International STEM Classrooms: The Experiences of Students Around the World Using Physical Remote Laboratory Kits

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International STEM Classrooms: The Experiences of Students around the World Using At-Home Laboratory Kits

1. Introduction and rationale

Massive Open Online Courses (MOOCs) have been promoted as vehicles for increasing students' access to interactive, high quality tertiary level coursework. However, virtual classrooms' lack of hands-on learning opportunities has been a major criticism leveled at MOOCs, especially in engineering and science disciplines[1]. One potential solution is to include remote laboratory experiences as part of the MOOC for diffuse global learners[2]. Still, little is known about the experiences and behaviors of students who engage with at-home lab kits in conjunction with online courses, especially in the worldwide MOOC context.

This paper begins to address the need to understand the ways in which diverse learners interact with and experience a novel online course while simultaneously using lab kits at a distance. We use detailed information from a pilot trial in which students assigned to the treatment group were provided with do-it-yourself (DIY) kits they could use at home alongside a neuroscience MOOC.

2. Research questions

In order to better understand the experiences of students who were sent at-home laboratory kits to use alongside this MOOC, we ask four primary research questions:

1. How can we characterize the ways in which students around the world use online resources with the at-home lab kits? What online behaviors can we identify for the students in the treatment group when they are likely to be using the kits at home? For example, how much time do they spend online watching lab videos that demonstrate kit experiments?

2. How is their use of the kits reflected in their online individual and collaborative behaviors? What patterns of behaviors (e.g., regularity of accessing videos related to the kits) can be discerned? Do sample students post in collaborative spaces like the discussion forum?

3. How do their usage behaviors and patterns relate to their performance in the course? Are the patterns of behaviors (RQ2) strongly correlated with students' grades in the course?

4. Are their usage patterns or behaviors mediated by their national setting? Are there significant differences in student behaviors or performance by country from which the students are accessing the MOOC?

3. Background and previous studies

Theoretical framework

Engaging students with learning materials at the cognitive, affective, and social levels has been shown to be an effective teaching and learning strategy for undergraduates in STEM fields [3]. We examine "active learning" in this study by applying Chi's ICAP framework[4,5]. This framework makes a hierarchical distinction between levels of "active learning": 1) <u>**P**assive consumption </u>of information as a baseline, 2) <u>**A**ctive learning</u>, which involves manipulating instructional materials or content (e.g., pausing and playing a video) and therefore demands focused attention (e.g., recording pause/play click behavior or recording eye-tracking in videos), 3) <u>**C**onstructive learning </u>activities, which require users to generate content (e.g., writing on a blog, responding to

an appropriately-vague hint), thereby requiring knowledge construction, and 4) <u>I</u>nteractive <u>learning</u> activities, which support students' peer-to-peer co-construction of knowledge.

In this study and our other investigations of MCB80x, we hypothesize that student behaviors that we observe may be classified into all four levels of this framework. Further, we hypothesize that those behaviors that can be classified into higher levels of the ICAP framework will be related to higher achievement, which has been demonstrated in face-to-face engineering classrooms [6]. We complement our broad use of the ICAP framework with other empirical work that suggests that physical interaction with manipulatives results in higher levels of cognitive engagement and higher performance on conceptual tests[7].

Remote and virtual laboratories: affordances and challenges

Blended learning broadly refers to the integration of face-to-face learning and online learning experiences [8–10]. Studies of "embodied cognition"[7] suggest that there is a hypothetical benefit to interacting with a physical demonstration component. In our work, we study at-home lab kits as this type of complement to open online courses.

Experiments as a teaching and learning activity are among the most effective types of inquiry-based learning[11,12]. Numerous critiques have pointed out that the benefits afforded by residential laboratory experiences are costly and difficult to replicate in an online environment[13], MOOC providers have found creative alternatives. These include both virtual laboratories and remote labs. Virtual laboratories utilize 3-D graphics, student-selected parameters, and simulations to demonstrate estimated laboratory outcomes without the physical equipment[14]. Remote laboratories are seen as a third option to traditional on-campus physical labs and simulations[15]. What comprises "remote labs" may include a broad set of lab structures, including home equipment, combinations of home equipment and remote sensing, and, most often, remotely manipulated or "remote controlled" inputs to real data collection mechanisms[13]. Jeschofnig further delineates *Computer simulations, Remotely-controlled experiments, Kitchen Chemistry, Instructor/Institution Lab kits, Commercial Lab Kits,* and *Hybrid* structures[16].

