Introduction

The MOOC movement has grown in a short duration.\textsuperscript{1,2,3} The MOOC movement has arisen to provide access to high quality education to the remote corners of the Unites States and the world. The early pronouncements regarding MOOCs have given rise to expectations that MOOCs will have a major impact on the educational world.\textsuperscript{4,5} However, much is needed to improve the pedagogical effectiveness of the MOOC offerings. Adaptive learning systems that customize content to the needs of individual learners have potential to provide personalized learning experiences to the large number of learners who intend to take the MOOC courses. Adaptive learning systems can provide the interface necessary for individual customization of content delivery on a massive scale, allowing each learner to reach the necessary competency.\textsuperscript{6,7}

Adaptive learning requires development of differentiated learning strategies and intelligent feedback for building learner competency. The adaptive mobile learning (AMOL) system described herein presents content in five distinct learning strategies. Differentiated learning strategies and dynamic rendering of the content are provided, building competency for each individual learner.\textsuperscript{1} The pedagogical framework that supports dynamic rendering requires appropriate computational and web services architecture that can accommodate delivery of web pages within an acceptable response time and requires substantial throughput.\textsuperscript{8,9}

Some MOOC courses deployed for worldwide audiences are expected to serve large numbers of concurrent users, in some cases more than 50,000 to 150,000 users. The problem becomes intractable for conventionally hosted adaptive learning systems. In this article we discuss a scalable cloud architecture that marries Amazon Web Services (AWS)\textsuperscript{9} with AMOL adaptive learning architecture to support the dynamic rendering of web pages leveraging service-oriented architecture of the AWS servers. The data indicate that even with large loads and stress applied to the system under load-testing conditions the throughput and response time remains within acceptable limits for the adaptive learning platform, with the auto-scaling of the AWS instances that add computational power as the stress linearly increases with the increase in the number of connections.

Adaptive Learning Methodology for MOOCs

Adaptive learning systems originate from the substantial contributions made in the area of artificial intelligence (AI), intelligent tutors, and adaptive controls.\textsuperscript{10,11,12} In these fields, adaptive learning systems are generally referred to as technological systems, with the ability to learn and adapt based on received input signals. Generally, educational adaptive learning systems organize content based on the learning preferences of individual learners with a goal to maximize learning performance through continuous intelligent feedback.

The first task for adaptive learning systems is to allow for different ways to organize content, offering different context and perspective...
for learners. The second task is to identify the way a learner would like to learn by conducting diagnostic assessments on the learning preference. The third task is to use assessment results to provide continuous intelligent feedback that motivates and provides guidance to overcome concept deficiencies and maximize learning performance. Figure 1 illustrates the four iterative processes involved in an adaptive learning cycle that rapidly converge to the learning style of an individual student.

The research conducted by cognitive psychologists indicates that the differences in learning styles originate from the difference in the learning strategies each learner develops based on his/her previous learning experiences. Within the AMOL system, learning strategies are related to the five learning pedagogies; apprentice (learning through mentor–student interaction), incidental (learning through case study), inductive (learning through example), deductive (learning through application), and discovery (learning through experimentation).

The “learning cube” pedagogical model suggested by the author in Figure 2 provides a multidimensional framework to organize learning objects developed in text, graphics, audio, video, animations, and simulations in the five learning pathways conforming to the pedagogy of apprentice, incidental, inductive, deductive, and discovery learning models. The third axis of the cube indicates increased interactivity between student and teachers, and the fourth axis is for social learning via blogs, wiki, podcasting, and YouTube to name a few. Details of the “learning cube” pedagogical framework are presented elsewhere.

