A Problem-Based Introduction to Nuclear Sciences

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Funded by the US Department of Energy (DE-FG07-03ID14531) under the Innovations in Nuclear Infrastructure and Education grant program, we have designed and are implementing a problem-based, web-assisted introductory survey course, Utilization of Nuclear Technologies in Society. The goals of the course are to provide non-majors a meaningful introduction to the many applications of nuclear science in a modern society and to stimulate student interest in academic studies and/or professional involvement in nuclear science. Rather than learning about nuclear science, the course requires students, working in collaborative groups, to solve one of three authentic nuclear problems in five different domains, including elemental and content analysis, materials modification, radiation gauging, solid/liquid Interface, and heart imaging.

Why Problem-Based Learning?

Problem-based learning (PBL) emerged in medical schools as a method for better preparing physicians to be problem solvers. From there, PBL has migrated to law schools, business schools, and engineering colleges. In fact, several engineering programs around the world (e.g., Aalborg University on Denmark, McMasters University in Canada, Monash University in Australia, Manchester University in England, Glasgow University in Scotland, Eindhoven University in the Netherlands, and Republic Polytechnic in Singapore) deliver the majority of their curricula via PBL. Additionally, PBL modules or courses have been implemented in numerous engineering programs, including biomedical engineerin[1], chemical engineering[2], software engineering [3,4], thermal physics[5], design processe[6], aerospace engineering [7], computing [8], civil engineering, microelectronic[9], construction engineering[10], control theory [11]. Limited efforts have even examined the use of PBL for engineering workplace training[12].

PBL has been shown to be effective in supporting both content knowledge and professional reasoning skills. Two early meta-analyses [13,14] found that traditional, basic-sciences medical students perform better than PBL students in basic science knowledge acquisition, while PBL students performed better than traditional students in clinical knowledge acquisition. However, other studies have shown that PBL is more effective than traditional methods in promoting in-depth understanding of content [15, 16, 17]. Recent research[18] has shown that when the University of Missouri medical school implemented PBL as a major component of their curriculum, the mean scores on both the knowledge acquisition and the clinical improved by a standard deviation. PBL is effective because the knowledge that is acquired while solving problems is better comprehended, more transferable, and retained longer. An engineer must possess both content knowledge and context-specific problem-solving skills in order to function effectively as an engineer. However, content knowledge alone is insufficient for solving engineering problems. The best predictor of problem-solving skill is prior experience. PBL focuses on engaging students as soon as possible in acquiring problem-solving experience.

PBL courses on engineering can help engineering students to think like engineers. Very little empirical research has been conducted on PBL implementations in engineering. Rather, reports of engineering PBL programs are most often descriptive, providing only perceptions of students and faculty satisfaction to justify the efforts. In other STEM fields, Lohman and Finkelstein[19] found that first-year dental education students in a 10-month PBL program improved significantly in their near transfer of problem-solving skill by an average of 31.3% and far transfer of problem-solving skill increasing by an average of 23.1%. Based on their data, they suggested that repeated exposure to PBL was the key for facilitating the development of problem-solving skills. Additionally, when the medical students were tested with their application of knowledge in an essay exam and a standardized patient exam, PBL students outperformed traditional students [20]. Other evidence from work places include rapid development of expertise of the first-year PBL residents in the emergency room and the employers' comment that students need to "think for themselves and solve problems upon graduation"[21]. Other engineering programs have reported similar results. The McMasters University's PBL chemical engineering graduates were praised for their outstanding problem-solving skills and job performance compared to other new employees who needed to be trained for one to one and a half years to be able to solve problems independently. Graduates from PBL engineering program in Denmark perceived that they had higher levels of skills in communication, ability to define engineering problems, ability to carry out a project, ability to carry out technical research and development, cooperating with different people[22]. An evaluation of 25 years of experience with PBL in engineering shows in very clear terms the superiority of problem based learning compared to more traditional learning strategies[23].

There are several justifications for designing and developing PBL programs in nuclear engineering. First, we were unable to find any reports of any effort to implement PBL in nuclear engineering. Second, few of the PBL projects in engineering education have ever reported any research related to their methods. The only researchable issue that has been reported compares the effects of PBL on declarative vs. procedural knowledge. Many educators believe that in PBL coursework, the focus on problem-solving know-how reduces the acquisition of domain knowledge. Matthew and Hughes[24] refute that claim, arguing that it is difficult to quantify whether PBL works. However anecdotes from employers suggest PBL students are more capable of independent work their first year out. We are planning to implement and research the efficacy of the learning environments that we develop.

PBL Environment for Utilization of Nuclear Technologies in Society

In order to facilitate a problems-based approach to teaching Utilization of Nuclear Engineering in Society (UNES), a web-enabled, problem-based learning environment (PBLE) is being developed (http://ne2201.missouri.edu). The UNES PBLE is based on a *Precursor-Action-Results-Interpretation* (PARI) method. Under the PARI method, subject matter experts are consulted in order to identify real-world, complex problems and generate viable solutions to these problems. Instruction is then developed based on these problems and expert solutions. The PARI method is intended to provide both breadth and depth of learning, and it engages learners in tasks that require learners to integrate and utilize their system, procedural and strategic knowledge[25].

