Teaching a Chemistry MOOC with a Virtual Laboratory: Lessons Learned from an Introductory Physical Chemistry Course

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ABSTRACT: An analysis is presented of the experience and lessons learned of running a MOOC in introductory physical chemistry. The course was unique in allowing students to conduct experimental measurements using a virtual laboratory constructed using video and simulations. A breakdown of the student background and motivation for taking the course is presented, and the student feedback on the course is also provided. It is concluded that even practical based chemistry courses can be successfully delivered online and such courses have the potential to provide a valuable addition to campus based chemistry teaching at university level.

KEYWORDS: First-Year Undergraduate/General, Distance Learning/Self Instruction, Computer-Based Learning, Physical Chemistry, Continuing Education, Internet/Web-Based Learning

INTRODUCTION

Massive Open Online Courses (MOOCs) are Internet-based teaching courses designed to handle thousands of students simultaneously. Typically, content presentation is delivered using short video presentations. Much of the learning comes from quiz completion, online comments, questions and discussions. In some MOOCs, participants can even mark another’s tests. The general hype around MOOCs, which peaked in 2012, is now subsiding and more realistic futures for them are now being promulgated. There is an enormous body of literature around the role of MOOCs in current and future education and a good up to date summary can be found in review.1 The ability of MOOCs to change the emphasis of campus-based education will likely be their most lasting legacy.2 While many distance/online learning courses have been offered since the development of the Internet, these have generally been regarded as inferior to campus-based higher education and were largely shunned by world-leading university brand names.3 The substantial entry into the MOOC market of world renowned higher education institutions like Harvard, Stanford, and Yale, often as the leaders in the area, has in essence legitimized the online/distance form of education, and many are now looking to the techniques used in MOOCs to enhance and indeed transform on-campus delivery. An excellent example of this is the predicted demise of the traditional on-campus lecture as means of delivering information. Many now believe lectures will be replaced by shorter, more-focused video delivery of information employed by MOOCs.4 This will allow a more personalized campus-based interaction between student and teacher that is dominated by seminar and tutorial style teaching, as opposed to information delivery via traditional lectures as occurs at present.

In the specific field of chemical education, MOOCs are relatively rare compared with other scientific disciplines such as computing. An extensive review of chemistry MOOCs available has recently been published outlining most chemistry related MOOCs available at the end of 2013.5 Since then, a few more chemistry related MOOCs, including the one described here, have become available and new platform providers have appeared. A good source of information on all chemistry or science MOOCs, plus availability and rating, is the ClassCentral Web site6 which gives information on all MOOCs offered on the vast majority of popular platforms. Most of the current chemistry MOOCs are in the general or organic chemistry area, but one specialist physical chemistry course on Statistical Molecular Thermodynamics from the Department of Chemistry at the University of Minnesota is available on the Coursera platform.7 The MOOC described in this article is the only one in the introductory physical chemistry area covering thermodynamics, kinetics, and quantum mechanics. An obvious difficulty in delivering chemical education online is the absence of laboratory experimentation which leads to an incomplete feeling to most online chemistry courses. Some of the chemistry MOOCs try to alleviate this by including video clips of experiments to illustrate concepts. In the Introduction to Physical Chemistry MOOC described here, we have created a virtual laboratory using combined video and simulation which allows students taking the MOOC to directly participate in experiments themselves, conduct the relevant measurements online, and submit results for assessment, bringing the student participation ever closer to the on-campus experience.
As part of The University of Manchester’s distance learning strategy, it was decided to invest in the production of five high-quality Massive Open Online Courses (MOOCs) in partnership with leading MOOC platform provider Coursera. The aim was to enable the university to showcase and share the education the university offers to students from all over the world and also to explore novel pedagogical approaches to online learning. The “Introduction to Physical Chemistry” MOOC was selected by the university as one of its five initial offerings to explore the feasibility of delivering laboratory-based subjects such as chemistry on an online platform. The course design aimed to be pioneering in its use of innovative pedagogy. This included not only the provision of a virtual laboratory for students to conduct experiments and be assessed, but also short focused video screencast lectures interspersed with short quizzes for immediate formative feedback. Interactive clicker-type questions were also uniquely adapted to allow a worldwide audience to test their knowledge against the on-campus Manchester students.