Remote laboratories: A blended learning experience

Many of the studies in engineering education focus on remotely-controlled experiments or distributed labs, which are perceived as offering greater flexibility[17] and similar effectiveness for learning outcomes[18]. Our study focuses on the category of distance or remote laboratory structures that include home kits or "lab at home" setups, which builds on the limited models and initial practical studies. Although a MOOC with an at-home kit may not be a typical blended learning course, the students who work on physical lab kits experience blended learning in the sense that they get to interact with an offline, hands-on component alongside online materials.

There are a number of key constructs of remote laboratories which matter for students in this context, e.g., complexity of the experiment, experimental interface (synchronous/asynchronous), and students' individual backgrounds[15]. Studies comparing the utility of physical and virtual laboratory manipulatives found the combination of both was related to enhanced conceptual understanding in science[19]. However, home kits provide less instructor oversight, and critics raise safety concerns[13,20]. Home kit studies are largely at an early viability stage[21–23], though these studies note increased student satisfaction and greater flexibility[24]. Provocative initial

results have found that the type of lab structure (remote, simulated, or hands-on) interacts with individual and collective lab group structures, and that "real" data is related to higher achievement than simulated data[25]. Studies of remote and virtual laboratories are concentrated in a few engineering fields (e.g., electrical engineering), while studies of at-home kits are largely in the physical/life sciences (e.g., chemistry). Our study of an at-home kit is one of the first to involve neuroscience and related electrical engineering topics.

4. Course context, data, and sampling

The course we study is MCB80x (identifying information removed), a MOOC offered from Harvard University with the edX platform. MCB80x videos were highly interactive and demonstrated a high production value, covering a number of core neuroscience topics and utilizing periodic interactive simulations and quizzes for students to make predictions and test their hypotheses. We utilize rich quantitative information from individual level survey responses. These data are complemented by pageview behavioral logs, which record every page on the website that students visit. Starting from the first lesson until the exam closed (10/31/2013 - 1/25/2014), sampled students made a total of 20,157 pageviews on the course website. This does not include the fine-grain interactions students make with the interactive videos, forums, etc.

This first course cohort included students from 143 different countries. Out of these, participants were solicited to take part in a randomized control trial (RCT), and 185 voluntary students were randomly selected and sent at-home lab kits that they could use to perform their own experiments on insects. This sub-sample of students came from 42 distinct countries, and, in the scope of this paper, we focus on the students who were sent the lab kits. Although it is typical in a MOOC that students' behaviors extend long after the exam period, we focus on data from the time lesson 1 was released to when the exam closed. For this course, three main categories of data were collected: 1) Student demographics, 2) Clickstream data, and 3) Final Exam results.

First, MOOCs often gather student demographic information, e.g., geographical location, previous education and/or work experience, and parental education. We utilize these data to answer our research questions by studying student behaviors or performance by country of access. In this paper, we focus on pageviews from the clickstream data, which comprise 8 different types of events: 1) DIY lab videos; 2) pageviews on lesson 1; 3) pageviews on lesson 2; 4) pageview on lesson 3; 5) pageview on lesson 4; 6) discussion forum visits; 7) survey visits; and 8) low priority navigational events ('Others'). Final exam results provide an outcome of interest for analyzing performance. Not all of the 185 students attempted the final exam. We have three categories of final exam results: 1) Students who have a grade over 60% are recorded as 'passed'; 2) Students who opened the exam but did not attempt or got everything wrong get a grade of 0; and, 3) Students who did not attempt the exam are grouped with Category 2.

5. Methods

We use standard descriptive and inferential statistics to describe and test the significance of relationships between key variables in our study. It should be noted that we have no way of absolutely confirming that students are using the home-kit. Our results use the proxy of observing their views of relevant at-home lab videos after having sent them the kits. Future work may include follow-up interviews and real-time support to address this limitation.

6. Results

Usage patterns

As with many studies of MOOC students[26], we see that usage levels in terms of page visits and time spent follow a highly non-normal skewed distribution, as shown in the density plot of students' time spent on DIY lab videos in Figure 1. Time spent was calculated using the timestamp of one activity subtracted by the timestamp of the previous activity. If this interval was smaller than 30 minutes, the time was counted as spent on the previous activity. Table 1 shows the total and median visits and time spent in minutes for all eight activity types.