Based on an analysis of nuclear engineering practice, we identified five common applications of nuclear science. These problem domains (elemental and content analysis, materials modification, radiation gauging, solid/liquid Interface, and heart imaging) were also chosen because of their potential interest to students. Within each of these problem domains, we identified three different problems (see Table 1). We identified subject matter experts for each of those problems and conducted extensive interviews with each of them to elucidate the problem, the alternative solutions, and the reasoning processes for choosing one method over another.

Table 1. Problem Domains and Domain-Specific Problems

Problem Domain	**Domain-Specific Problem**
Elemental and Content Analysis	▪ Application of Nuclear Methodologies to Determine the Baseline Selenium Status in Human Subjects ▪ Source Identification of Obsidian Artifacts ▪ Determination of Chemical Composition Using SEM/EDS
Material Modification	▪ Food Irradiation ▪ Sterilization of Medical Instruments ▪ Modification of the Mechanical Properties of Materials
Radiation Gauging	▪ Determination of the Thickness of Aluminum Sheet for Beverage Cans ▪ Measurement of the Thickness of Adhesive on a Bandage ▪ Gauging Fluid Levels in a Sealed Tank ▪ On-line Measurement of a Solid/Liquid Interface
Radiation Imaging	▪ Gamma Camera Imaging for Diagnosis of Bone Cancer ▪ PET Imaging for Diagnosis of Lung Cancer ▪ Nuclear Imaging of a Beating Heart
Nuclear Power Systems	▪ Design of a Nuclear Battery for a Space Mission ▪ Design of a Nuclear Reactor Based Propulsion System ▪ Design of an Emergency Lighting System for a Remote Location

For each problem domain, users of the learning environment are presented with a simulations of an authentic, real-world problem in the form of a story, for which they are required to provide a viable solution. For example, for the problem "Determine the Baseline Selenium Status in Human Subjects":

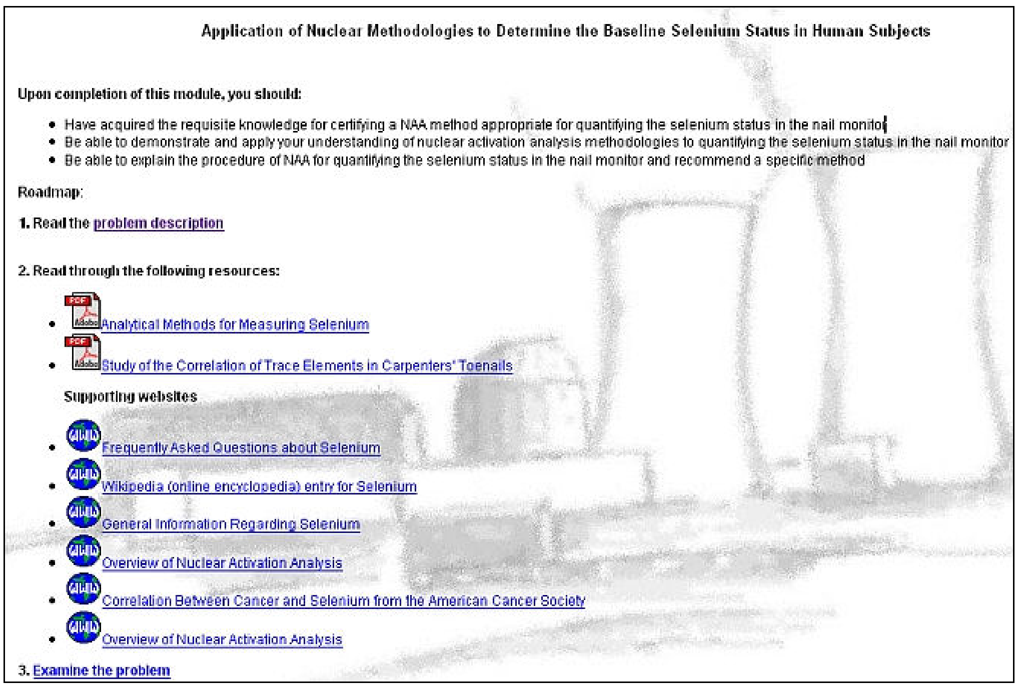
> "A large medical company, Meditech, has contacted the firm you work for, Baker Engineering, with an interesting contract. A large fraction (>25%) of the U.S. adult population has a sub-optimal selenium status. Consequently, Meditech needs a methodology by which a reliable measure of baseline selenium status can be accurately determined from a self-collected biologic monitor of selenium intake. Meditech has asked Baker Engineering to propose an appropriate method for measuring the baseline selenium status in human subjects."

As with most authentic problems in practice, the problems that learners are presented can be solved in a number of different ways. This presents a significant challenge for novice learners who are just learning the concepts of nuclear science. Because learning new concepts and immediately applying those concepts to complex problems imposes a high degree of cognitive effort, the UNES PBLEs have been designed with support to help mitigate learners' cognitive effort and help them through the subsequent problem solving process. In addition to related articles and websites, the UNES learning environment provides learners support in the form of a problem solving scaffolding. The scaffolding is designed to help learners' solutions model expert thinking by emulating the decision-making processes elucidated from subject matter experts.

