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Repurposing MCNP use for nuclear engineering demonstrations while applying Physics Education Research (PER) best practices

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Abstract:
This paper aims to employ best practices in Physics Education Research (PER) while repurposing MCNP from the valued monte-carlo transport code used to support research to a powerful demonstration tool for educating students of nuclear engineering. Thirty years of PER has validated the need to complement traditional lectures with some activity-based learning. Educators widely accept the notion that lectures alone fall short in maximizing undergraduate student gains in learning and understanding, and the gap is most severe when evaluating student conceptual learning. Physical demonstrations often help to bridge this gap, but when misused they can perpetuate student misconceptions rather than resolve them. A recent PER study published by the *Mazur Group* at Harvard University observed that even with quality demonstrations students' prior knowledge may interfere with students observing the demonstration correctly. Those researchers systematically evaluated demonstration techniques and concluded that the best practice is to have students predict outcomes before observing demonstrations. In this work, assessment data from our capstone individual oral examinations administered in the month before graduation was used to identify shortcomings in conceptual understanding. The five dominant misconceptions were in certain areas of radiation health effects, detector operations, fission cross sections, reactor kinetics, and neutron scattering. Elements of these five broad concepts were chosen to be modeled in MCNP with the aim of complementing MCNP results with a simple PowerPoint animation. Specific misconceptions were targeted in the demonstration. A pedagogical model referred as *U-POSE* methodically sequences students through the five steps of these proposed MCNP demonstrations: Understand, Predict, Observe, Synthesize, and Explain. The final step culminates with students explaining the concept by authoring a representative concept question with a solution for a peer. This paper discusses an example for executing these MCNP demonstrations and provides preliminary assessment plan in improving student gains in understanding these topics.

Key words: modeling & simulation, education research, nuclear

Introduction

In 1996, The American Association of Physics Teachers (AAPT) began holding new faculty workshops to help new faculty "understand how to become more effective educators and support their quest to gain tenure."[1] The next year, Harvard University physicist Eric Mazur published his manual on *peer instruction* and began a campaign to question existing university teaching methods and to promote new practical classroom techniques that involved immediate and anonymous student assessment using *clickers*.[2] Since then, many physics classrooms have evolved into activity-based studios for student learning and assessment, and Physics Education Research (PER) has emerged as a research field at many universities.[3] In 2005, the revered Physical Review Journal of the American Physical Society introduced its Special Topics in Physics Education Research which has grown to about 50 peer reviewed journal articles in 2013.[4] This philosophical change in the way physics teachers think about student learning has been accompanied by new classroom technologies that included video analysis techniques, student response cards (clickers), and a robust suite of sensors that bring classrooms and laboratories to life with the ease of plug-and-play data acquisition. Even standard physical demonstrations have been rethought and scientifically examined. PER research has found that student prior knowledge (and misconceptions) can interfere with *correct* observations. Even with the best executed physical demonstrations, pedagogy matters. Recently, Miller, *et al*, examined the timing of student predictions and found that "students are 23% more likely to observe a demonstration correctly if they predict the outcome first."[5]

Predictions can often be driven by intuition, especially in mechanics where many concepts are supported by everyday observations. Physical demonstrations are relatively easy to construct by varying mass, height, roughness, or paths. In electricity and magnetism, there are greater challenges in offering the necessary visualization, but demonstrations can present causality by varying charge, potential, dielectrics, or geometry. Unfortunately, in nuclear engineering, the development of physical demonstrations are challenged by the random nature of radioactive decay, radiation safety constraints, and sometimes the large and expensive facilities needed to establish the particular interaction to demonstrate. The fallback for educators is to show a graph (e.g., fission cross section for ^{235}U) and an equation (e.g., fission rate) and require students to do calculations on homework and exams. Sometimes misconceptions are revealed when students are asked conceptual questions about their calculations. This can arise during oral examinations or during exam questions that require students to explain an interaction.

The Los Alamos Monte Carlo transport code MCNP6 can offer a modeling and simulation capability to fill the gap in nuclear engineering physical demonstrations. MCNP can model the transport of any particle at a variety of energies and temperatures for any user-defined geometry and material. It plots geometry and graphs results in a variety of formats. Its results are under constant V&V (verification and validation) efforts and offer a means to peer-reviewed publication in the nuclear field.[6] For complex problems, computing power might be its only limitation.