Table 1: Types of resources, number of visits, and time spent

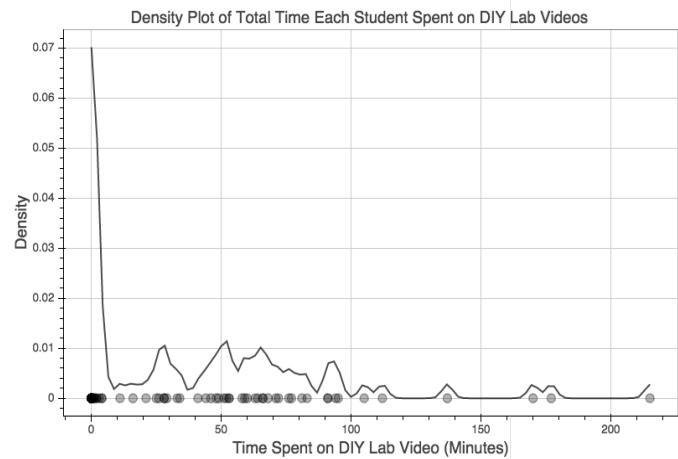| Types of Pageviews	Number of Visits		Time Spent (Minutes)	
	Count	Median	Count	Median
DIY Lab Videos	1016	8.5	2994	29.42
Lesson 1	4870	25	15955	90.72
Lesson 2	2034	17	6320	62.30
Lesson 3	1673	17.55	4904	58.05
Lesson 4	1408	18	4534	60.98
Discussion Forum	970	3	2599	9.03
Survey	340	1	1893	10.98
Others	7846	33	12286	52.37

Figure 1: density plot of students' time spent on DIY lab videos

Relationship between usage and achievement

The Spearman rank correlation (ρ) between views and grade is 0.71. We use Spearman rank correlation as it is less sensitive to outliers. If we only consider students who received a grade, ρ = 0.26. The correlation between grade and time spent on DIY lab videos is 0.62 (ρ = 0.26 for students who received a grade). Figure 2 (a,b) shows that students with a high volume of activity do not necessarily receive high grades. This is typical of MOOCs, as students might interact with resources to learn the content without observable concern for certification or grades.
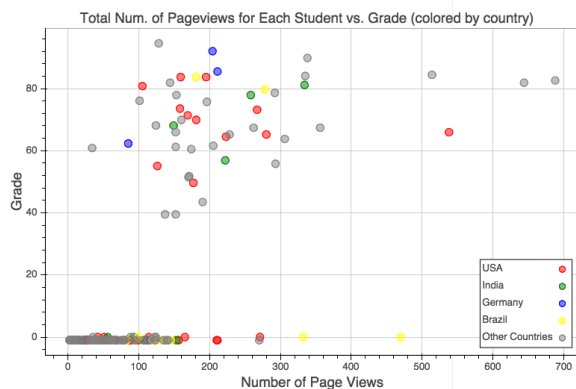

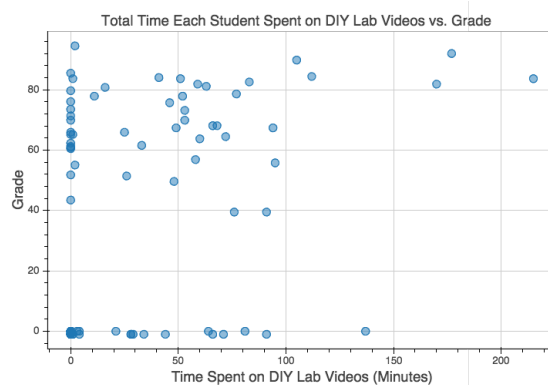Figure 2 (a): Correlation between number of views and grade

Figure 2 (b): Correlation between time on DIY videos and grade

DIY lab session

We identified a "DIY Lab Session" based on the intensity of students' access of the DIY lab videos. If the DIY lab activities happened close together (no more than 1 hour apart), we clustered them into one DIY lab session. After identifying a discrete session, we then studied other pageviews happening during, before, and after the session (+/-30 min.). The average number of DIY lab sessions is 4.4. This was calculated after eliminating students who do not ever access DIY lab videos. Within a DIY lab session, the average time that students spend on a different resource they have switched to is a little over 2 minutes. The average interval between any 2 lab sessions is 7 days. This long time interval between sessions is consistent with our observation that students usually have a very focused "study period" within 1-2 days on the course website and then will usually have breaks of approximately one week. This regularity might correspond with students' weekly routine. Students accessed lesson 3 and lesson 4 the most ("Action Potential" and "Action Potential Propagation"), which were most relevant to lab experiments. However, most of the students likely did not receive the lab kits until the time of lesson 3 and lesson 4.

