Investigation of an Online, Problem-Based Introduction to Nuclear Sciences: A Case Study

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Abstract

An online, grant-funded course on nuclear engineering in society was developed at a large Midwestern university with the goal of providing non-majors a meaningful introduction to the many applications of nuclear science in a modern society and to stimulate learner interest in academic studies and/or professional involvement in nuclear science. Using a within-site case study approach, the current study focused on the efficacy of the online learning environment's support of learners' acquisition of knowledge and the impact of the environment on learners' interest in and beliefs about nuclear sciences in society. Findings suggest the environment successfully promoted learning and had a positive impact on learners' interests and beliefs.

KEYWORDS: Online learning environments, problem-based learning, nuclear engineering, learner interest, learner beliefs

1. Introduction

Funded by the US Department of Energy (DE-FG07-03ID14531) under the Innovations in Nuclear Infrastructure and Education grant program, a problem-based, online, introductory survey course, "Fulfilling Madame Curies' Dream: Utilization of Nuclear Engineering in Society" (UNES), was developed for a department of nuclear engineering at a large Midwestern university. 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. These goals are of particular interest to the field of nuclear science, as the need for qualified nuclear personnel is increasing.

The UNES course implements a problem-based approach to learning. Such an approach to learning is virtually unknown to the field of engineering in general and nuclear engineering specifically [1]. Engineering graduates are ill-prepared to function professionally after completing their program [2]. Indeed, engineering schools in the United States do not sufficiently prepare learners to solve problems [3]. Further, the problems that engineering students do solve are not authentic, and engineering curricula often remain dominated by teacher-centric programs utilizing lectures as the primary mode of instruction [4, 5]. There is a need in engineering education for learner-centered curricula that focuses on authentic learning activities [3]. Thus, 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. Third, anecdotes from employers suggest PBL students are more capable of independent work their first year out.

2. Instructional Design of the Learning Environment

Based on an analysis of nuclear engineering practice, we identified five common applications of nuclear science. These problem domains were also chosen because of their potential interest to learners. Within each of these problem domains, we developed three different problems (Tab. 1). We then identified subject matter experts for each of those problems and conducted extensive interviews with each of the experts to elucidate the problems, alternative solutions, and reasoning processes for choosing one method over another. Learners working individually and/or in collaborative groups were tasked to solve these problems.

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
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

Problems within each of the five domains resemble case analysis and dilemma-type problems [6]. For each problem domain, learners are presented with a real-world, ill-structured problem in the form of a story, for which they are to provide a viable solution. An example problem from the elemental and content analysis domain, "Determine the Baseline Selenium Status in Human Subjects," is as follows:

> "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."