The aim of this paper is to employ best practices in Physics Education Research (PER) while repurposing MCNP from the valued Monte-Carlo transport code used to support research to a powerful demonstration tool for educating students of nuclear engineering. In this work, assessment data from oral examinations administered in the month before graduation was used to identify shortcomings in conceptual understanding. The five dominant misconceptions were in certain areas of radiation health effects, detector operations, fission cross sections, reactor kinetics, and neutron scattering. Elements of these five broad concepts were chosen to be modeled in MCNP6 with the aim of complementing the Monte-Carlos results with a simple PowerPoint animation. Specific misconceptions were targeted in the demonstration. A pedagogical model referred as *U-POSE* methodically sequences students through the five steps of these proposed MCNP6 demonstrations: Understand, Predict, Observe, Synthesize, and Explain. The final step culminates with students explaining the concept by authoring a representative concept question with a solution for a peer. This paper provides a model for nuclear engineering demonstration and proposes means for sharing demonstrations created using this model.

The Problem

In nuclear engineering studies at the U.S. Military Academy, the NaI (th) scintillator radiation detector is a workhorse in our laboratory courses, and it is analyzed in depth in our radiation detection course. Students use the detectors to make measurements, calculate efficiency, determine FWHM, examine secondary interactions, and assess shielding characteristics of materials separating the source and the detector. Our problem sets and written exams assess student achievement on calculations relating to these type tasks. And the results are good. But, what our students never see are the visible photons produced when the gamma rays interacts with the scintillator crystal, how that light makes its way to a photocathode to produces electrons, how the electrons numbers are multiplied at different dynodes, and how those electrons generate the pulse that enables radiation detection. A revelation in my career as an educator came last year on the bus to a nationally recognized design competition. One of my best students ever had advanced through preliminary competitions and on the bus was considering possible questions from the next set of judges. Despite demonstrated excellence in our laboratory courses and the detector course, he approached me on the bus to ask me “How does a scintillator detector work?” I gave him a brief tutorial and sketched a few figures that I am certain he had seen before. Yet, he responded that he had never really understood how the detector worked until then.

The problem is that we as educators have relied on student performance on calculation problems to indicate their conceptual mastery. In nuclear engineering, the validity of these assessments is confounded with the difficulty of teaching nuclear concepts through use of physical demonstrations. As mentioned earlier, many nuclear interactions become probabilistic, and issues of safety and facility costs restrict physical demonstrations. And even with the scintillator detector example, what if any of the interactions can be seen? Not only are we assessing the wrong behaviors, we may also be failing to effectively teach the concepts.

The Learning Model, U-POSE

The U-POSE acronym is intended as both a five-step learning process and figuratively an end state requiring the student to *compose* a question that best measures conceptual mastery of a peer. The process employs the “predict before observing” best practice in physics demonstrations and the modeling/simulation capacity of MCNP6. It also aspires to guide the student across cognitive mastery boundaries defined within Bloom’s taxonomy.[7] This is achieved through effective visualization and analysis of MCNP6 results but more importantly with entrusting the student with peer educational responsibilities. The logistical consideration is to execute these activities in groups of 2-3 students during a 1 hour meeting period.

The five step process is briefly discussed below.

Understand. This is Bloom Level 1. Students are shown a model equation or a figure that helps them to build some fundamental understanding of causation.

Predict. This is Bloom Level 2. Students are introduced to what is modeled or simulated. For nuclear engineers, they need to understand the MCNP6 input card. To do this, simple PowerPoint figures and animations are used to show the source, transport media, and calculation type (*tally*). The prediction relates to a comparison when a variable like energy, density, or geometry is changed.

Observe. This is Bloom Level 3. Students are provided a short and simple MCNP6 input card for them to execute. Specific and detailed instructions are given to guide the students through the intended observation. They make changes to the input card and conduct a parametric study to collect results, visualize effects, and to evaluate their predictions.

Synthesize. This is Bloom Level 4/5. Students analyze their MCNP6 results looking for trends and anomalies to trends. They shift roles from discovery and novice learner to considering how others learn. They compose concept questions intended to assess mastery of the studied interaction.

Explain. This is Bloom Level 6. Students explain how they crafted their concept question and what learning objective it was intended to assess. Two techniques are used, one with direct interaction with a peer, and the other using a short video up to 2 minutes long.

An Example Product

Neutron interactions with target material are strongly governed by the incident neutron energy. The fission of ^{235}U is one frequently studied neutron interaction. For most nuclear reactors in the US, the interaction rate is greatest for thermal neutrons. But, most neutrons are born (emitted) fast and much of the study of reactor multiplication factors rests with slowing these fast neutrons to thermal energies. This is the example selected for this paper and the MCNP6 input examines how fission rate varies with neutron energy.