Country-level Differences

Of the 185 students who received the home kits, 49 (26.48%) students attempted the final exam and received a grade, and 40 (21.62%) students received a passing grade. Figure 3 shows the country-wise participation of students, which reflects participation patterns in other MOOCs. We also highlight the number of students who attempted the final exam and the number who passed for countries with greater than 5 students.
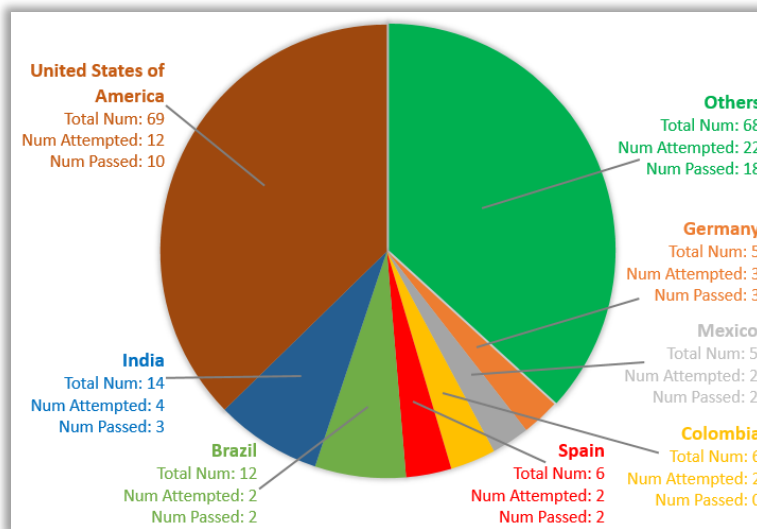
Figure 3: Country-wise participation of 185 DIY lab-kit students

We further categorized national contexts into English speaking countries and non-English speaking countries. More of the sampled students in non-English speaking countries received an exam grade than in English speaking countries (32 and 17, respectively). It is interesting to note that students in non-English speaking countries had significantly higher average pageviews than peers in English speaking countries ($p = 0.02$).

Individual student behaviors and their performance

We observe a wide variety of student behaviors, even in this small sample of select RCT treatment group students. Here, we select four illustrative students to show the behavioral diversity in this MOOC (Note: these plots do not include survey and other navigational events.) We visually separate types of activities for clarity using color and distance above the x-axis:

- Figure 4(a) shows the behavior of a student with a high volume of pageviews, who did not receive a grade; although this student is extensively interacting with the learning environment,

the student does not appear interested in activities required to receive a grade. This figure also shows a sub-section of student activity zoomed in to provide an example of this student's detailed interactions and the way the student switched between different activities.

- Figure 4(b) shows a student with a high volume of pageviews, with a low passing grade. Although the student is interacting with the learning platform, heavily participating in the discussion forum, and attempting the exam, the student did not achieve a high grade.

- Figure 4(c) shows a student with a low volume of pageviews, who received a high grade. This may mean that the student did not feel the need to interact with the learning environment in order to attempt the exam and may also imply that this student is already adept in neuroscience and only interested in review.

- Figure 4(d) is similar to the previous example but his/her score is the highest amongst the students sent the home kits. From the graph, we see that this student is not only reviewing concepts but also completing activities to receive a grade.
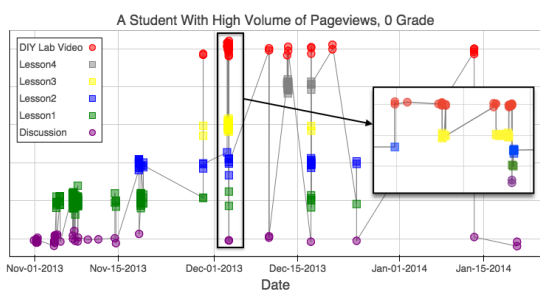
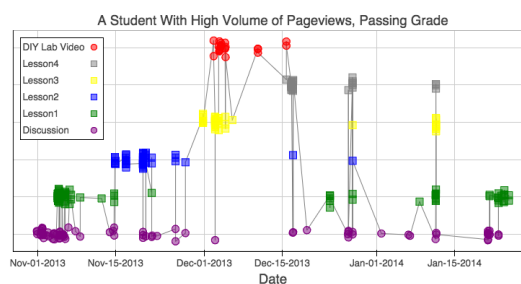Figure 4(a): Student with high pageviews and no grade