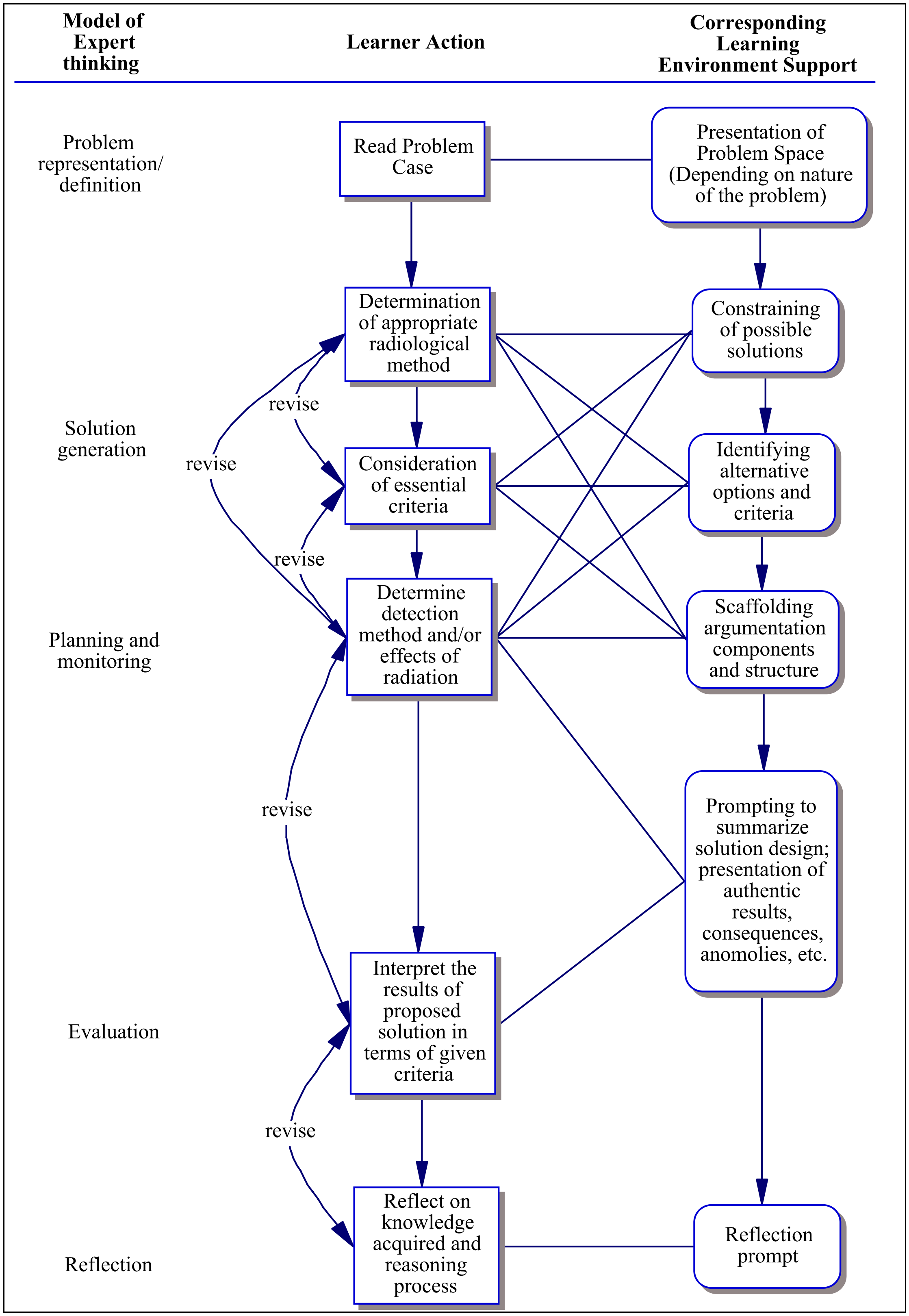
As with most authentic problems in practice, the problems that learners are presented can be solved in a number of different ways. This presents a significant challenge for novice learners who are just learning the concepts of nuclear science. Because learning new concepts and immediately applying those concepts to complex problems imposes a high degree of cognitive effort, the UNES learning environment was designed with support to help mitigate learners' cognitive effort and help them through the subsequent problem solving process.

In addition to a face-to-face instructor, related articles, and websites, the UNES learning environment provided learners support in the form of a problem-solving scaffold (Fig. 1). The problem-solving scaffold consists of four separate sections:

1. Determination of an appropriate radiological method
2. Consideration of essential criteria
3. Determination of a detection method and/or effects of radiation
4. Interpretation of results and reflection

In all four sections, learners' responses were automatically saved and summarized for the instructors' review. In the first and second section, learners were required to determine the most appropriate method for solving the problem, while at the same time considering the various criteria essential to a successful proposed solution. Rather than asking novices to generate original solutions, we provided them constrained options from which they chose. After learners selected the response they believed to be most appropriate, they were asked to justify their decision, after which expert feedback was provided. Additionally, learners were required to provide evidence of their domain knowledge, which was necessary to develop a full justification of the method chosen. The third section entailed two parts: determining a radiation detection method and/or determining the effects of radiation. This included such components as the detection system, measurement procedures, and measurement method. The fourth section required learners to interpret the results of their proposed solution. The problem-solving scaffold described here was designed to help learners' solutions model expert thinking by emulating the decision-making processes elucidated from subject matter experts. This problem-solving scaffold is discussed further in [1]. Given the multiple affordances of the learning environment, we hypothesize that learning is effectively supported. Further, we believe solving authentic problems may not only promote learning, but also may promote learners' interest in the field of Nuclear Sciences.

Figure 1: Diagram of problem-solving scaffold based on expert reasoning processes.



3. Learner Interest and Beliefs

Learner interest is often viewed as either situational or individual. Situational interest is state based and is often triggered by environmental and task stimuli while individual interest is more dispositional and develops slowly over time [7]. We focused on situational interest in this study, as it is unlikely that individual interest would be impacted in only one semester,

Research suggests that presenting content in an authentic manner will not only “catch” learners situational interest, but it will also “hold” this interest [8, 9]. Such authentic presentation of problems in the UNES environment draws the attention of learners, effectively enacting situational interest in the content. Additionally, situational interest may be sustained due to the personal relevance and utility that learners perceive. Perceptions of personal relevance and utility value are likely to cause learners to deeply engage in the learning process. As [10] reports, greater understanding can be a major influence on belief change. Thus, it is reasonable to conclude that beliefs about nuclear technologies may be impacted due to learners’ deeper understanding of how nuclear technologies work.

4. Methodology

4.1 Research Questions

The literature suggests the UNES environment may promote learners’ situational interest in the field on Nuclear Sciences, and we speculate this interest may impact beliefs about the field. Of course, if learning is not properly supported, neither of these assumptions are plausible. Thus, the following research questions were investigated in the current study:

RQ1: Do the available resources, problem-solving scaffold, and overall structuring of the learning environment support learning?