Since the last two steps of U-POSE rest with the creativity and unique approaches of the students, the first three steps will be highlighted below.

Understand. Understanding rests with the fundamental equation for the reaction rate and graph of the microscopic fission cross section for ^{235}U.

$$F = \sigma_f INAX \qquad \text{(Equation 1)}$$

F = reaction rate

σ_f = microscopic fission cross section

I = neutron source intensity

N = target number density

A = neutron beam area

X = target thickness

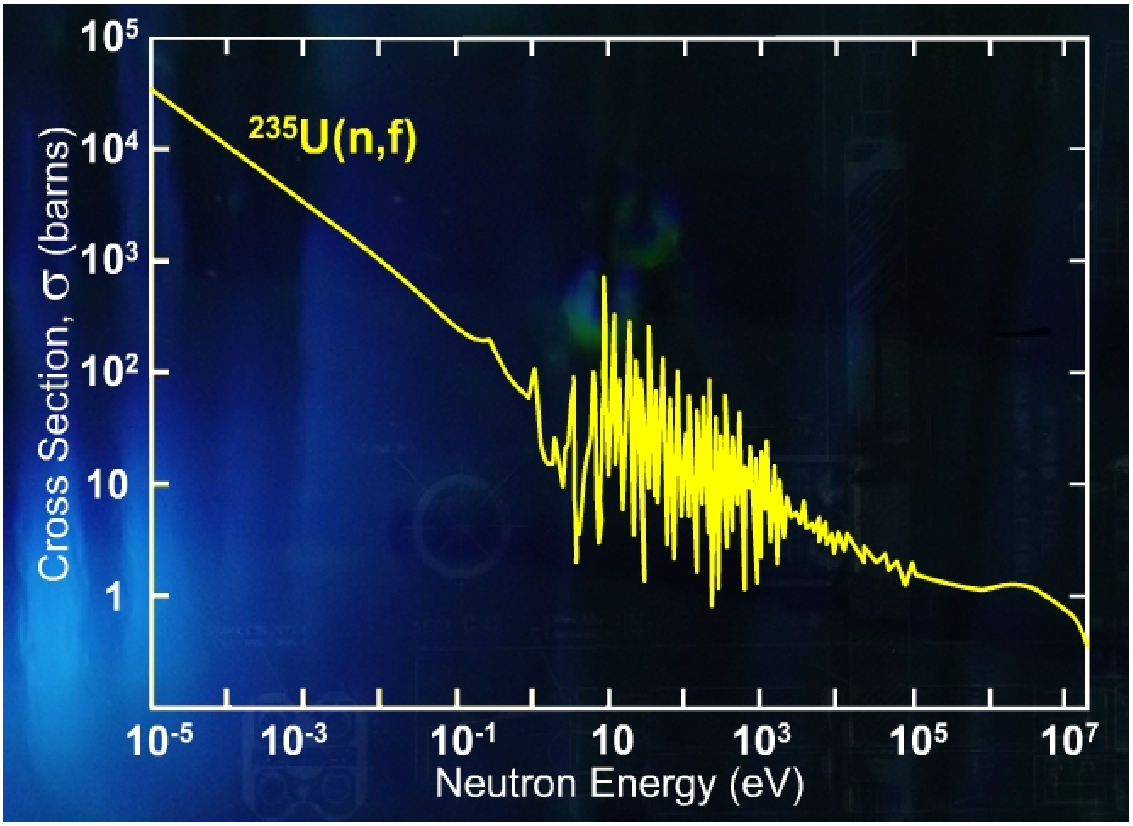

Figure 1. ^{235}U Microscopic Fission Cross-Section

Predict. A simple model is used for the fission of highly enriched uranium. The source neutrons are emitted isotropically at the center of an HEU spherical shell with thickness of 0.5 cm. The neutron energy is monoenergetic, 0.0001 eV, and the calculation is for fission energy deposited in the HEU shell. The animation will be presented during the conference talk. This calculation takes less than 1 minute on a 32-bit, 2.5 GHz laptop. Student use the input and vary the neutron energy to assess the change in the fission reaction rate.

```
Fission Energy--
1      0                -1       imp:n=1 $ Air inside
2      1   -18.732854   -2 1     imp:n=1 $ HEU
3      0                -99 2    imp:n=1 $ Air void outside box
99     0                 99      imp:n=0 $ zero-importance outside

1      so 2              $sphere with r=2 cm
2      so 2.5            $sphere with r=2.5 cm
99     so  3             $Surface to outside world

c      Neutron source
sdef   pos=0 0 0 par=1 erg=1E-10  $E=thermal,isotropic at origin
C Russian HEU [PNNL source]
m1     92234.66c 0.009722    $HEU, atom fraction
       92235.66c 0.898982
       92236.66c 0.003798
       92238.66c 0.087498
mode n
phys:n
e0     0 1E-5 .14 99i 14 t   $99 steps 140 kev to 14 MeV
f7:n 2                       $fission energy deposition
nps    100000
prdmp 2j 1
print
dbcn  145353571
```

