Early Introduction of Computational Methods in Undergraduate Nuclear Engineering

Kenneth S. Allen,[a] Blake K. Huff[b]

[a]*Associate Professor, United States Military Academy Department of Physics and Nuclear Engineering, BLDG 753 Bartlett Hall, West Point, NY, 10996, Kenneth.allen@usma.edu*
[b]*Instructor, United States Military Academy Department of Physics and Nuclear Engineering, BLDG 753 Bartlett Hall, West Point, NY, 10996, Blake.Huff@usma.edu*

INTRODUCTION

The use of advanced computational transport codes, either deterministic or Monte Carlo-based, is an important tool in nuclear engineering design. How and when those codes are introduced to students in either their undergraduate or graduate education varies significantly from one university to another.

The United States Military Academy recently underwent a complete review and update to its core and major curriculum for all disciplines. As the result of past assessments, the nuclear engineering program took the opportunity provided by the curriculum review to create a new introductory course in computational methods.

The course is similar to those found in many universities as an introduction to radiation interactions and transport with a focus on using advanced codes to solve problems and perform engineering design. The uniqueness of the course was its very early placement in the curriculum.

Motivation

All ABET-accredited engineering programs perform self-assessment using a model that seeks out continuous improvement. In addition to the General Criteria required by the ABET Engineering Accreditation Commission (EAC), programs must fulfill the requirements specified by their professional organization.[1] The American Nuclear Society is the lead professional organization that specifies the program criteria for Nuclear, Radiological, and Similarly Named Engineering Programs.[2]

The last Student Outcome specified in the ABET general criteria for 2016-2017 is, "(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."[2] In addition, the Program Criteria from ANS specifies that "The program must prepare the students to apply advanced mathematics, science, and engineering science, including atomic and nuclear physics, and the transport and interaction of radiation with matter, to nuclear and radiological systems and processes;…"[2]

The USMA nuclear engineering program conducts annual assessments on their Student Outcomes using a variety of tools. Those tools include, among other things, the quantitative evaluation of student performance on their work, final oral examinations, performance on the Fundamentals of Engineering Exam and course and program feedback surveys from students and faculty.

Based on several years of assessment, the program identified that students had difficulty employing and using the modern engineering tools of the nuclear profession. Specifically, many demonstrated poor skills using MCNP or deterministic transport codes and failed to understand the relationship between the results provided by those codes and the radiation interactions and overall operation of a system or design.

Opportunity

The curriculum at the United States Military Academy is unique in the large number of core courses that all students must take to prepare them to become officers in the US Army. These include courses in military history, law and American Politics to name a few. When the Academy completed its curriculum review in 2013, all disciplines cited a lack of depth of coverage as something they would like to address. As a result, engineering majors starting with the class of 2019 were no longer required to take a couple of humanities courses. This change in the core curriculum provided the necessary room to include a new course in the nuclear engineering major. Based on previous years of assessment and input from the Nuclear Engineering ABET Advisory Board, a new course was created in Computational Design in Nuclear Engineering.

COURSE DESIGN AND PLACEMENT

Many undergraduate nuclear engineering programs take the approach that students should know and understand all or most of the theory behind radiation transport before using advanced codes. This is understandable because the potential exists for a "black-box" where the user fails to identify if the code is giving reliable results leading to poor design and erroneous answers. There is also a challenge with waiting until all the theory and practice is complete before introducing computer programs. That challenge is the use of the tools comes too late in the undergraduate curriculum for the students to develop any proficiency. If all students went on to at least one year of Master's education, the course placement would easily be solved, however that is not the case and ABET does not allow for the deferment of meeting criteria to graduate school.

Students

When designing the new course at USMA, the program looked beyond the assessment data and what other programs had done in the past. The approach for the new course focused on the current millennial student. Specifically, we looked at their strengths and weaknesses and the ways in which they learn. Our current students grew up with computers and were very comfortable with the interface. However they had little or no programming experience in compiled languages such as C++ or FORTRAN. They had no familiarity with using DOS or UNIX. Our students, as a whole, were not as strong in math as we would like and sometimes struggled to conceptualize the abstract interactions of particles with matter. They were very good at picking up new programs, not intimidated using cloud-based applications, and were highly proficient using internet resources. They were eager to learn and were confident in their abilities.

Our assessment was that millennials were practiced at learning through a variety of media and were especially adept at using computer tools. Unlike students from previous generations, they didn't see a computer as a "next step" to solving a more challenging problem. They viewed the computer as something they would access and use for anything. This led us to believe that an early introduction of computer tools was within their ability. The question still remained if early introduction was a good choice based on pedagogy.