Even though the course requirements stated that a good general chemistry plus calculus knowledge was desirable, a wide range of Massive Open Online Courses (MOOCs) in general, but from quite different backgrounds enrolled on the course as shown in Figure 1A. Whereas most classified themselves as taking the course out of pure curiosity or as a hobby. In Figure 1B, we show the educational background of the students enrolled. Again the diverse range of students is illustrated. The introductory description of the course stipulated clearly that a good knowledge of general chemistry plus a familiarity with calculus such as differentiation and integration was desirable to complete the course. Twenty-nine percent of the students who responded had been educated up to second level, whereas most surprising was a 3% cohort with only a primary education!

Because of the differing backgrounds of the students enrolled, the engagement with the material was expected to be quite diverse ranging from browsing just some of the video content to full interaction via the discussion forums and the completion of all assessments and achievement of a statement of accomplishment.

Students were surveyed as to their intentions with respect to engagement with the material and the results are illustrated in Figure 2. Much has been written about the low completion rates for MOOCs in general. However, some of these arguments misconstrue the motivation for many students enrolling on a MOOC. Video viewing was most popular with 98% of those surveyed indicating this preference. Participation in the quizzes was also popular at 96%. Only 40% of those surveyed indicated a desire to participate in the discussions and...
just over 60% wished to progress to a statement of accomplishment.

■ CONTENT

The course covered the principal topics taught in a typical first-year U.K. undergraduate physical chemistry course including thermodynamics (Box 1), chemical kinetics (Box 2), and quantum chemistry (Box 3). The course syllabus was as briefly shown in Boxes 1–3.

Box 1. Thermodynamics Topics Explored

- Thermodynamic definitions
- The zeroth law of thermodynamics and temperature
- The first law of thermodynamics and enthalpy
- The second law of thermodynamics and entropy
- The third law of thermodynamics and absolute entropy
- Heat capacity
- Reversible change
- Hess’s law
- Gibbs energy and spontaneous change

Box 2. Chemical Kinetics Topics Explored

- Reaction rate
- Effect of stoichiometry
- Order of reaction
- Half-life
- Determining reaction order
- Molecularity
- The Arrhenius equation
- Collision theory
- Transition state theory
- Complex reactions
- Rate-determining step
- Steady state approximation
- Catalysis

The entire content was navigable via the Coursera platform front end, and an example content page is shown in Figure 3.

Box 3. Quantum Chemistry Topics Explored

- Planck’s constant
- The photoelectric effect
- de Broglie’s particle waves
- Heisenberg’s uncertainty principle
- Schrödinger’s wave equation
- The free particle
- The particle in a box and application to linear polyenes
- Hydrogenic atoms
- Born’s interpretation of the wave function
- Interpretation of radial and angular wave functions for hydrogenic atoms

All of the content of the course was made available to the students from the beginning of the course. This gave the flexibility to students to progress through the material at their own pace. The only stipulation was that for those wishing to achieve a statement of accomplishment, the summative assessment quizzes had to be completed by stipulated deadlines.

DELIVERY

Our campus-based first year module on physical chemistry was selected as suitable for adaptation to an online delivery format. The course is traditionally taught on-campus using two weekly 1 h lectures and is accompanied by a laboratory class each week. Chemistry is by its nature a practical subject and it is the practical aspect that often is attractive and stimulates interest in students. It was therefore believed to be important to include a virtual simulated laboratory which allowed students to complete their own experimental measurements and also include assessment. The formal lecture content was delivered using short (10–20 min) video screencasts. These were interspersed with online quizzes allowing the student to assess their comprehension of the material as they viewed the content. Much of the delivery was done using real time annotation of slides on a tablet computer adopting an approach similar to the Khan Academy videos and illustrated in Figure 4.

