Blended Learning with Nuclear Reactors

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Abstract

Cadets majoring in Nuclear Engineering (NE) at the United States Military Academy (USMA) at West Point have the opportunity to participate in a blended learning laboratory experience using the reactor critical facility (RCF) at Rensselaer Polytechnic Institute (RPI). RPI, through a grant from the Nuclear Regulatory Commission, developed a series of laboratory modules and associated lectures using their RCF. As a pilot program, the cadets at West Point conducted a blended learning laboratory exercise using a series of online videos which included both lecture and the conduct of a laboratory. Prior to conducting the blended learning laboratory, cadets mapped the neutron flux in a sub-critical assembly at West Point. A survey conducted of the cadets at the conclusion of the blended learning laboratory exercise indicated that the previous work with the sub-critical assembly at USMA was most helpful in understanding the material presented by the module laboratory developed by RPI. This paper outlines the laboratory program and presents lessons learned from the conduct of this series of exercises from the student's perspective.

Introduction

During their sophomore year, cadets can choose to major in NE at West Point. Their initial NE class concentrates on learning core concepts and does not include any laboratory work. In the second semester of the NE major, cadets conduct laboratory exercises with plutonium-beryllium (PuBe) neutron sources in a sub-critical facility as part of a course dedicated to nuclear reactor design. This lab exposes students to working with nuclear material and to detecting and plotting the neutron flux.

Conducting laboratory exercises with a sub-critical assembly helps the students reinforce the knowledge learned in the classroom environment and prepares them to take the next step in the educational process of the NE program. Because West Point does not have a critical reactor, NE Faculty at USMA teamed with RPI Faculty to offer students an opportunity to gain experience with the RCF. This experience was delivered using multiple videos that first present lectures given by RPI instructors about the concept of the lab and then the conduct of the laboratory itself.

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This blended learning opportunity enables cadets to broaden the skills and knowledge gained in the classroom to the laboratory environment. It is essential for the cadets to work with the West Point sub-critical assembly prior to the conduct of this blended learning experience, as it prepares them to better understand the experiment conducted with the RPI critical reactor.

West Point Nuclear Reactor Design Laboratory Program

Nuclear engineers must understand the neutron flux distribution in a reactor. Therefore, the laboratory exercises conducted during the nuclear reactor design course at West Point revolved around measuring and calculating the flux at different positions in a given geometry. The neutron flux is the number of neutrons per unit area per unit time. Because the neutron density is higher within proximity to a fission source, it follows that the flux will be the highest near the center of the source and decrease with distance from the source.

Later in the course, cadets derive the equations needed to solve for the neutron flux at any point away from the source, given the geometry. Students also learn that for a cylindrical reactor the flux in the radial direction away from the center follows a Bessel-function shape, while the neutron flux along the length of the fuel rod in the axial direction varies with the shape of a cosine function. Reactors with moderating reflectors will also have a small peak in the thermal moderation of fast neutrons that leak from the core and are moderated in the reflector region. This theoretical distribution of neutrons within the reactor can be observed in Figure 1 and is verified experimentally by taking measurements of neutron counts at various positions within the reactor core.

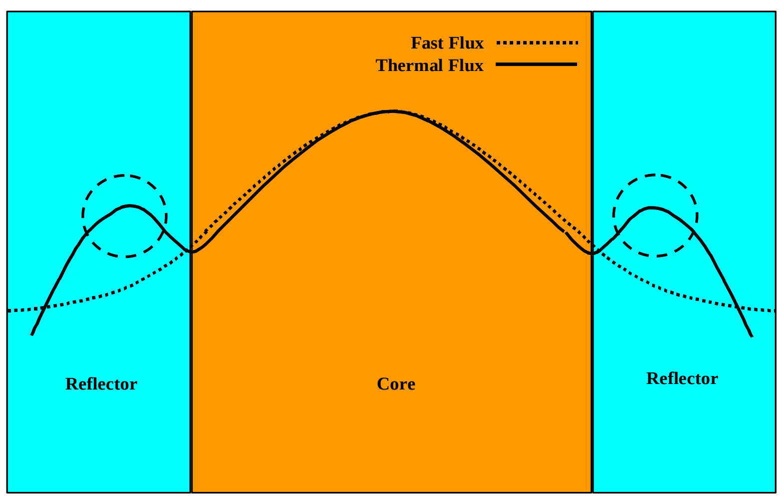

Figure 1: Fast and thermal radial flux profiles for a cylindrical, reflected, homogeneous reactor.[1]

Following these conceptual lessons, the cadets conduct a laboratory exercise utilizing a plastic, rectangular container filled with water, referred to as a sigma-pile. In the sigma-pile exercise, cadets place a single one curie PuBe neutron source at the bottom, center of the sigma-pile. A BF_3 detector system is used to measure the number of neutrons at various positions from this source. The BF_3 detector is positioned at known radial and axial distances from the source and neutron counts at each position are measured and plotted. This laboratory serves as an introduction to the experimental process with the goal of measuring the diffusion length of thermal neutrons in water. Cadets also gain hands-on experience with the detector system which is used in the sub-critical assembly laboratory.