RQ2: Do the pedagogical assumptions of the learning environment effectively promote learners’ situational interest in the field of nuclear sciences?

RQ3: What impact, if any, does the learning environment have on learners’ beliefs regarding nuclear technologies in society?

4.2 Case Study

We used an intrinsic, within-site case study methodology for data collection and analysis [11-13]. This tradition of qualitative inquiry provides a means to examine differing perspectives regarding a phenomenon under investigation. A case study explores a ‘bounded system’ over time through detailed, in-depth data collection involving multiple data sources, such as interviews, observations, and artifacts [14]. This case study focused on the specific case of the UNES course during the winter 2006 semester.

4.3 Data Collection and Analysis

Data were collected from interviews, observations, and artifacts over the course of the semester in order to provide data triangulation and saturation, as well as to ensure trustworthiness of findings. Participants consisted of four learners enrolled in the UNES course who consented to participate in the study. Three learners were seniors and one was non-degree seeking. Eva and Zuri were industrial engineering majors, Julia was a nuclear medicine major, and Patrick was a nuclear worker. Data were gathered using various recording methods such as written field notes, observation notes, and audio recordings. Classroom observations were conducted over the course of the semester, and emergent themes were identified. From these themes, two semi-structured interviews were created and conducted during the last two months of the semester with all participants. Approximately 80% of all classes were observed and all participants were formally interviewed on two separate occasions. Prior ethnography [15] was conducted during the pilot phase of the course in the Fall 2005 semester.

We used descriptive and interpretative techniques to analyze the data. Data collection and analysis took place concurrently. All data was reviewed to gain a sense of the whole, relevant literature was reviewed and impressions noted, and emergent themes were identified and recorded in memos. These memos were then reviewed and initial interpretations and hypotheses were made. After this, data were re-read and coded by the research team. To ensure inter-rater reliability, norming sessions were held, coding was discussed in-depth, codes were revised, and all data were re-coded collaboratively by the team. Iterative, open coding was used [16] in which we organized the data, sorted them, and built a cohesive whole by putting them all back together.

5. Findings

5.1 Learning and Pedagogical Supports

In general, learners reported a deeper understanding of nuclear technologies in society and high recall. Eva stated, “I actually remembered stuff we did from the first module, that assignment. I think because I spent more time researching it and I’m retaining it better, and it will stay in my head for a longer period of time.” She states the course was “a lot more inductive [than other classes].” Zuri, Patrick, and Eva reported that they worked harder than in other courses and felt this contributed to their understanding and retention of course content. Learners felt they gained deep understanding of the material, and they related that the variety of pedagogical supports assisted their learning. Further, the problem-solving scaffold appeared to help learners solve the given problems. Eva stated, “The best part about the module was the multi-choice questions. They provide some direction in what to look for in the resources.” Julia, Patrick, and Zuri all felt that the face to face meetings with the instructor were a great asset to their learning. These learners noted that the ability to meet with the instructor to ask questions helped them better understand their proposed solutions to the problems. Expert solutions were also of assistance to the learners. Patrick stated after reviewing the expert answers, “Even though I kind of thought I wanted to go this way, that’s a bunch of crap, and here’s the way I think we should go now.”

Perceptions of resources in UNES learning environment and problem scenarios were mixed. Julia found the resources to be helpful and easy to understand: however, other learners noted otherwise. Zuri was sometimes unable to find necessary information in the resources, and others noted that the resources were confusing because they often contradicted one another. Nevertheless, learners did realize that this was the nature of the ill-structured problem solving process. All learners noted that problem scenarios made them want to learn more about the problem; however, Eva noted that some of the problem scenarios were less engaging than others. In sum, it would seem that the UNES learning environment effectively supports student learning. Despite the perception that some supports were of less utility than others, overall, learners perceived them to be helpful.

5.2 Learners' Interest in Nuclear Sciences

All four learners reported being more interested in the field of Nuclear Sciences after having taken the course. Patrick stated that he will probably take other Nuclear Science courses. Eva stated that she would have considered switching majors if she were not so far along in her degree program. Julia stated that she would be willing to take more nuclear technology classes. Zuri stated that she felt compelled to have more background in nuclear sciences but would not necessarily want to major in it.

Two factors that seemed to promote learners' situational interest in Nuclear Sciences were the broad range of topics covered in the course and the real-life application of the problems. Eva reported, "It was interesting in the sense that I had no clue nuclear engineering was used for so much." Zuri found the topics to be interesting and engaging. Eva noted, "It all looked like a typical, real-life situation. You actually paid attention more to the different aspects of it, getting more of an understanding of how it's actually used and what it's used for." Julia stated, "I was amazed to see how much nuclear technology affects everyday life. I mean, I was aware, but not that aware." All learners reported being more interested in Nuclear Sciences, and that it was the broad range of topics and utility value that promoted this increased interest. These data suggest the course positively impacted learners' situational interest in Nuclear Sciences.

