In recent years, massive open online courses (MOOCs) have been a matter of public discussion in Europe, much as they are in the US. I had kept myself at a safe distance from the debate until about a year ago, when École normale supérieure (ENS) asked me to participate in a pilot project to set up and teach a masters-level MOOC in statistical/computational physics. The ENS project also included a course on French philosophy (www.coursera.org/course/philofrancaise) and Galois theory (www.coursera.org/course/introgalois), a branch of mathematics. A recording studio was to be installed on our campus in the Latin Quarter, with videos recorded, cut, and edited by professionals. Courses would be hosted on the Coursera platform (www.coursera.org), and I could recruit additional teachers and student assistants. All this effort was quite engaging.

I first checked that my colleagues with whom I had taught a successful course in our English-language physics master’s program (www.phys.ens.fr/spip.php?rubrique284&lang=en) were interested in adapting the course to the Internet. I then signed up, not expecting what was going to happen: our 10-week MOOC, “Statistical Mechanics: Algorithms and Computations,” attracted 30,000 registered students, 256,000 video downloads, and 120,000 visits to its forum (www.coursera.org/course/smac). When it was all over, we were overwhelmed with an enthusiastic international and transcultural class of students that neither we nor our university had chosen. We had gone to the center of core subjects in science, including the nature of phase transitions, the physics of liquids, random processes, path integrals, and Bose-Einstein condensation, discussing many deep connections between physics and computing.

By the time it was over, we had presented and prepared for download about 250 programs (in Python) and initiated a great amount of practical computing, program writing, and program rewriting in the nine homework sessions. When we were done, we could finally take our eyes off the forum that for three months had been a buzzing platform of heated discussions and mutual help. We had motivated students toward a common goal, but we had also been boosted by their enthusiasm. When the course was over, we hadn’t suffered from the absence of a live audience during lectures, although we find it rewarding to talk with former students when they occasionally stop us on the street in Paris, New York, or elsewhere at conferences and seminars.

Students worked hard, although not for university credit. They handed in 6,300 homework solutions and corrected about 20,000 of them through the peer-correction system, which worked amazingly well. They authored 5,200 posts on the forum. After the course, 5 percent of the students who had followed the course diligently indicated that they would use what they had learned on a daily basis, 23 percent said several times per month, and 50 percent said a few times a year. At the end of the course, they were as exhausted as we were. A student from the Netherlands indicated that “it was a very challenging experience that totally absorbed me for almost three months… the coolest thing I ever did….” From Norway, our own feelings were mirrored: “Now, the course is over, I look up from my PC—the wife and child are still there….” Countless posts and comments reflected on the experience, the material, and the medium in which it had taken place.

It’s difficult to foresee to what degree MOOCs will permeate core-level academic training. I’m even unable to tell whether the second edition of our course, scheduled for early 2015, will recreate this year’s ambiance, and transmit knowledge or foster communication and exchange as efficiently. The present text can’t provide a blueprint for online teaching, but it might enrich the ongoing discussion about MOOCs from the vantage point of a long-time teacher and recent home-comer from the MOOC battlefield.

**Teasers, Green Screens, Mother of Studies**

Our MOOC project came to life four months before the launch date. It was time to do the promotional video, the
only live item to be rendered visible without registration. Writing this three-minute “teaser” took one hour. Recording it brought us into contact with the camera and editing team from ENS and from FEMIS, the Paris school of cinema. The video professionals guided us toward the green screen technology that dissociates the recording of the “actor” from the creation of the scene: during takes, the otherwise empty scene was bathed in intense green light that reflected from the background and was then eliminated (see Figure 1). Text, equations, images, and animations were then incorporated by the editor. From the start, we were comfortable with the fact that our pedagogical project was to be realized by videos that used a genuine video technology (green screen), rather than by the mere videotaping of a classroom course using classroom tools (such as a blackboard and PowerPoint).

MOOCs differ from classroom teaching not only because the medium is different but more because of a difference in viewing modes and therefore the relation to time. Students routinely accelerate or slow down the video player (at constant audio pitch); they stop and may even quit. Videos aren’t viewed in linear time, and difficult sequences are replayed over and over again. The power to repeat is now in the hands of the individual student, and it suits individual needs. This power gives new meaning to the eternal truth that “repetition is the mother of studies” and implies that the teachings must be less redundant than before. Our usual kickoff classroom meeting melted down into the three-minute teaser, and our 90-minute live classes turned into half-hour videos, without any loss of content. In the shorter, less repetitive videos, even slight imprecisions (such as omitted words and half sentences) would create terrible confusion, further amplified by the multiple viewings. To avoid this confusion in our MOOC, the material was carefully scripted, and all shootings were controlled by a fellow teacher. This workflow was initiated with the teaser and was kept during the entire course.

In their responses, 30 percent of the students participating in the final survey indicated that the single item that they liked best during the course was the quality of the videos. Many messages on the forum and in the survey made us think that our choices worked well.