Within the AMOL system, content is presented to students based on the learning style of preference. For example, in the incidental learning study, learning happens primarily within a context of case studies. Content provided by the expert is sequenced in ways that explain the events involved in the case study. For students who like to learn this way, the content makes sense. For students who prefer to learn inductively, deductively, or through discovery, AMOL sequences content in ways that best facilitate the given style of learning. These learning strategies allow students to pursue the study of difficult subjects within the pedagogical environment that works best for them. The five learning strategies used in the adaptive MOOC pedagogical framework—apprentice, incidental, inductive, deductive, and discovery—adhere to learning models representing

![Fig. 1. The learning cycles for self-improvement in the adaptive learning system.](image-url)
cognitive approaches from behaviorist, constructivist, and cognitivist learning theories.\textsuperscript{1–5}

A student using the adaptive learning system determines which strategies work best through interaction with an inference engine that administers diagnostic tests for making the assessment. The methodology involves using the assessment to measure performance in real-time and providing continuous intelligent feedback necessary for online learning assistance.\textsuperscript{6,7} Diagnostic quizzes are embedded within each concept to assess the level of competency that a learner has achieved. Based on the student’s results, an accelerated revision path with intelligent suggestions may be provided to each individual learner.

As illustrated in Figure 1, a learner circles through this powerful learning and revision cycle until the learner achieves the desired level of competency. The adaptive learning systems:

- Provide instructional support to faculty to create multiple teaching pathways.
- Deliver content with different learning pathways and reduce the dependency on “sage-on-the-stage” faculty lectures used in most of the MOOCs today.
- Allow students to learn better by customizing their own learning strategies in a MOOC environment.
- Provide increased cognitive opportunity to students to learn difficult concepts by presenting multiple perspectives on each concept.
- Provide continuous feedback to students, freeing faculty to be involved with student learners in the role of “guides on the side” on social media interaction sites—blogs, chats, discussions.
- Monitor learning progress of the students and provide remedial content in real time.

Adaptive learning systems thus support instructional learning strategies,\textsuperscript{20} pedagogically driven instructional design, pedagogical effectiveness for online education, and learning technology standards, including accessibility best practice and ADA compliance.\textsuperscript{18,21}

A Molecular Dynamics MOOC
THE COURSE: MOLECULAR DYNAMICS FOR COMPUTATIONAL DISCOVERIES IN SCIENCE

Molecular dynamics (MD) simulation has become a method of choice for researchers in the area of applied physics and engineering, material science, molecular biology, biochemistry, genetics, computational drug design, and many more areas.\textsuperscript{22–24} The molecular dynamics and Monte Carlo methods have gained significant popularity in the last two decades for solving physics and engineering problems. The phenomena, such as phase transition, deformation, melting, crack-tip progression, and dislocation movement—all conventionally studied by engineering disciplines at macroscopic scale—can now be studied from microscopic and atomistic points of view.\textsuperscript{25–27} Computational science is a critical and highly desirable skill in growing sectors of advanced manufacturing. An increasing number of engineering and science curricula are now including modeling and simulation courses as part of undergraduate and graduate programs. However, access to quality instruction in molecular dynamics remains hard to come by due to the shortage of well-qualified instructors and of practitioners trained in the field. Dr. Sonwalkar brings to this course both his years of experience teaching molecular dynamics and the benefits of his own ongoing practice in the field. As the only public university in the city of Boston, The University of Massachusetts Boston extends its public education mission by offering this free, globally available course.

This course was designed to help learners develop a deep understanding of the fundamental concepts of computational molecular dynamics while gaining experience with the most popular methods for atomistic simulations leading to discoveries in science. After completing the course successfully, learners were able to:

- Understand and apply statistical mechanics and thermodynamics and concepts of thermodynamics applied to MD.
- Learn computational algorithms for ordinary differential equations (ODE).
- Understand software programming and packages behind MD simulations.
- Apply MD simulation methods for property calculations.
- Select thermodynamic ensembles for complex physical problems.
- Analyze MD simulation data for complex science experiments.
- Prepare yourself for a career in computational science.