Cadet conceptual knowledge of the neutron flux is further expanded through the use of the sub-critical assembly. The sub-critical assembly, fueled with natural uranium and moderated with distilled water, cannot sustain a nuclear chain reaction without an external neutron source. In this laboratory exercise, five one curie PuBe neutron sources were placed in the sub-critical assembly, initiating fission of the natural uranium, and a steady-state neutron flux was established. The sub-critical assembly is shown in Figure 2.

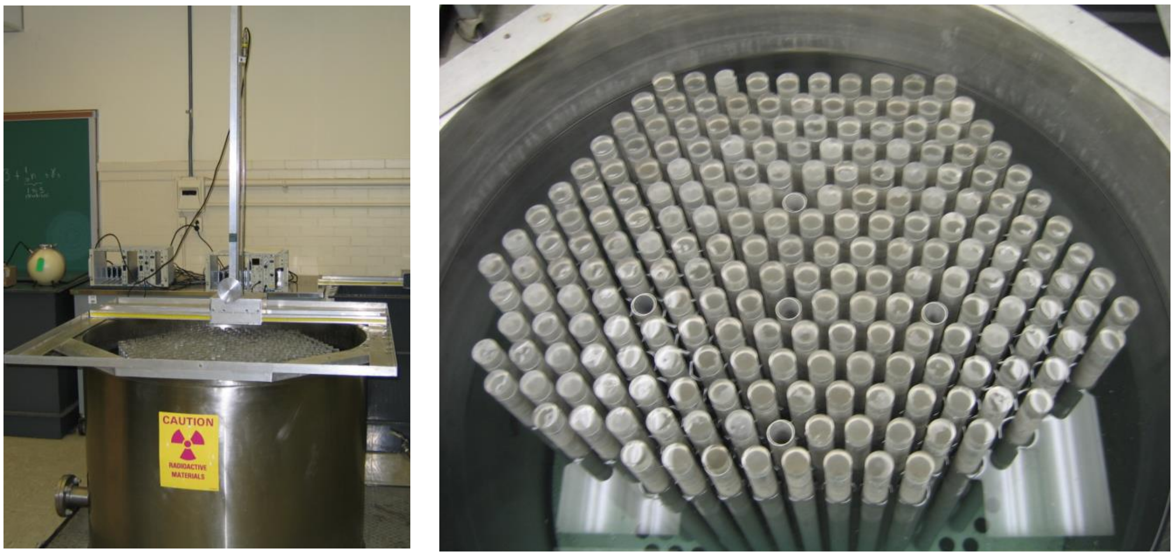

Figure 2: Images of the sub-critical assembly setup with the BF_3 detector system (left) and the sub-critical assembly top view (right). The fuel tubes are arranged in a hexagonal shape.

The goals of this laboratory exercise were to measure and map the axial and radial thermal neutron flux distribution of the sub-critical facility and then to ultimately calculate its effective neutron multiplication factor.

Video Experience: Critical Reactor Lab

The final lab of this nuclear reactor design course series was conducted using an online module provided by RPI through a grant from the Nuclear Regulatory Commission. West Point cadets were provided an access user ID and password to RPI's Learning Management System (RPI LMS) by the RPI laboratory instructor. Cadets were given a week to watch the video of the laboratory experiment conducted at the RCF by RPI students and then to write up the results in a report.

The module chosen for use at West Point was a laboratory experiment to determine the RCF power distribution. This power mapping is related to the West Point laboratory exercises because the power distribution within a reactor is correlated to the thermal neutron flux distribution. If there are more thermal neutrons available at a position in the reactor, there will be higher probability of fission and hence, higher power at that position. Therefore, it is expected that the power distribution will have a similar plotted shape as the thermal neutron flux depicted in Figure 1.

To enhance viewing of the experiment, the instructor provided additional videos that present an overview of the concepts behind the module. The first was a video lecture by Dr. Wei Ji at RPI which included the underlying theory behind radial and axial power mapping. Figure 3 is a screen capture of Dr. Ji's lecture.

