says Stevens. "We certainly don't know the extent to which digitally mediated college experiences will deliver the same returns as a four-year residential experience." Now, however, he and his colleagues can begin to see what education science will look like as it merges with data analytics. Instead of looking at aggregate data about students on average, for example, researchers can finally — with appropriate permissions and privacy safeguards — follow individual students throughout their university careers, measuring exactly how specific experiences and interactions affect their learning. "It's thrilling," he says, "a huge intellectual frontier."

What remains to be seen is how higher education will change in response to the new technology. Maybe not much, says Dede. Yes, the major universities will extend their courses beyond their own campuses; the MOOCs have already shown them that they can do so with relatively little effort and potentially large profits. But the MOOC founders' other goal — fundamental reform in on-campus teaching — is a much tougher proposition.

"Universities think of themselves as being in the university business, not the learning business," explains Dede. That is, they mostly take their existing structures and practices as given, and look to MOOCs and other online technologies as a way to do things more cheaply. But experience with earlier innovations such as personal computing shows the limits of that approach, he says: real gains in the productivity and effectiveness of learning will not come until universities radically reshape those structures and practices to take full advantage of the technology.

No one knows exactly where that restructuring might end up. Lectures becoming a rarity, for example? Vast numbers of students getting their degrees entirely online? But the revolution has already begun, says Stevens. Major universities such as Stanford are taking the lead, "trying to integrate and embed digital learning into the fabric of the entire university" — and trying to master the new technology before it masters them.

Virtually everyone participating in this upheaval agrees on one thing. Colleges and universities will change — perhaps dramatically — but they will not disappear. "No one says that all education has to be online," says Thrun. "Sometimes, a classroom is better." Especially in communal endeavours such as science, "education is more than just knowledge", says Dede. "It's abilities like leadership and collaboration, and traits like tenacity", all of which are best learned face to face.

An unspoken irony weaves through almost every discussion about MOOCs: thanks to innovations such as flipping, online technology's most profound effect on education may be to make human interaction more important than ever. As Krakauer puts it, "what's absolutely clear is that the very large lecture hall can be completely replaced: there's no value added over watching it at home on an iPad screen with a cup of tea. But there is also no substitute for a conversation." ■

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