Large Numbers, City Marathons

Registration was free of charge, and there was no academic prerequisite—after all, one of the “O’s in “MOOC” stands for “open.” Three days after posting our teaser on the Coursera website, 667 students had enrolled. One month later, there were 5,000, and this number was still far from the final count. We came to understand that our MOOC was to be massive, but sensed that even with thousands of students, we should continue to draw on all the advanced mathematical tools of our classes at ENS and aim for the same deep physical insights. We thus confirmed that, even with a big crowd, we would engage in core-level (rather than introductory) academic teaching.

Facing massive registrations, we thus arrived at the same conclusion as the organizers of large-scale sports events. City marathons, for example, have become extremely popular, but they still run over 42.195 km (see Figure 2). Like our MOOC, they appeal to a large and quite ambitious public with different backgrounds and a great span of personal goals and performance levels.

The large number brings many new opportunities, beyond the fact that it simply means more people. A larger forum is usually richer, especially with a modern voting mechanism that allows the best posts to rise to the top. In fact, MOOC teaching needs a large audience to “take off,” and certainly more than what a regular classroom and the graduate school of a single university can offer. Their massive nature is an opportunity but also a survival condition to sustain necessary liveliness in teaching. The sheer size carries its own dangers. Catastrophic failure—for example, the inability to go through with a course—is a real threat. However it happened in other MOOCs, it was widely publicized and discussed.

Among the students participating in the final survey, 20 percent had completed a bachelor’s degree (or similar), 40 percent had completed a master’s degree, and 30 percent a doctorate, with 90 percent obtaining their degree in a scientific discipline. The multiplicity of personal goals was clearly expressed on the forum. One student had struggled with homework 5, the first one on quantum mechanics. When he was done, long after the submission deadline, he opened a thread, “Yay! HW5 finished,” which drew a half-dozen comments such as, “Congratulations on completing HW5!”

Several French post-high school (prep-school) professors participated in the course to gain inspiration for scientific Python programming projects in their own classes.

Going Live, Classes

On 3 February 2014, the first week of our course went online. A lecture, a tutorial, and a homework session

92 March/April 2015
introduced Markov chains and Monte Carlo methods. Week two was about the emergence of statistical mechanics from classical mechanics. In later weeks, we discussed phase transitions and virial expansions, and derived the Maxwell and Boltzmann distributions, among many other subjects. Students stayed tuned when we turned our attention to quantum physics: density matrices, path integrals, and Bose-Einstein condensation, before returning to magnetism, optimization methods and Lévy distributions. Each subject was illustrated by short Python programs that students could download, run, and modify. Every week, we opened subforums corresponding to the current themes. Contributions to these subforums took off shortly after the video upload and abated when the corresponding homework assignment had passed its due date.

Subjects such as the above are usually too difficult to be learned from books or from videos alone. Rather, they’re mastered by attending a class, abstractly defined as a group of students that meets regularly during a given time period for instruction on a given subject (alumni status is also often included in the definition). Classes take place at universities, seminars, conservatories, and so on; this organization into classes made them survive the Gutenberg media revolution in the 15th century, when knowledge became available in printed books. Classes are also the essence of present-day MOOCs. Students must register (this defines the group), and the classes have starting and end dates. Regularity is provided through weekly organization. Students meet on the forum and, in our case, during the mutual correction of homework. The prime originality of MOOCs, compared to other forms of distance learning, is the consistent organization of classes with these characteristics.

From the start, students embraced the idea of our MOOC being a class rather than an illustrated and animated textbook. On the first day, a student spontaneously created a thread named, “Please allow me to introduce myself….” Its first post, from Norway, drew 69 answers from fellow students in Canada, the US, Brazil, Serbia, Macedonia, Sweden, India, Saudi Arabia, Spain, Argentina, Greece, and other countries. Student-created threads could address questions about Python installation on different platforms, as well as specific issues with threads such as, “lecture 5: 11.14 sec” or “tutorial 8 @ 8:00 characteristic peak….” Initial posts triggered animated discussions on subjects ranging from computer issues to Python programming to quantum mechanical wave functions for students who had often never studied the subject. About 150 posts on the forum (2.5 percent of the total) were written by the teachers; many of those posts brought an end to the discussion.

There were also many more general threads. One was entitled, “My notes on the course,” and made accessible the student’s full notes from the 10 weeks, nicely written in LaTeX and fully illustrated. It drew 50 “likes” and comments such as, “Thanks Tony! Excellent! Top Class notes indeed!!!” A 15-minute YouTube clip that a student spontaneously created and then announced on the forum went over a particularly intricate six-line algorithm in tutorial 3 (www.youtube.com/watch?v=6HWQaGwBbC4). It was greeted with, “Dennis, you are a hero.” Clearly, our MOOC functioned like a class.