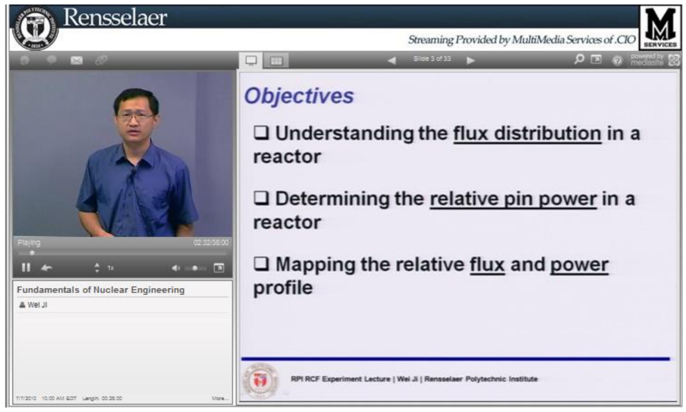

Figure 3: Screen capture of the video module provided by RPI. Dr. Ji reviews the theory behind flux distribution and power in a critical reactor.

The second video was three hours long and taped at the RCF which included an introductory lecture by Dr. Timothy H. Trumbull about power mapping (approximately 25 minutes) and then the conduct of the lab itself. Figure 4 is a screen capture of the power mapping lecture portion of the video. Figure 5 is a screen capture of the conduct of the lab itself.

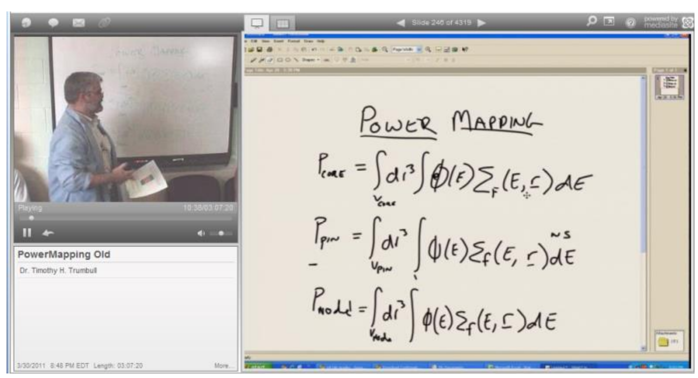

Figure 4: Screen capture of the video module provided by RPI. Dr. Trumbull reviews the theory behind power mapping of a critical reactor in this three hour video.

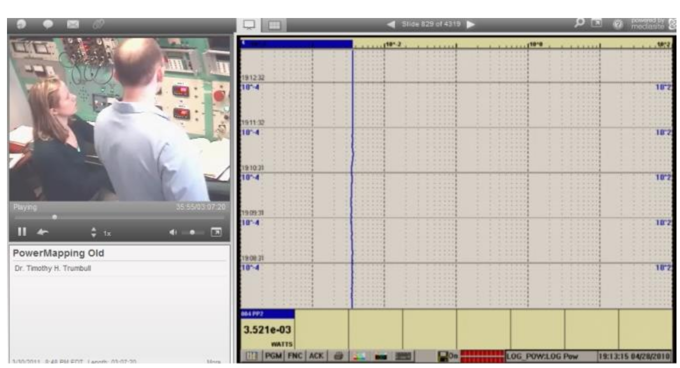

Figure 5: Screen capture of the video module provided by RPI. Reactor operators prepare the RCF for operation during the laboratory.

Viewing of a third video was optional. It was a video giving an introduction to fission and other related RCF processes which provided an overview of some reactor analysis and design considerations. Figure 6 provides a screen capture of this video in which Dr. Thomas C. Haley presents an overview of the fission process and the RCF.

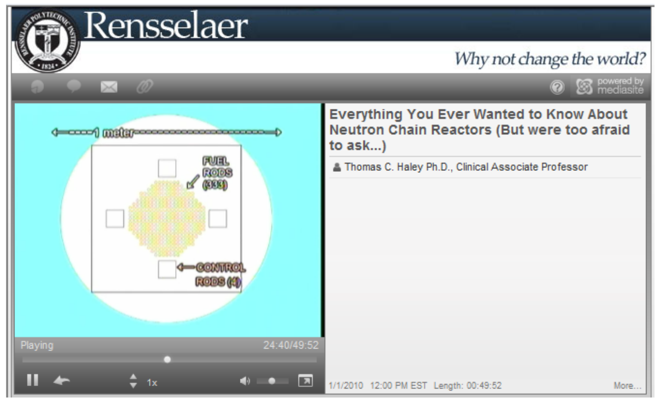

Figure 6: Screen capture of the "Everything You Ever Wanted to Know About Neutron Chain Reactions (But were too afraid to ask…)" introduction video to the RCF.

The video of the laboratory exercise being conducted was also viewed online. Although the cadets at West Point were not able to directly participate in the experiment, the video followed every step of the RPI students' experimentation. Instead of BF_3 detectors, students at RPI used a collimated shield and a sodium iodide detector gamma spectroscopy system to find the number of delayed fission product gamma rays at locations in the core. Because the gamma-ray intensity is proportional to the concentration of fission products, the power distribution within the reactor can be determined from this data.