The course consisted of twelve modules, each made available at the beginning of the week. In each week, MOOC participants explored two main topics consisting of text content, short video lecture segments with accompanying transcripts, practice quizzes, and weekly quizzes. In addition, students were required to practice and simulate the concepts learned using various (free) simulation software programs. Discussion forums were available through which MOOC participants were encouraged to communicate and collaborate with other learners in the course.\textsuperscript{2}
Adaptive learning strategy. At the beginning of the course, learners were presented with a diagnostics quiz and were required to answer a few questions about how they learn. This process identified each learner’s preferred learning strategy, based upon which each learner then was guided on an adapted learning path throughout the course, by which process designers hoped to accelerate learning and improve score results.2

**COURSE ASSESSMENT**

The assessment rubric for MOOCs required special consideration as the large number of participants would not allow the instructor to grade students manually. Hence the assessments both formative and summative had to depend on weekly autograded assignments, practice quizzes, and graded assessments. The continuous improvement of competency was the goal of the current adaptive MOOC; hence, there were two forms of assessments that were provided to the students: (1) Nongraded practice quizzes that allowed students to self-test their competency with a real-time intelligent feedback system that dynamically rendered revision content in different learning strategies, and (2) graded assessments of competency. There was no provision for a proctored exam for this course.2

**Practice quiz.** The course included a graded practice quiz after each lecture segment. Practice quizzes were designed to assist

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**Table 1. Response Time and Throughput for Adaptive Mobile Learning Cloud Server for Adaptive MOOCs**

<table>
<thead>
<tr>
<th></th>
<th>RESPONSE (AVERAGE)</th>
<th>ERRORS</th>
<th>REQUESTS</th>
<th>RPS (AVERAGE)</th>
<th>RPS (PEAK)</th>
<th>THROUGHPUT (AVERAGE)</th>
<th>THROUGHPUT (PEAK)</th>
<th>TOTAL TRANSFER</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTML</td>
<td>0.848</td>
<td>0</td>
<td>10,090</td>
<td>6</td>
<td>11</td>
<td>73 KB/s</td>
<td>130 KB/s</td>
<td>111 MB</td>
</tr>
<tr>
<td>Othera</td>
<td>0.341</td>
<td>0</td>
<td>92,782</td>
<td>59</td>
<td>103</td>
<td>2,464 KB/s</td>
<td>4,258 KB/s</td>
<td>4 GB</td>
</tr>
<tr>
<td>Total</td>
<td>0.391</td>
<td>0</td>
<td>102,872</td>
<td>66</td>
<td>115</td>
<td>2,537 KB/s</td>
<td>4,388 KB/s</td>
<td>4 GB</td>
</tr>
</tbody>
</table>

*aOther includes javascript, CSS, images, pdf, etc. (any content type except html and xml).*
learners to master the concepts taught in each segment. Each practice quiz was worth 10 points, and completion of all practice quizzes comprised 20% of a student’s overall course score. Practice quizzes could be taken multiple times until a satisfactory score was achieved, with the highest score being counted toward the overall course score.

Adaptive feedback. At the end of each quiz attempt, the learner was provided immediate feedback through the adaptive learning system in the course. The instructor highly recommended MOOC participants take all segment practice quizzes and score more than 80% on practice quizzes before taking the weekly graded assessment.

Weekly graded assessment. In addition to the practice quizzes, a weekly assessment was made available at the beginning of each week. Each weekly assessment was worth 20 points. The combined score of all weekly assessment accounted for 80% of the grade. Weekly assessments could not be retaken.

Hands-on simulations experience. Learners used virtual molecular dynamics lab (VMDL) and MATLAB to derive the answers of the weekly questions. Software packages used in this course were made available to registered participants at no cost for the duration of the course.

TEXTBOOKS
There weren’t any required textbooks for the course. Several books were suggested for reference in the course.

CERTIFICATION
Students who completed the course successfully were provided with one of three types of certificates. The type of certificate granted will depend on student’s scores in the weekly assessments:

• Certificate of Success: An average of 80% or higher achieved on weekly assessments with all assessments attempted and submitted on time.
• Certificate of Completion: An average of 50% or higher (but less than 80%) achieved on weekly assessments with all assessments attempted and submitted on time.
• Certificate of Participation: An average of 35% or higher (but less than 50%) achieved on weekly assessments with all assessments attempted and submitted on time.

