1 Developing and Assessing an Undergraduate Nuclear Engineering Program at the U.S. Military Academy

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Abstract

In 2002 the U.S. Military Academy (USMA) at West Point established a nuclear engineering (NE) major beginning with graduates of the Class of 2005. The major represents a significant broadening of the West Point academic program and will provide the Army with additional nuclear trained officers as leaders in homeland defense, health physics, and the development of national nuclear defense and policy. A four-step evaluation and assessment process has been developed to assess accomplishment of program goals. Through the use of concept maps, block learning objectives, rubrics, and embedded evaluation instruments, changes to the program can be made while ensuring that USMA continues to graduate outstanding officers and leaders.

Introduction

In 2002, the U.S. Military Academy at West Point established a nuclear engineering (NE) major available for study beginning with the Class of 2005. The NE curriculum was developed to meet all accreditation requirements for the Accreditation Board for Engineering and Technology (ABET). The establishment of the NE major represents a significant broadening of the West Point nuclear program, and will provide the Army additional officers schooled in nuclear disciplines. Cadets first develop strong fundamental skills in mathematics, physics, and general science. They then apply these fundamental skills to the study of nuclear power plants, nuclear weapons, radiation effects, radiation shielding, and the environmental impact of nuclear power. Embedded design problems reinforce and integrate concepts presented in the classroom. To determine if our courses accomplish specified outcomes, we have developed an innovative methodology to assess accomplishment of program outcomes through a process of assessing embedded indicators.

The splitting of the nucleus has made available to mankind an almost limitless source of energy. This energy source is currently used throughout the world to generate electricity in nearly 450 nuclear power plants. In addition many nations, including potential adversaries, have acquired nuclear weapons. Such widespread use of nuclear energy, and the proliferation of nuclear weapons, suggests that officers in the Army of the 21st century should have some knowledge of nuclear processes. NE is relevant to today's Army for many other reasons. Officers must be effective leaders in a nuclear or radiation environment, they may participate in homeland defense as part of a nuclear and radiation detection task force, or work with antiterrorist teams in radiation detection and counter-proliferation. Army officers may work in health physics or nuclear medicine, work with research teams in nuclear weapons development, participate in nuclear treaty verifications, or assist in the development of national nuclear policy. Therefore, leaders should understand the benefits and dangers of the uses of nuclear energy, the biological effects of radiation, and the effects of nuclear weapons. The West Point nuclear engineering program will provide the information necessary to meet these responsibilities.

As early as 1965, West Point offered cadets a limited number of courses in nuclear engineering. Oversight for the program originally fell under the Department of Military Art and Engineering. In 1969, responsibility for nuclear engineering was given to the Department of Engineering. Nuclear engineering came to the Department of Physics in 1989. Prior to the Class of 2005, cadets desiring an in-depth study of nuclear engineering could only choose a Nuclear Engineering Field of Study (FOS). The FOS, though a good option for cadets, did not include courses in many important areas of nuclear engineering because the Department did not have the faculty expertise or the manning to offer such courses. Changes to the Academy curriculum, changes to the ABET requirements, the strong nuclear engineering credentials of the department's faculty, and the increased need of the nation and the Army for nuclear specialists led to the decision to create the nuclear engineering major at West Point.

The Army and the nation have a cadre of specialists trained in the social, political, and technical aspects of the use of nuclear weapons. The cadre is designated Functional Area (FA) 52, Nuclear Research and Operations. FA52 officers are an important aspect of the national response to a terrorist attack, serving with various civilian and military agencies including the FBI, DOE, the Office of Homeland Security, and Combatant Commanders' staffs. The Physics Department has a close working relationship with the FA52 community; with eight to ten FA52 officers serving as rotating military faculty in the Department. The experience and the technical expertise of the FA52 officers at West Point have enhanced our ability to establish this major. An important side benefit of the nuclear engineering major is the professional development opportunity for our FA52 rotating faculty. By integrating the real-world issues facing the nuclear community into our curriculum, we return to the Army FA52 officers who are more in tune with the issues they will face in their follow-on assignments.

The Nuclear Engineering (NE) Major

The NE study program consists of eighteen required courses from a variety of academic disciplines. Eight of the courses are taught by the Department of Physics with the remaining courses taught by the Departments of Civil and Mechanical Engineering, Electrical Engineering and Computer Science, Geography and Environmental Engineering, and Mathematics. Exposure to a wide range of disciplines broadens the science knowledge of the cadet and prepares the cadet for lifelong science literacy and study. Cadets in the program augment their education through an Advanced Individual Academic Development (AIAD) program that provides research and development opportunities with national and military laboratories such as the Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratory, Aberdeen Proving Ground, and others. These intense summer training programs offer cadets the opportunity to participate in ongoing programs that are relevant to their future careers. The NE curriculum was developed to meet all ABET accreditation requirements, and will undergo an ABET accreditation visit in 2008.