After watching the two required videos, the West Point cadets were then given RPI's laboratory manual for the experiment, as well the data from the lab that would otherwise have been available to them if they had conducted the measurements taken in the video themselves. Based on this information, cadets then analyzed the data, and provided analyses similar to those exercised while conducting the sigma-pile and sub-critical assembly experiments at West Point.

Assessment

The desired outcome of the blended learning program was to enrich the West Point curriculum by offering cadets an opportunity they would otherwise not be afforded because USMA does not have a critical reactor facility. To assess the effectiveness of this pilot program, in addition to grading the laboratory reports, West Point NE faculty sought feedback from the cadets involved. This feedback was collected via a course survey and results were measured using a constructed proxy scale of 0 to 5. The scale numbers represent the following responses:

0. I didn't watch the video.
1. Not at all.
2. Slight extent.
3. Moderate extent.
4. Great extent.
5. Very great extent.

The questions specifically inquired about the effect each video had on the learning process. The survey also asked the cadets if they found prior laboratory exercises conducted at West Point helpful. Because RPI's Laboratory Manual provided an explanation of the theory for the experiment, it was also included in the survey. The overall effectiveness of the blended learning laboratory program was reflected in an average score of 3.56 based on the results from 18 cadet participants. The breakdown for each rated material is reflected in Table 1.

It was important to note that not all cadets watched all the videos. Because some cadets had no basis to judge the efficacy a given video, it was more accurate to only account for those cadets who actually watched the video. Therefore, dividing the sum of the scores by only those cadets that watched the video showed a significant increase of the rating for each video. These results are depicted in the adjusted column of Table 1.

Table 1: Collected data from surveys. The raw data column depicts all the student responses. The adjusted column shows the rating of the video by only those cadets who actually watched each video.

Material	Raw data	Adjusted
Video lesson by Dr. Wei Ji	2.06	2.64
Video on power mapping by Dr. Tim Trumbull	2.44	3.14
Video of the actual experiment	1.61	2.41
Video on fission by Dr. Tom Haley (optional)	1.11	4.00
RPI's Lab Manual	3.44	N/A
Prior Laboratories at West Point	3.78	N/A

The required videos had an average of 2.73 on the 5 point scale as rated by the cadets. The optional video on the basic principles of fission and an overview of the conduct of RCF lab by Dr. Haley was viewed by only 20 percent of the class. However, those students that did view this video, found it more helpful when compared with the other videos with an average of 4.00 out of the 5 point scale. The video of the actual experiment was rated the lowest likely because the conduct of the laboratory involved repetitive tasks with relatively long gaps between taking data. Additionally, the laboratory video was 2 and half hours long.

The results in Table 1 also show that, besides the optional video, prior laboratories conducted at West Point provided cadets with the most effective and useful experiences to help them complete the RPI laboratory. This result indicates that it may be better to have a "crawl, walk, run" approach to education in a blended learning environment. In the crawl phase, concepts can be introduced in class and preliminary laboratories can be conducted to introduce students to the equipment and experimental methods. During the walk stage, similar laboratories can be conducted with equipment available locally (i.e. the sub-critical assembly). Finally, during the run stage, students are able to synthesize their experiences from hands-on laboratories and apply that knowledge in a virtual environment.

There are a few suggestions for improvement to the blended learning laboratory program. One obvious improvement is that the video of the basic principles of fission and the RCF overview should be made mandatory for the cadets at West Point. Those cadets that watched the video, thought it very useful. The primary sustain for this program is the progression of the laboratories, starting with an analysis of neutrons diffusing in water, the sub-critical assembly and ending with the RCF. The increasing complexity of the laboratories and the advancing depth of nuclear engineering concepts tailor the laboratory experience to cadets beginning with little understanding of the behavior of nuclear reactors to successfully equip them with more advanced knowledge and a fuller understanding of nuclear reactors.

Conclusions

The collaborative effort between USMA and RPI proved to be successful. RPI's pilot program to create and export blended learning laboratory modules proved to be very beneficial to the cadets' learning and gave them experience that they would not have had otherwise. NE Faculty at West Point also gained valuable insights into the educational benefits of blended learning laboratories and learning in a virtual environment.

The survey results offer a valuable assessment of the nuclear reactor design laboratory exercises at West Point, and the blended learning exercise created by RPI. Clearly the laboratory exercises have been an effective tool for enriching the NE curriculum and contribute to a comprehensive understanding of key concepts and materials the course is designed to target. The blended learning laboratory reinforced cadet learning while giving them exposure to a critical reactor facility.

Reference

1 T. H. Trumbull, "MANE-4440: Critical Reactor Laboratory," *A Manual of Experiments* (2008). 2.