Homework, Goals, and Grades
In all but the final week of the course, a homework assignment enhanced the lecture and the tutorial. The assignments were progressive, and the required programming skills increased from week to week. After the release (typically a four-page text), students had two weeks to hand in their solutions. Immediately after the submission deadline, a master solution was communicated to students who had contributed work, and detailed instructions for grading were given. Students then anonymously corrected three (or more) homework solutions of other students. The entire process was handled on the Coursera website, and it worked flawlessly. Conceiving the assignments and writing the master solutions required great concentration. The grade was computed from the points obtained in the homework assignments (50 percent) and from a final two-hour multiple-choice exam (50 percent). The overall requirements of our course were very high, and it was difficult to make the cut to receive a certificate. The certificate, which wasn’t endorsed by ENS, did not provide real university credits. However, reaching the certificate level constituted an undeniable academic achievement. More than 2,000
students stayed with the course until the end, and 350 students earned the certificate. These 350 students participated in the final survey.

To understand the massive student participation in a course that offered no degree and few certificates, it's appropriate to analyze students' motivation. In education research, motivation is understood along two categories. The learning goal applies when students pursue educational programs (such as lectures and courses) primarily to increase their competence. In this category, new challenges are readily accepted, and failure is easily handled. As emphasized in seminal psychological research, the focus of individuals who pursue learning goals (whether they believe their ability to be high or low) is on improving ability over time, not on proving current ability. As noted, obstacles will not as readily be seen to imply goal failure and will, therefore, not require defensive maneuvers, not as readily generate anxiety, and not detract from the intrinsic rewards shown to derive from involvement and progress on a valued task.” Clearly, our MOOC was firmly planted on the learning goal.

In the performance goal, great value is attached to doing better (in grades) than others. The performance goal is a standard setting in higher education. It requires a homogeneous class from which there’s a high social price for dropping out and great recognition for performing well. However, the social implications of the performance goal can lead weaker students to shy away from challenges, and even the stronger students can be led to avoid risk. Binge studying, self-handicapping, and cheating have been associated with the performance goal.

In the final survey, 98 percent of students who had obtained the certificate indicated that the absence of a real degree posed no problem to them. Students thus confirmed the learning goal motivation. It made them adventurous and contributed to the excellent atmosphere during the class. Although students concentrated on learning, they did voice their frustrations with the built-in imperfections of the peer-correction systems. Students were also quite critical of the few delays that occurred in the uploads of lectures and homework assignments. Notwithstanding their learning goals and their great attitude, they perceived themselves as participating in a class, and they expected the regularity that's part of its definition.

Party in Pink, Violence of Learning

The course ended, in the final tutorial, with an online party and with champagne from a pink bottle (because of the green screen, see Figure 3). Our high-intensity project had been a fierce battle. With thousands of students watching (and staying), we had been in a 10-week euphoria. But with hundreds of students reacting week after week, scrutinizing every sequence of the videos and struggling through each sentence of the homework assignments, we were constantly on alert. Most of the material was created, in anxious euphoria, while the course was running. Lacking experience, we needed the feedback from week \( n \) to prepare weeks \( n + 1 \) and \( n + 2 \). Fortunately, all the science had been cleared up well ahead of the launch date and, following expert advice, we included no last-minute scientific results. Our course was a stand-alone project. We didn’t try to integrate it into the regular program at ENS, which would have
implied breaking it up into different tracks, with proctored exams and staff-graded homework for the local students. The split into different tracks might have broken the spell of the course and destroyed its lighter-than-air atmosphere. Courses such as ours don’t necessarily appeal to all students of physics, but it would be easy to set up additional exams, outside of the MOOC, to meet requirements for university credits at ENS or elsewhere.

It’s evident that lecturing (in MOOCs or in the classroom) is only one part of our teaching activity, which encompasses lab sessions, practicals, and small research projects. Teaching also extends to tutoring—the essential one-to-one relation between a professor and a student—that MOOCs will never supply. In evaluating MOOCs’ possible impact, we must take into account that learning is a complicated, multifaceted process that consists of the student’s violent confrontation with the outside world. Even decades after our student days, we all retain vivid, indelible memories of only a handful of very special courses spread out over our years of study. Those courses were the ones that shaped us into what we have become. Time will tell whether the new medium of MOOCs is strong enough to leave this kind of imprint on students, and whether tomorrow’s professionals will have received formative influence from courses delivered over the Internet. The answer to this question isn’t clear to me, but our first attempt to find out was sufficiently encouraging to try again, with the second edition of Statistical Mechanics: Algorithms and Computations.

Acknowledgments
Alberto Rosso, Michael Köpf, and Vivien Lecomte taught in the tutorials and participated very actively in all stages of our MOOC. Tommaso Comparin provided final versions of Python programs and produced the English subtitles. Maxim Berman produced the computer animations inside the videos. Emilie Noblet directed the studio. Baptiste Ribault was the editor. Additional camera was done by Nordine Meziane and by Frédéric Borja. Yves Laszlo was in charge of the ENS MOOC program. My deep gratitude goes to all of them.

References

Werner Krauth is director of the physics department at École normale supérieure. Contact him at werner.krauth@ens.fr.