Teaching an Undergraduate Nanotechnology Course Online

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Abstract

With a support from National Science Foundation, an upper-level undergraduate online course "Nanostructures: An Introduction" was developed and taught as a component of Missouri Physics Collaboration and Missouri Alliance for Collaborative Education (MACE) initiatives. Students from six different university campuses throughout the state of Missouri have participated. This paper describes the choice of delivery technology as well as adapting the course content and assessment strategy for the online format.

Motivation

An upper-level undergraduate course "Nanostructures: An Introduction" has been developed and later adapted to an online form as an education and outreach component of grants DMR-0704981 and DMR-1205223 sponsored by the National Science Foundation. These projects are titled "Mesoscopic Transport and Localization in Active Random Media" and "Anomalous Transport and Wavefront Shaping in Complex Photonic Media". Rapid advances in nanotechnology have enabled the fabrication of micro- and nano-photonic structures with high degree of precision. Joined experimental and theoretical effort aims to uncover unusual optical properties of the artificially designed and purposefully fabricated nano-structures. This course provided an opportunity to expose students to the cutting-edge technologies employed in the project as well as to survey the field of nano-science as a whole.

After an initial development, the course ran in the spring 2009 semester at the physics department of Missouri University of Science and Technology. In the fall 2011 semester the course was offered at all public institutions of higher education state-wide under umbrella of Missouri Physics Collaboration – a part of a broader Missouri Alliance for Collaborative Education (MACE) initiative[1]. MACE's primary vision is:

> "… to provide a medium through which institutions in the state of Missouri can collaborate and offer a full range of course offerings in programs that are facing enrollment/resource challenges.
>
> It is believed that collaborative programs such as these can contribute to a more efficient use of our increasingly scarce resources and prevent the loss of programs that are currently challenged. However just as importantly, by pooling faculty resources across institutions, we can move to increase the breadth and depth of instruction to the students at the participating institutions.
>
> Consequently, through these more comprehensive offerings to our students, there can also be long-range benefits for all. As these programs enhance the human capital of the graduating students, they can provide positive

contributions to the workforce, catalysts for economic development, and enhancements to the quality of life in the state and region."

Missouri Physics Collaboration

The course's structure, content, delivery and assessment policy had to conform to the policies and guidelines of Missouri Physics Collaboration as well as those of MACE[2]:

- "Participation in the collaboration is strictly voluntary. A department may decide to participate in all, some or none of the collaborative courses. By participating as a receiving institution, there is no obligation to be an offering institution
- Students at receiving universities will register at their home institutions and pay tuition for these courses to their home institutions. No money will be transferred between universities. Each department is responsible for creating a course number, title and description for their own catalogue, schedule and student transcripts
- Each receiving university will appoint a faculty member from their own department who will have a role in the administration of the course. At a minimum, this faculty member will deal with arranging and proctoring exams, student complaints and grievances, technological problems, and advising of their own students
- The students will be bound by all the rules and dates of their home institution, including admission and drop rules and dates
- The academic calendar and technology used for these courses will be chosen by the institution offering the collaborative course, in consultation with the other institutions
- All the students in these collaborative courses will be evaluated. The evaluation questions and process will be determined at a later date through an exchange of emails
- The instructor of the collaborative course will grade all homework and exams and determine the final grades for all students participating in the class, using the same standard for all students"

Out of the above guidelines, the content delivery and assessment of student progress at different institutions presented a particular challenge.

Content Delivery Options

As of fall 2011 semester, two online content delivery options were available at Missouri S&T.

1. WebEx[3] through Missouri S&T's Video Communication Center:
    - High definition video of presenter with Microsoft PowerPoint slides in the background (as in a weather broadcast)
    - A technician is always present and controls the camera and is available to assist with technical issues
    - A write-on monitor for comments and annotations in the Microsoft PowerPoint slides or separately
    - Lectures are broadcast live and their recording are made available for later access by students

- This option incurs as substantial charge (on the order of $6,000) to the department which offers the course
- Students tuition is on the order of $1,000 per credit

2. Wimba[4] feature in Blackboard through Education Technology department at Missouri S&T:
- Lower-res video feed with (imported) Microsoft PowerPoint slides in a separate window
- No in-class technical support
- A webcam and write-on monitor for comments and annotations in the imported Microsoft PowerPoint slides (no animations)
- Lectures are broadcast live and their recording are made available for later access by students who have access to Blackboard system at Missouri S&T
- No extra costs to the department except for a one-time upgrades in the classroom (on the order of $2,500 for SmartPodium[5])
- Students pay standard fees per credit hour

Because MACE agreement states explicitly that no money will be transferred between the universities participating in the project, the first option above was not available. With the second Wimba/Blackboard option, the out-of-donor-campus students had to be granted access to the Missouri S&T's Blackboard system. This presented a technical challenge because only students properly registered at the S&T are given access to the campus Blackboard system. This limitation was overcome with the help from S&T's EdTech team who enabled proper guest access for all external students and their supervisors, see below.