Development of Adaptive MOOC Weekly Modules
The most ambitious task for this project was to create the adaptive learning modules for the 12-week course. The course curriculum was divided into weekly modules that included 2 hours of lectures presented in 12 modules of 10 minutes each. The 10-minute modules were video recordings including instructor lectures, slides, text, graphics, and presentation of the virtual molecular dynamics laboratory. Video segments were captioned by the Liberate Learning Consortium in a two-step process involving the use of voice recognition software followed by hand editing accomplished by staff caption-writing editors.

The converted and edited video caption text was then used by the instructional design team members to create the concepts and sub-concepts that became the core aMOOC content. The course content thus derived for each 10-minute video segment was then transcribed to provide five learning strategies, namely, apprentice, incidental, inductive, deductive, and discovery. The details of the learning strategies and the differentiated instructional model for the brain-based adaptive learning can be found elsewhere.

The production was successfully completed by a video production and instructional design team from the College of Advancing and Professional Studies (CAPS) at the University of Massachusetts and by the adaptive learning development team of the Synaptic Global Learning.

A Scalable AWS Cloud Architecture
The adaptive learning module was deployed on the AMOL platform SaaS tools. An existing patented AMOL platform was modified to accommodate the adaptive learning pedagogical framework and to provide ample social interaction. The AMOL software technology platform leverages EC2, S3, and RDX web services on the LAMP stack for the deployment of online programs worldwide.\textsuperscript{8,9} The course was deployed on the Amazon Web Services cloud computing with auto-scaling option.\textsuperscript{9}

The primary architectural consideration for a mission-critical application is to make the system completely fault tolerant. The fault tolerance allows systems to function even if there are components in the
system that fail during the operation (see Figure 3). The secondary critical requirement is to develop a scalable architecture to accommodate increasing numbers of users connecting without any prior notice and increasing numbers of processes that in a normal case can crash an entire network. A scalable architecture will increase required resources to automatically meet any increased demand for web services.

Fault tolerance and scalability are accommodated by the cloud computing architecture. The main differentiators for cloud architecture as compared to the conventional server-based architecture are:

1. Automation of processes involved in the running, back-up, and fail-over of the web services.
2. Auto-scaling of application instances based on the growth of demand using Amazon Machine Image processing.
3. Fault tolerance with distributed zone deployment of the application.
5. Reliability of AWS services over the period of time for 99.9% uptime.

As shown in the attached schematic of the cloud architecture diagram, the front end connectivity for the Hypermedia Instruction and Teaching Environment (HITE) server is a load-balancer that has a dedicated IP address. HITE server is the back-end technology of the AMOL platform. The load balancer then sends requests to a number of available instances that are auto-scaled to meet the user demands based on the auto-scaling protocol, elastic computing (EC2) in AWS application services. The HITE application server is connected to the cloud simple storage service (S3) and relational database service (RDS) as the master database. The scalable S3 and RDS along with EC2 are also stored in Amazon Machine Image (AMI), which is replicated based on the increasing user demand by the virtue of auto-scaling protocol. This is the underlying cloud-based scalable architecture for AMOL platform used for the first adaptive MOOC.

The fail-over is then distributed to Zones 3 and 4, which are located in different geographical locations from Boston, to make the AMOL completely fault tolerant for large numbers of students. Testing indicated the design could have auto-scaled to accommodate 500,000 registrations.