Figure 4(b): Student with high pageviews and passing grade
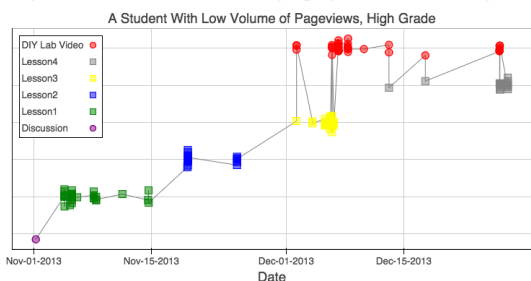
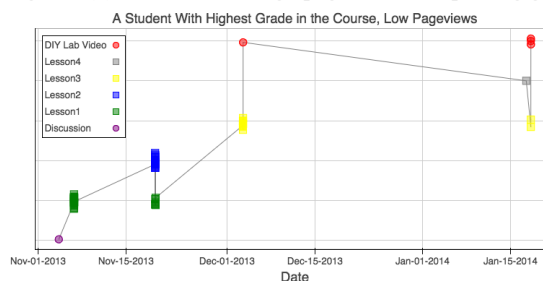Figure 4(c): Student with low pageviews and high grade

Figure 4(d): Student with the highest grade in the course

7. Findings, discussion, and future directions

Despite targeted provision of relevant learning materials, the highly constrained sample of students who were sent at-home lab kits still demonstrated a level of diversity in their behaviors and performance that reflects the findings of other MOOC studies[26]. Indeed, pageview behaviors had no predictive power for achievement; as with other open online courses, students appear to participate with varied intentions, some related to the grade and others less so. From Figure 4 (c, d), we see that these two students had very few page views but received high grades. This suggests that these students may have some prior knowledge or experience and therefore chose to engage with the assessments but not the learning materials. On the other hand, many highly active students did not receive high grades (Figure 4[a]). A very high proportion of the students who attempted the exam passed it. However, just over 25% of the treatment group students attempted the exam in the first place, regardless of their level of engagement. Future work may further investigate pre- and post-course survey information regarding students' goals/intentions

for the course in order to better understand these highly varied and sometimes counterintuitive behaviors and performance. In addition, we will interview selected students to gather deeper insights into student intentions, behaviors, and learning.

The regularity with which students viewed DIY lab videos was approximately every 7 days, which is less frequent and more regular than the sporadic course access patterns that have been observed in other MOOCs. This may suggest that using the at-home kits requires greater planning or energy than solely online activities. For example, students may need to plan their schedules around limited time they have at home with access to appropriate tools, or they might be spending time and effort to find specimens for use with the lab kits. While watching the DIY videos, our sample of students more frequently accessed related lessons (*Passive* or *Active*) than *Interactive* spaces such as the discussion forum (according to Chi[4]). This could suggest that treatment group students did not feel the need to interact with other MOOC students and/or the instructional team and instead chose to focus on the course material combined with the lab kits.

Although there were no significant differences in performance between students by national language, we found differences in terms of behaviors. Students from non-English speaking countries had significantly more pageviews than their counterparts from English speaking countries. This may suggest that they were viewing the video content repeatedly in order to understand it. Further work utilizing background survey information on students' language proficiency, detailed investigation of their video-watching behavior (e.g., pause/play and video speed metrics), and follow-up interviews may help us to test this hypothesis. In future work, we attempt to understand in more detail such patterns of behaviors of kit users, to reconcile the unique behaviors of at-home kit users with what we know about general MOOC users. There is also a need to further investigate the differences in behaviors and performance between students who did and did not receive kits. This may provide additional insights into the benefits of adding at-home kits to MOOC experiences to provide blended learning experience to global students.

8. Conclusions and implications

As described above, a major limitation to our study is that we could not record real-time off-line usage of the home lab kits. Once the kits were mailed, it was ambiguous when students received their kits in the mail and when they were actually in use. Future work should include direct student follow-up to more precisely measure offline kit behaviors. Based on the online patterns we observed, instructors should also provide greater connection between kit activities and interactive and collaborative online activities like the discussion forum. Although the discipline of the course studied here is neuroscience, there are key implications for engineering classes. The experiments in this course ask students to apply not only biological but also electrical engineering concepts (e.g., measuring electrical potential across a neuron). Engineering MOOCs have struggled to incorporate hands-on experiences, and those that do might only use virtual simulations. We hope that the ongoing experience of this course and our future work will inform the structural and pedagogical design of open, global courses for engineering.

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