5.3 Learner Beliefs about Nuclear Technologies in Society

To address the question of the impact of the learning environment on learners' beliefs, we asked the learners about their beliefs prior to taking the course as opposed to after they finished the course. Learners' responses regarding initial beliefs can be categorized as apprehensive, indifferent, and uninformed. Zuri and Patrick reported that before taking this course, nuclear technologies were "scary." Eva reported that she had no feelings toward nuclear technologies, and that it was something she had never dealt with. Julia reported similar beliefs: "I never really thought about it […] I didn't really have any feeling […] I was very indifferent." Learners reported limited knowledge about nuclear technologies before taking this class. Patrick felt that nuclear technology was "unknowable stuff." Zuri reported, "When I think of nuclear engineering, I honestly think of the atom bomb and Hiroshima and that kind of stuff [rather than] everyday things."

After taking the course, all learners reported more positive and informed beliefs about nuclear technologies in society. Patrick noted “a pretty thorough idea of what it [nuclear technologies] is actually,” and that he did not feel it was “scary any more.” He believes his clearer understanding has helped him to become “a safer and more understanding employee.” Eva stated, “I’ve kind of understood that as long as they’re handled carefully, they’re not really as dangerous as people make it out to be.” Zuri reported similar beliefs: “I don’t think there’s really anything to be scared of as long as the proper precautions are taken and the isotopes and things like that are used properly.” These findings imply that after taking the UNES course, a better understanding of nuclear technologies was gained, which seemed to have a significant and positive impact on learners’ beliefs about nuclear technologies. This is exemplified in Julia’s discussion of changes in her beliefs and how she wanted to share this with others:

> I would want to tell people about all the stuff that’s out there and try to eliminate all these (pause) subdue their fears, as opposed to […] having people being so close-minded. If people knew exactly how it worked and what it can be used for, all the good things and stuff like that, I think we would just do better as a society, period. I mean, there’s dangers with everything. There are (pause) dangers that people feel about nuclear stuff is just too much, it’s overwhelming, and it shouldn’t be there.

6. Discussion

The findings discussed in this paper indicate that the UNES learning environment may foster deep understanding, high recall, and may necessitate increased effort in order for learners to successfully complete assignments. Learners reported these learning benefits were well supported by the UNES learning environment’s problem-solving scaffold and corresponding expert solutions, as well as the face to face course instructor. In contrast, while support in the form of problem scenarios and resources were perceived to be helpful, the perceived benefits were not of the same degree as the problem-solving scaffold and expert solutions. Although not direct measures of learning, these findings indicate that learning did occur, and that the UNES learning environment supported learning. In addition to this, all learners reported increased situational interest in the field of Nuclear Science. This was apparent in that learners indicated a desire to take more courses in the field, to gain more background in the field, and even to switch majors. This increased interest was attributed to the real-life applications of Nuclear Science, as well as the broad range of topics covered by the course. In this sense, it would seem that the learning environment was able to both “catch” and “hold” learners’ situational interest. In addition to this, the findings show evidence of belief change. Prior to taking the UNES course, learners reported apprehensive, indifferent, and uninformed perceptions of nuclear technologies in society. After having taken the course, learners reported they felt safer and more informed. Some learners discussed that they now believe radioactivity is safe if handled properly. One even indicated a desire to share informed beliefs with others.

In light of these findings, we are reasonably confident that the UNES course supports learning while promoting interest in the field and belief change in regard to nuclear technologies in society. These findings are encouraging, as the goal of the course was to promote interest in the field. Further, our pedagogical assumption that an problem-solving scaffold augmented with expert solutions and resources would effectively support learning appears to be valid. Of note is that learners consistently reported that the availability of a live instructor was of great value to their learning process and ability to successfully complete assignments. Finally, we hypothesized that increased interest in the field along with well-supported learning would affect learners' beliefs about nuclear technologies in society. It would appear that this is indeed the case for the participants in this study.

As this study was limited by the small number of participants and short duration, we consider these findings preliminary, and by no means conclusive. Because case study research focuses on a particular phenomenon in a specific context, we make no claims that the results of this study are generalizable or transferable. However, these findings do align with previous research and educational theory. The implications discussed above are indeed promising and of interest to the fields of education and nuclear engineering. Thus, we believe further research will strengthen the trustworthiness of the findings reported herein and open additional areas for investigation into the benefits of technology-supported problem-based approaches to instruction.

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