Figure 2. Simple MCNP6 input for fission energy from HEU

Observe. Students can replicate the linear, “1/v” region of the ^{235}U microscopic fission cross-section by simply varying the neutron energy from thermal energies to about 1 eV. This is seen in the log-log plot shown in Figure 3. Students are then asked to increase the neutron energy in small increments. They will modulation of the reaction rate as predicted with the resonance region of the ^{235}U microscopic fission cross-section.

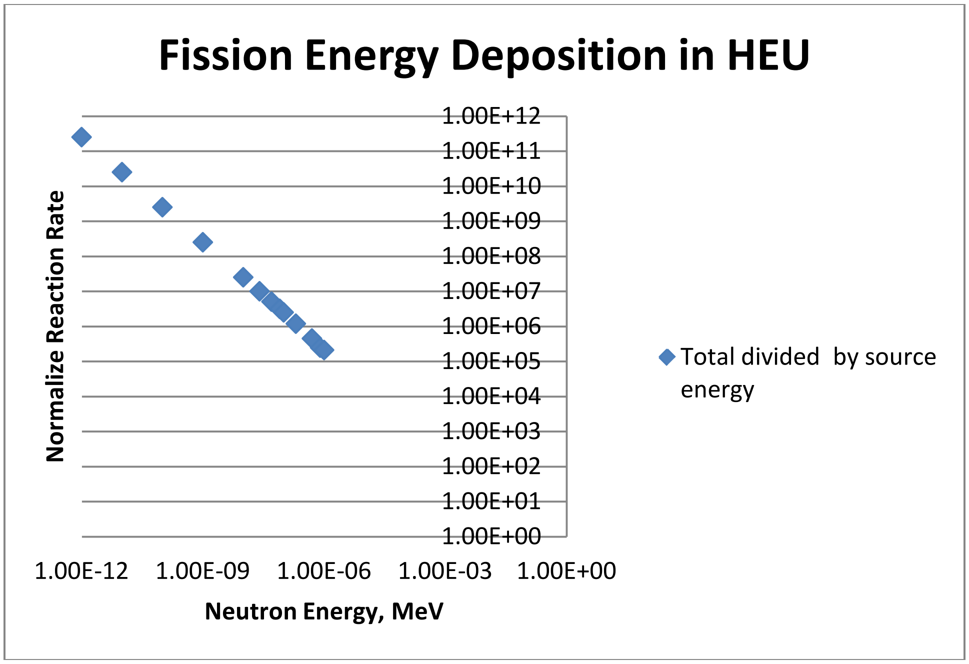

Figure 3. Log-log plot of normalized HEU fission rate

Assessment Plan

The U-POSE demonstration learning model will be introduced in nuclear engineering courses at my university. Assessment data will be taken from the oral exams just prior to graduation. Additionally, survey data will be collected and an archive of the student prepared questions and their videos will be recorded and assesses for future use in our classes.

Future Work

These demonstration developments using MCNP6 are being shared with the Los Alamos developers. While this work does not directly contribute to new scientific discovery, it does contribute to building a workforce comfortable with using MCNP6 for future graduate studies or engineering employment. If the assessment results show some increased student learning, we would collaborate with Los Alamos to make the demonstration modules available to other MCNP6 users and nuclear engineering educators.

References

[1] http://www.aapt.org/Conferences/newfaculty/nfw.cfm

[2] Eric Mazur, *Peer instruction, A User's Manual*. New Jersey: Prentice Hall, 1997.

[3] AAPT New Faculty Workshop, Funded by National Science Foundation Division of Undergraduate Education Grant DUE-0813481, DUE-0121384, and DUE-9554738.

[4] TUES Research Grant, Funded by National Science Foundation, Division of Undergraduate Education, Transforming Undergraduate Education in Science, Grant TUES-0919264.

[5] PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH 9, 020113 (2013)

[6] Los Alamos, Monte Carlo N-Particle Transport Code, MCNP6,

[7] http://teaching.uncc.edu/articles-books/best-practice-articles/goals-objectives/writing-objectives-using-blooms-taxonomy