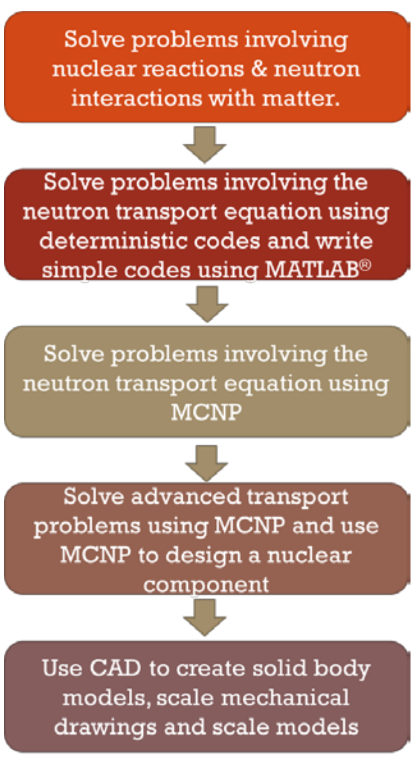

Fig. 1. Course Concept Map for Computational Design in Nuclear Engineering.

Topical Coverage

After examining the student's, we looked at what topical coverage we would like to address. We were limited to creating a one-semester 3.0-credit hour class with no associated lab. We looked at what our students were expected to know and we came up with the course map described in Figure 1. Each of the blocks represents a portion of a 40 – lesson semester. The course would be all individual work. This was to ensure that each student was required to learn and use each of the computational methods. The course was tied together with a final individual design project that linked each of the blocks. Students would submit portions of the design throughout the term as they were receiving instruction with the final design drawn in Solidworks and a scale 3-D model printed to accompany their written report.

Final Placement in the Curriculum

The final decision was made to integrate the new course in the first year of the major. Specifically in the sophomore spring term as the 2nd course in nuclear engineering. This was right after their Introduction in Nuclear Engineering Course. This early placement provided the opportunity to have the students use computational tools in each of their final four semesters. For example, we could create laboratory exercises using the subcritical facility where they would measure results and then model the assembly in MCNP and compare. The students could also use their skills during summer internships at National Laboratories and spend more time on their capstone projects doing design rather than learning tools.

Challenges and Solutions

The first and immediate challenge was trying to teach tools that solved concepts prior to them being introduced to the students and avoiding the "black box" scenario. Everyone in the engineering discipline is familiar with the pitfalls of computing without context. To address this concern, whenever the students were introduced to a tool, they would use it, provide a result and then they were required to give an assessment on the validity of the result. Because they were new to the subject, care was given to not expect the student to enumerate all possible effects of assumptions, boundary conditions etc. but rather to ask them leading questions and then provide constructive feedback on their responses. The feedback would include rational for other things they should consider with the understanding that they had not been formally taught that theory but with the expectation that they would see it again. This requires a program-level integration and implementation of computer design. Each subsequent course in the major was modified to include homework, designs and labs that used the computer codes so the students never go a semester without doing some form of MCNP or SCALE etc. As they gain further theoretical background, they are expected to verify their computation results with hand calculations and experimentation. Essentially this is the reverse of most pedagogical models.

The second major challenge was the lack of a sufficient textbook for the students. Because transport codes are written to handle the most complex engineering problems, many textbooks and resources available are not written for novice users especially those who do not have a significant formal education in nuclear engineering, radiation interaction, and transport. Therefore, to meet our needs, we decided to write our own textbook specific for the course. The book is aimed at addressing all of the course topics shown in Figure 1 on a level associated with our student's skillset. The text was not intended to replace any current text but rather serve as the first introduction to computer programming, decay, transport and computer-aided design.

Another challenge was the student's lack of familiarity with programming. Because of the resources available and limited time in the course, we chose to use MATLAB as an interpreted code for all programing versus a compiled language. We also considered PYTHON but MATLAB was used across the engineering curriculum to include courses our majors take in the Electrical and Mechanical Engineering departments.

The new course required us to have some upgrades to our infrastructure. Namely, we needed an adequate classroom and computing resources. We were extremely fortunate to have gone through a building renovation program which created a state-of-the-art computer classroom complete with multiple workstations and integrated flat-screens and projectors. The challenge was getting all the software necessary loaded and accessible to the students. As with any student, we had them register through the Radiation Safety Information Computer Center (RSICC) and individually request the required code packages for SCALE and MCNP. We then installed the packages on the lab computers. In order to control access, the lab, which also serves as the classroom, is equipped with a Common Access Card (CAC) reader on the door and each of the computers is CAC-accessed. The students cannot enter the lab or log onto the computers without their government-issued CAC card and they are logged off whenever they remove their card.

This lab allowed us to control where the software was installed and we did not have to put it on their personal laptops. However, the students needed to have access to the lab at any time in order to do their work after hours or if they were traveling. We were able to create a network of remote access jump computers that cadets could log on to. The remotes were clones of the lab computers. This allowed us to have up to 100 students using lab resources simultaneously with only 18 terminals in the classroom.