The problem solving scaffolding consists of three separate sections.

- Determine a radioactive analysis method
- Sample Preparation
- Determine detection method

In the first section, learners are required to determine a the most method for solving the problem, while at the same time considering the various criteria essential to a successful proposed solution. In terms of PARI, this section of the argument scaffolding helps learners identify what *action* will be carried out to solve the problem. For example, for the problem "Determine the Baseline Selenium Status in Human Subjects".



<u>1. Determine a method</u>. Rather than asking novices to generate original solutions, we provide them four plausible options from which they choose.

1.) It has been determined that you will be using nuclear activation analysis (NAA) to determine the selenium level in a biological monitor. From the following choices, which do you think is best suited to measure the selenium level in a biological monitor?

A. Prompt Nuclear Activation Analysis (PGNAA)
B. Delayed Nuclear Activation Analysis (DGNAA)
C. Instrumental Nuclear Activation Analysis (INAA)
D. Radiochemical Nuclear Activation Analysis (RNAA)

After learners have selected the response they believe to be most appropriate, they are asked to justify their decision (determine the *precursor* to their proposed *action*). For example, for the problem "Determine the Baseline Selenium Status in Human Subjects":

1a.) Why did you choose to use this particular method? What are the similarities and differences between the above methods? Discuss in terms of:

- What you learned from the readings (be sure to relate your answer to the problem)
- Advantages and disadvantages of the above methods in terms of:
  - Time to complete the analysis
  - Cost to complete the analysis
  - Accuracy of the chosen analysis method

If the justification does not match the method, feedback is provided and the students must begin the selection process again. All student responses are automatically saved and summarized for the professor's review, so that students will not engage in random button clicking. This cycle of determining *actions* and *precursors* is repeated until learners have constructed a viable solution based on reasoning that emulates expert thinking. For the problem "Determine the Baseline Selenium Status in Human Subjects", we also ask students to provide information that provides evidence of their domain knowledge. This information is need to develop a full justification of the method chosen. These are questions or issue that novices would not likely consider.

<u>2. Sample Preparation</u>. In this section, students must learn enough nuclear science to determine the best method for preparing the sample. Again, questions scaffold their decision-making.

<u>Essential Criteria</u>

2.) The toe and finger nail samples you have received must be prepared for analysis in order for them to be analyzed. How will you prepare your samples for analysis?

2a.) Why is it important to prepare your specimens in this manner? Discuss in terms of:

- preparation method
- sample integrity
- potential interferences

3.) For the following nuclides

Se-77m
Se*-75

3a.) Provide the half-lives of these nuclides.

3b.) Which of these nuclides will take longer to decay? Why?

3c.) Which of these nuclides will take longer to count? Why?

3d.) Based on the answers you provided above, analysis of which radionuclide will be more cost effective? Explain.

<u>3. Determine detection method</u>. The third part of the decision-making process is to determine the method for detecting radioactivity in order to complete the chosen method. This process entails two parts: determining the radiation that will be used and determining

how to measure it, including the detection system, measurement procedures, and measurement method.

4.) What type of radiation will you measure?

A. alpha particles
B. gamma rays
C. beta particles

5.) How do you propose to analyze the results of your nuclear activation analysis? Discuss in terms of:

- detection system
- measurement procedure
- method of measurement

Interpreting Results. When learners complete the first section of the problem, they have constructed a viable solution to the problem based on their own reasoning and modeled after expert thinking. The second section of the scaffolding requires learners to interpret the results of their proposed solution. This section of the problem solving scaffolding encompasses *results* and *interpretation* in terms of PARI. To draw from the example of "Determine the Baseline Selenium Status in Human Subjects":

6.) Briefly discuss why the NAA method you chose is favored over other nuclear or non-nuclear methods that can be used to quantify selenium in a biological sample. Be sure to use examples from the reading and relate your response to the problem.

Examples of non-nuclear detection methods include (you only need to discuss two of the following):

- Mass spectroscopy
- X-ray fluorescence
- Biochemical measuring of enzymes
- Atomic absorption
- Optical emission

Once learners have completed the second section of the problem solving scaffolding they select "submit" and are taken to the third and final section of the environment. In this section, learners are provided with a summary of their responses and given the opportunity to revise them. If learners are satisfied with their responses they can submit the responses to the instructor. These responses are then immediately available for assessment or monitoring by the instructor.

Course Design

Students work in collaborative groups to solve one problem for each problem domain in three weeks. There are three problems per domain, meaning that different groups will be working on different problems and comparing and contrasting their findings during each 3-week period. Each group will solve a total of five problems in one semester.

In addition to the scaffolds, each UUNES PBLE contains links to background materials. They need to study these materials in order to be able to meaningfully answer the questions posed by the scaffolds. The assumption that underlies all PBL is that what students learn in the context of solving problems will be better comprehended and retained.

These PBLEs are being evaluated during the spring semester 2005. After they are validated, they will be made available to nuclear science educators everywhere.

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