Course Scope and Target Audience

Goals of the course were defined as:
- To overview field of nanotechnology with an emphasis on physical phenomena involved
- Lay a foundation for a research career in the rapidly growing area of nanotechnology
- Enhance students competitiveness on job market

Target audience was chosen carefully to allow participation by the students from institutions without rigorous graduate programs. Upper-level undergraduate students who have taken the standard undergraduate physics, calculus curricula as well as a "Modern Physics" courses were eligible to enroll. All student enrolled into a graduate program (with the above physics prerequisites) were also eligible. For the latter group, the course would serve a post-"Modern Physics" course to broaden their knowledge of the field. The following fields were included in the syllabus:

I: Nanoscale Fabrication and Characterization.
1. Nanolithography
2. Self-Assembly And Self-Organization
3. Scanning Probe Microscopes

II: Nanomaterials and Nanostructures.
4. The Geometry of Nanoscale Carbon
5. Fullerenes

6. Carbon Nanotubes
7. Quantum Dots
8. Nanocomposites

III: Nanoscale and Molecular Electronics

9. Advances In Microelectronics
10. Molecular Electronics
11. Single Electron Transistors

IV: Nanotechnology in Magnetic Systems

12. Nanostructures For Quantum Computation
13. Magnetoresistive Materials And Devices
14. Nanotechnology In Magnetic Storage

VI: Nanoscale Optoelectronics

18. Quantum-Confined Optoelectronic Systems
19. Organic Optoelectronic Nanostructures
20. Photonic Crystals

Six campuses participated during fall 2011 semester – S&T, University of Missouri – Columbia, University of Missouri – St. Louis, Missouri State University, Truman State University, Southeast Missouri State University. Varying academic standards at six participating institutions as well as the varying degree of preparedness within each school presented the challenge in applying the same grading standards across the entire class. The next section details how this and other challenges were addressed in the course design.

Course Structure and Evaluation

The majority of the out-of-donor-campus students had a time conflict and were not able to watch three weekly live lectures being broadcast online. Instead, they were asked to watch the recorded material prior to the next lecture. This required a great deal of self-motivation from the students. Weekly homework (see more below) assignment, based directly on the material covered, provided a substantial incentive for students to keep up with the flow of the material. Two textbooks[6,7] were chosen with additional reading materials distributed via the Blackboard system.

There were four types of mandatory graded assignments:

• Homework	30% (2 lowest out of 12 dropped)
• Presentation	10%
• Presentation reviews	10%
• Three exams (each)	16.7%

1. Homework:

During each Friday class (excluding the weeks before the midterms and the final exams) students were assigned 2-3 test-bank questions related to the material discussed during past week. Appendix A shows examples of such questions. Neatly handwritten or typed solutions were due at the Wednesday lecture of the following week. Off-campus students submitted homework solutions via email (optionally in Word or PDF). Homework was accepted only until the end of the class on the following Friday (with 20% penalty for turning the assignment after the deadline). There were twelve homework assignments during semester with the two lowest homework grades being dropped.

2. Student presentation:

Every student was asked to prepare a 15 minute narrated presentation (after composing the slides one used "Slide Show/Record Narration" feature of Microsoft PowerPoint). Students were free to suggest a topic related to your area of interest/research. Narrated Microsoft PowerPoint presentations were made available to all students via S&T's Blackboard system. The presentation contained the following mandatory parts:

(i) Brief history of the subject of the presentation;
(ii) Detailed description of the subject;
(iii) Description of how it enabled (or was enabled by) an advancement in nanotechnology;
(iv) Possibly, how it is being used in our every-day life;
(v) Bibliography used in preparing the presentation

Students were encouraged to consult the instructor before finalizing their presentation. The grade for the presentation was determined based on:

(i) Quality of the PowerPoint presentation. Correctness, completeness and appearance were considered – 50% of the grade
(ii) Oral presentation – 30% of the grade
(iii) Ability to answer questions (see presentation reviews below for details) related to the topic of the presentation – 20% of the grade

3. Presentation review:

For every presentation two student peer reviewers were assigned. Within three days after the presentation had been made available, each reviewer was expected to listen carefully the presentation being reviewed and make a clarification/addition through Blackboard discussion board. The student in charge of the presentation had additional four days to post his/her comments/rebuttal. The grade for the presentation review was determined by students' participation in the discussion board. Each student participated in two reviews.