The following AWS components were used for the AMOL scalable aMOOC architecture:

1. EC2 (elastic cloud computing)
2. RDS (relational database service)
3. S3 (simple storage service)
4. Could Watch (cloud monitoring service)
5. Elastic Load balancer (load distribution service)
6. Auto-scaling (auto-scaling using Amazon Machine Images)

Load and Performance Test Results and Discussions

Load and performance testing was conducted on application software by simulating requests from concurrent users. Normally the concurrent users represent 10–20% of the total registered users. The load test showed the response time of the server when numbers of users increased and related requests from the users for the HTML pages and other multimedia increased. While the load test ensured stability of the systems under concurrent connections, the response time indicated the performance of the systems against the load patterns for users to access the content.

SGL used LoadStorm.com as the simulation tool for extensive load testing. Almost 25 different test scenarios with 1–10 steps were simulated, and the AMOL cloud architecture was subjected to rigorous tests to support 100,000 to 500,000 users and with 10,000 to 250,000 concurrent users.

<table>
<thead>
<tr>
<th>CC USERS</th>
<th>RESPONSE(S)</th>
<th>ERROR (%)</th>
<th>THROUGHPUT (KB/S)</th>
<th>EC2 INSTANCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>1.74</td>
<td>0.53%</td>
<td>15121.71</td>
<td>5</td>
</tr>
<tr>
<td>50000</td>
<td>2.67</td>
<td>0.84%</td>
<td>25635.04</td>
<td>7</td>
</tr>
<tr>
<td>100000</td>
<td>3.07</td>
<td>0.97%</td>
<td>30162.88</td>
<td>8</td>
</tr>
<tr>
<td>150000</td>
<td>3.30</td>
<td>1.04%</td>
<td>32811.50</td>
<td>9</td>
</tr>
</tbody>
</table>
Table 1 indicates the response time in seconds, which is less than 1 second with 0% errors in responses made as results of request per second during the run from 5 users to 200 users with average requests per second as 6.

As indicated in the chart of Figure 4, the load test simulation shows a linear increase in the user login, which also has linear increases in the requests per second made to the AMOL server and the throughput. The trend indicates a very healthy growth in throughput response from the servers in response to the requests made.

Figure 5 shows that the performance of the AMOL server remains error-free even with the request growing from 5 rps to 115 rps, representing over 6000 requests made to the server with responses within an average of 1 second and few requests taking longer.

This load test data indicates excellent performance of the AMOL server as the errors to the request response remains at 0% even when the load is increased from 5 concurrent users to 200 concurrent users.

LOAD TEST MATRIX FOR LARGE CONCURRENT USERS

Numerous load tests were performed with over 25 test conditions and scenarios. Load test data for 10,000 to 300,000 concurrent users indicates following trends:

As shown in Table 2, the auto scaling feature of AMOL cloud architecture scales very well with the need for large number of concurrent users. The EC2 instances grow from a baseline of 5 to over 9 to accommodate concurrent users from 10,000 to 150,000. The EC2 instances are also accompanied by database replications and load balancing, which ensures that the response time remains within an acceptable limit of 5 seconds and the errors remain within 3.3% level.

It is important to note that auto-scaling does not create spikes when reaching the desired threshold, which prevents hick-ups in the response time. The replication is made available before the peak loads are reached, ensuring smooth transitions of users to higher number of instances.2

Conclusions

The adaptive MOOC platform developed for the deployment of the first adaptive MOOC course in the areas of molecular dynamics for the computational discoveries in science was successful in handling the large loads of the Massive Open Online Course and concurrent user stress. Following conclusions can be drawn from the first part of this case study:

1. The pedagogical instructional design was modeled to accommodate five learning strategies.
2. The AMOL tools were effective and adequate for the rapid production of the adaptive MOOC course in a very difficult subject matter.
3. The cloud architecture was necessary to accommodate expected large loads for a MOOC, where the number of concurrent users is a cause of concern for acceptable throughput and page return time for a dynamic rendering of content.
4. The pedagogy and technology developed for the adaptive MOOC shows great promise for the future creation and conversion of the one-size-fits-all MOOC into effective adaptive MOOC.

The author and his research team are currently analyzing the learner behavior data collected during this case study, which will be presented in Part II of this research article.

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Author Disclosure Statement

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