The final pedagogical challenge was to provide and instructional format that would allow the students to follow along in class doing examples and have good references to repeat calculations without providing extensive one-on-one tutoring. The solutions came in the form of video tutorials. We implemented a video capture program used extensively by the on-line gaming community to make a series of around 20 short videos where the faculty member talks through the example problem on the laboratory computer. The tutorials were posted to the course Blackboard site. Some of these include, "Solving as Series of Bateman Equations Using MATLAB" and "Setting up a Materials Card in MCNP." Homework and design problems closely followed the tutorials and they were an invaluable resource which allowed the students to follow along in class without taking extensive notes and provided essential instruction for students who may miss a class for medical or other authorized reasons.

RESULTS

Figure 2 is a graphical representation of how the topical coverage between theory, hand calculations and the use of transport codes changed from the old curriculum to the new curriculum in a selection of nuclear engineering courses taught in the major. Note this is not all of the courses in the major. The new program curriculum emphasizes the use of modern tools throughout the last five terms in their undergraduate degree.

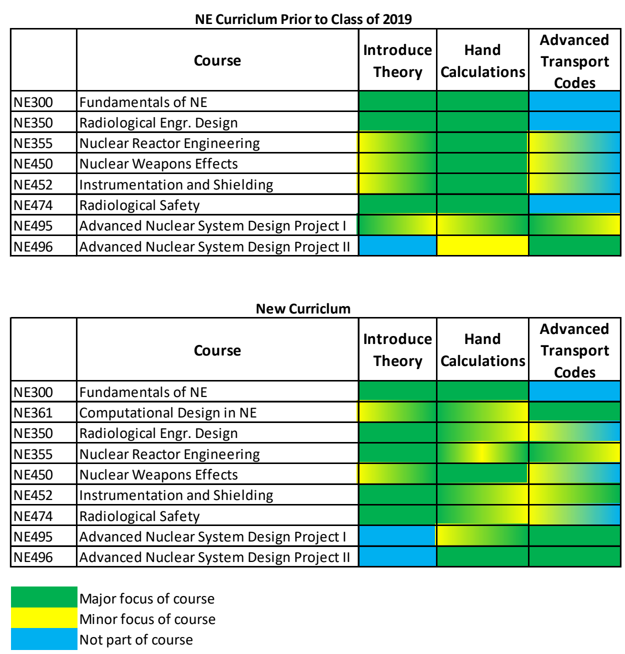

Fig. 2. Comparison of old and new curriculum with the addition of computational design early in the major.

Results of the First Class

The spring of 2017 saw the first class of students to go through the new course. The final course end assessment indicated that the students met or exceeded all of the objectives set out by the program. The exclusive use of individual work ensured that none of the students were by-standers in a group and provided a large dataset for performance that was not skewed by a few motivated students. Each student completed the final design to include the engineered drawings and 3-D printed model. Their individual understanding and skill with the use of the tools varied but they were all successful in meeting the standards.

When the first class of alumni progressed to their next course in Radiological Engineering Design, they were required to use advanced tools in addition to the hand calculations that they were being taught. Specifically, each nuclear engineering student was in a group that included non-nuclear engineering majors and they were the subject-matter experts responsible for the design of a particular product. These included devices such as a water-level gauge, radiation storage container or a metal thickness gauge. The alumni of the computational course would optimize the design in MCNP and draw the final product in Solidworks while verifying the initial calculations by hand taking into account various aspects of the problem that they had not learned earlier such as buildup. By requiring the students to use the code, they were forced to retain some level of proficiency. Once again, we found that our original textbook along with access to the video tutorials was essential to the student's success.

Future Assessment – Capstone and Graduate Success

It is still early in the new curriculum paradigm and it is important for us to continue to assess in each term how the new instructional model is meeting the needs of our students and ultimately the need of our constituency. We will continue to assess and refine the introductory course and the use of those techniques. We are very interested to see the effects on our two-semester capstone projects and the quality and detail of work they produce. We are also interested in how the new curriculum compares in how are students are prepared for graduate studies.

CONCLUSIONS

We looked at our student population, assessed what we wanted our graduates to do, and created a course with sufficient resources to address those goals. We were innovative in our approach by starting out our students using some of the most powerful computational codes available at the beginning of their educational experience. We have accepted risk in the area of a deep theoretical understanding of the inner workings of the transport code and tried to mitigate that risk by creating a text and instruction throughout the entire program that emphasizes the importance of verification of results. Our text and video tutorials are designed for the novice user but continue to be an essential resource for students in subsequent courses.

One of our recent graduates from the class of 2017, Second-Lieutenant Adam Reynolds went directly from West Point to the Massachusetts Institute of Technology as a Draper Scholar. Within weeks of starting the program he wrote to the Nuclear Engineering Program Director and stated, "I wish I could somehow communicate to future NE graduates how important and useful knowing a transport code is in research. There was definitely an attitude of 'why does this even matter?' in my graduating year group." With the creation of a course dedicated to the instruction in advanced tools at the start of their major and integrating the use of those tools throughout the curriculum, we hope to better prepare our students for the future.

REFERENCES

1. ABET, *Accreditation Policy and Procedure Manual*, Baltimore, Maryland, ABET (2017).
2. ABET, *Criteria for Accrediting Engineering Programs*, Baltimore, Maryland, ABET (2016).