4. Three (two midterm and one final) examinations:

Midterm exams were given on Mondays instead of a regular class. The final exam was given during the finals week. Final exam only included the material covered after the midterms. Both the midterm and the final tests (one hour) were in closed-book format. They consisted of four questions drawn from test bank which had been made available to all students at the beginning of the semester. On-campus student took the test in class. All other schools assigned a faculty sponsor who would

(i) administer the test;
(ii) ensure the test security;
(iii) transmit the tests via fax/email to the S&T's instructor for grading.

Because the tests were composed based on a random selection of the test bank questions, preparing multiple versions of the test for different campuses presented no problem – there was no need to ensure their simultaneity. All makeup tests were also composed using the same guidelines as the regular tests.

Student Participation Statistics

Online format of the course made it possible to track students performance on the day-to-day basis. Figure 1 provides statistical information about student access to the course material. It shows clear correlation between for-grade assignments (homeworks and tests) and access rate. This indirectly supports the idea of employing lecture-based weekly assignment as means of encouraging students to keep up with the material.

Presentations served as a powerful tool to personally engage individual students. Roughly a half of the presentation topics, c.f. Appendix B, were based on the students current/intended research topics. Presentation reviews served to both introduce students to the concept of peer-review process in scientific literature and to establish personal connection between the students in class. To accomplish the latter goal, students from different campuses were purposefully chosen to perform the reviews.