This form of presentation was chosen as it has been proven to enhance learner concentration in online delivery. In addition,
footage of interactive clicker sessions with campus-based students was adapted so that the MOOC students could directly participate and allow them to compare their performance relative to the campus-based students. The virtual laboratory experiments comprised an initial video segment filmed in the laboratory followed by a simulated experiment allowing the student to fully participate in the practical. The virtual laboratory was designed in collaboration with the faculty eLearning team who were in charge of producing the videos and the simulations. Examples of simulated experiments include a virtual calorimeter for heat of reaction measurements (Figure 5), a gas buret experiment to measure kinetics of hydrogen peroxide decomposition (Figure 6), and a visible absorption spectrophotometer for measuring the visible spectrum of hydrogen atoms (Figure 7).

Students were enabled to interact with the simulated equipment allowing them to take their own measurements and submit results for assessment purposes. Virtual laboratories distinct from course offerings are an emerging trend such as Phet, Vlabs, and OpenScienceLaboratory. These may provide an alternative for course designers who wish to include virtual laboratories without undertaking the development costs of bespoke simulations. The first version of the six-week course was delivered on the Coursera platform, starting on June 2, 2014. Direct support of student learning was mainly via the discussion forums. Six teaching assistants including the three presenters continuously monitored the discussion forums and provided guidance and advice when required. Both formative and summative assessment was conducted via online quizzes.

### OUTCOMES

The course was groundbreaking in a number of ways; it was the only chemistry subject MOOC course delivered in the U.K. to an undergraduate audience and is at the present time the only physical chemistry distance learning course in the world using a virtual laboratory. While there are some general
chemistry subject MOOCs delivered internationally, none contain a virtual laboratory. The scope and breadth of this undertaking can be gauged from the enrolment of 15,169 people from 164 countries around the world providing an unparalleled exposure of U.K. chemical education to a worldwide audience and also an opportunity to experience teaching online to a worldwide audience. Engagement of the students with the course is shown in Table 1.

The most popular activity was watching the video lectures. A total of 198,005 video-lecture views were recorded during the course.

Table 1. Number of Students Engaging with Different Aspects of the MOOC

<table>
<thead>
<tr>
<th>Visited the course</th>
<th>Watched a lecture</th>
<th>Submitted an exercise</th>
<th>Browsed the forums</th>
<th>Obtained a statement of accomplishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,311</td>
<td>8,102</td>
<td>1,766</td>
<td>2,794</td>
<td>468</td>
</tr>
</tbody>
</table>

The Hydrogen Emission Spectrum

Figure 6. Screenshot of gas buret experiment used to measure the decomposition of hydrogen peroxide to water and dioxygen molecules by monitoring the production of dioxygen gas. Students can use the manometer to monitor the pressure increase as a function of time using the clock in the bottom left-hand corner.

Figure 7. Hydrogen emission spectrometer simulation illustrating red line in hydrogen visible spectrum. Students can use the slider control to scan through the visible spectral region and observe the hydrogen line spectrum.
210 course. As found in the precourse survey of student intentions, 211 most of the participants did not take the MOOC with a view to 212 obtaining a statement of accomplishment. The MOOC 213 audience is quite distinct and heterogeneous from the more 214 homogeneous on-campus student body. Participants differ in 215 nationality, age, and academic backgrounds. Even a highly 216 academic topic like physical chemistry attracts participants 217 whose motivation is primarily in learning or refreshing their 218 knowledge of a topic they find interesting.

219 Student feedback via the discussion forums and post course 220 survey has been very positive with 94% of 455 respondents rating 221 the course as either excellent or good. Students were also asked 222 to comment on what they enjoyed most about the course and a 223 word-cloud of the comments received is shown in Figure 8.

■ CONCLUSIONS

224 Due to the positive student feedback of the initial offering, other 225 sessions for the course are planned in future years. Reacting to the 226 feedback received on the first version, the virtual laboratory will be 227 extended in future versions with more experiments available. 228 There are also plans to have an “on-demand” version of the course 229 available on the Coursera platform in late 2015. Parts of the course 230 will also be made available to our on-campus students to facilitate 231 a more blended learning approach to our teaching. Due to the very 232 positive feedback received on the virtual laboratory section, we 233 would encourage future teachers of chemistry MOOCs to 234 incorporate similar interactive activities for the students.

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Notes

The authors declare no competing financial interest.

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Figure 8. Word-cloud of student free text comments in answer to question about what they liked about the course.