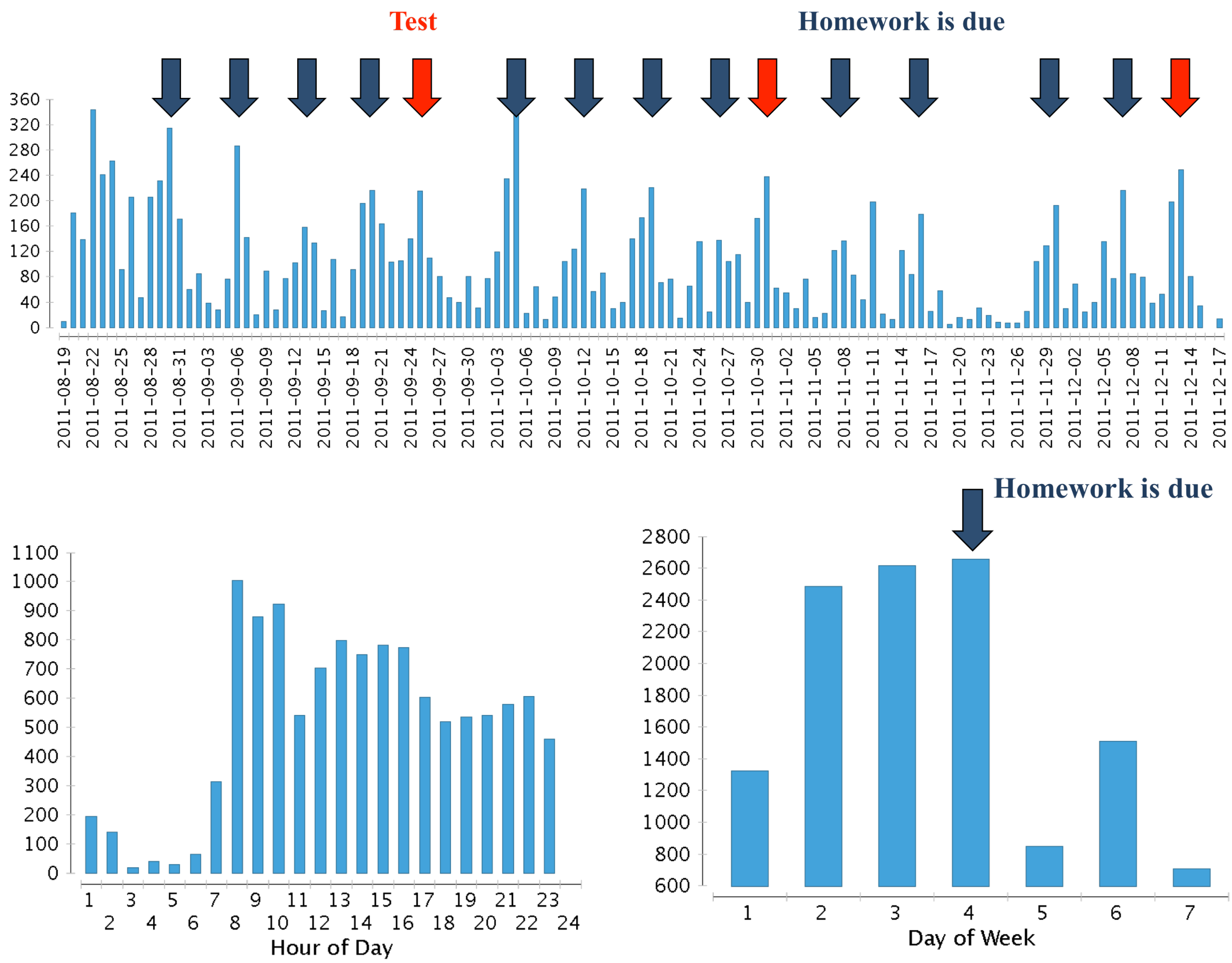

Figure 1. Statistics of the hourly/daily access (number of visits) to web-based content (recorded lectures, posted homework assignments, etc.). Correlation between major assignments and the access rate is clearly seen.

Conclusions

An upper level undergraduate course "Nanostructures: An Introduction" which surveys the modern topics in the field of nanotechnology was developed and adapted for an online delivery. It had emphasis on conceptual understanding of the underlying physics. "Test bank questions"-strategy was adopted to (i) encourage students to keep pace with the lectures (via homeworks); (ii) relieve test anxiety; (iii) emphasize the key concepts in the material covered; and (iv) simplify administering tests at different locations. Student presentation and review provided an engaging opportunity for students showcase their research aspirations.

Students embraced the "test bank questions" concept with 95%, 86% and 92% average on three tests. It also led to 90% homework submission rate (web access statistics suggests that the ability to access prior lectures has been a major factor). Overwhelming participation in student presentation discussion forums clearly showed the high level of engagement. These conclusions are further reinforced by the answers to the anonymous online survey[8], the results of which are shown in Tables 1 and 2.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
To overview field of nanotechnology with an emphasis on physical phenomena involved	0%	0%	0%	0%	100%
Lay a foundation for a research career in the rapidly growing area	0%	0%	12%	25%	62%
Enhance students competitiveness on job market	0%	12%	12%	38%	38%

Table 1. Syllabus stated three goals set by the instructor. At the end of semester, students were asked whether these goals have been met.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The course increased my interest in the subject	0%	0%	0%	25%	75%
Having completed the course, I feel knowledgeable in the subject	0%	0%	12%	50%	38%
The course contributed to the completeness of my education	0%	0%	12%	50%	38%
Overall, the course met my expectations	0%	0%	0%	50%	50%

Table 2. Student responses to question on how they benefitted from taking the course.

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3. http://www.webex.com/
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5. http://smarttech.com/
6. "Introduction to Nanoscience and Nanotechnology," Hornyak, Tibbals, Dutta, (2008)
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8. http://www.zoomerang.com/

Biographical Information

ALEXEY YAMILOV is an assistant professor of physics at Missouri University of Science and Technology. His research interests are in wave propagation in complex (random, aperiodic, partially or fully ordered) nano-structured media (http://web.mst.edu/~yamilov/).

Appendix A: An Example of Test Bank Questions

Below is list of test bank questions covering "I: Nanoscale Fabrication and Characterization" part of the material:

1.1 Sketch and describe diagrams for the three modes of printing in photo-lithography technique. For each mode, list at least two advantages and two disadvantages

1.2 List three factors which limit optical resolution in photo-lithography. Describe practical approaches to reducing each factor. What is the approximate numerical value of each factor in the current state-of-the-art photo-lithography?

1.3 Describe the physical principles behind the following three approaches to improving the resolution in photo-lithography: (i) Phase Shift Mask; (ii) Optical Proximity Correction; (iii) Immersion

1.4 Describe the components and their functions in projection electron-beam lithography. List two advantages and two disadvantages of the E-beam technique in comparison to photo-lithography

1.5 Describe the components and their functions in X-ray lithography. List two advantages and two disadvantages of the X-ray technique in comparison to photo-lithography

Appendix B: Student Presentations

Below is list of presentation topics selected by the students:

- Synthesis of magnetic nanoparticles for biomedical applications
- Nanorobotics
- Energy storage in carbon materials
- Quantum Computer
- Hydrogen bonding and self-assembly in nature
- Boron Neutron Capture Therapy
- Gecko-nanotechnology

- Self-healing nano-paint
- Nanostructures of stained glass
- Quantum Dots
- Mass Production and Potential Applications of Graphene
- Nanocomposite materials
- Cancer treatment and controlled drug release with magnetic nanoparticles
- Nano encapsulation
- Nanoparticles in petrolium engineering
- Biometics
- Bioengineering artificial musles
- Nano-medicine