In developing the courses to be offered for our nuclear engineering major, we reviewed other ABET certified programs and benchmarked our program against theirs. However, since our graduates will serve as officers and leaders in the Army, during each course in the major we ensure that material covered in class is relevant to the Army. Most course outlines and design projects are written in operations order format using a military relevant scenario as an underlying motivation for the course. Course developers are currently seeking "links" between coursework and the military. As courses are executed and refined, course directors continually seek to update the military relevance of their coursework. The goal of the nuclear engineering program at West Point is to provide the Army with junior officers who have a broad understanding of the current social, political, environmental and technological challenges and issues in nuclear matters.

As part of the required general curriculum, West Point cadets take a significant number of math and science courses. These courses provide a solid foundation for the study of nuclear engineering. The learning model for the nuclear major, depicted in Figure 1, illustrates the

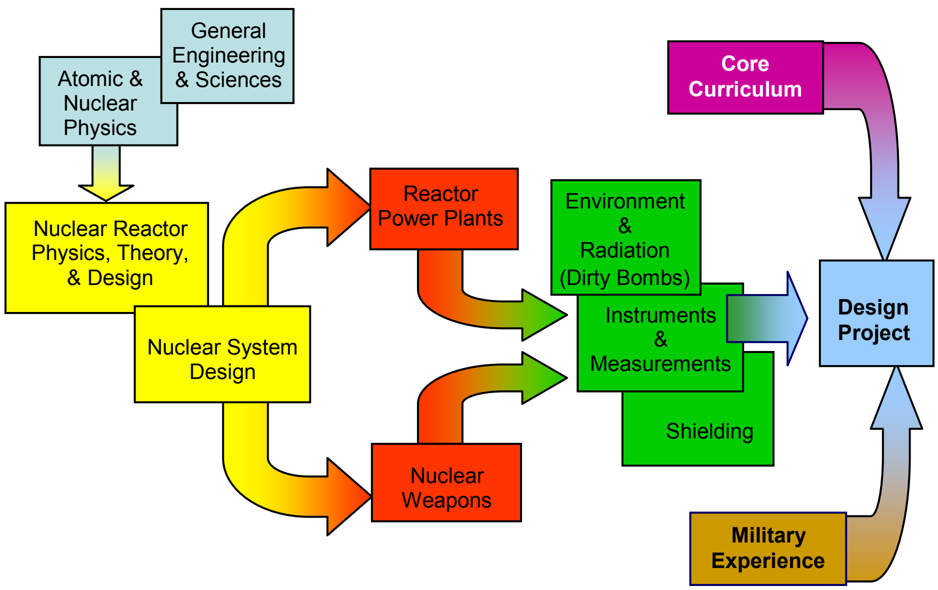

Fig. 1. Learning Model for the NE Major at USMA

principal topics of study. Courses in general engineering, science, and atomic and nuclear physics provide the foundation for further studies in nuclear engineering. The underlying principles taught in nuclear reactor analysis and the design courses are applicable not only to cadet understanding of nuclear reactor engineering and power plant systems, but also to coursework in nuclear weapons. Common to the nuclear reactor engineering and the nuclear weapons instruction is the impact of radiation on the environment. Much of the major will include instruction on radiation effects on personnel and equipment, radiation detection, shielding, and management of radioactive waste.

The cadet experience in the NE program culminates with an integrated design course that synthesizes their broad curriculum in the core program, and their study-in-depth in the major, to solve a problem that includes social, political, economic, and technical aspects. In general, cadets take required courses during their first three semesters at West Point and begin the study of courses in their academic major during the spring term of sophomore year. The specific courses constituting the nuclear engineering major are listed in Figure 2.

Sophomore Year (4th Term)

MA364	Math for Scientist and Engineers
CE300	Fundamentals of Engineering Mechanics and Design

Junior Year (5th Term)

PH365	Modern Physics
ME311	Thermofluids I
ME370	Computer Aided Design
NE300	Nuclear Reactor Analysis

Junior Year (6th Term)

ME312	Thermofluids II
EE301	Fundamentals of Electrical Engr
EV385	Fundamentals of Env. Engr
NE355	Advanced Nuclear Reactor Design

Senior Year (7th Term)

CE364	Mechanics of Materials
ME480	Heat Transfer
NE452	Instr. and Measurements
NE456	Nuclear Weapons and Weapons Effects

Senior Year (8th Term)

IT305	Military IT Systems
PH374	Medical Radiation Physics
NE496	Nuclear Engineering Seminar
NE400	Advanced Nuclear Systems Design Project

Fig. 2. Curriculum for the Nuclear Engineering Major at USMA

NE Program Assessment Methodology

An integral part of the NE program is assessment. How do we know we are accomplishing the goals and outcomes that we expect? To answer this we have developed a four-step evaluation and assessment process that consists of:

1) connecting program objectives, program outcomes, course outcomes, and course block objectives,
2) selecting an evaluation instrument set,
3) assessing the level of attainment, and
4) analyzing results and proposing recommendations.

Step 1: Connecting program objectives and outcomes with course outcomes and block objectives.

There is a hierarchical structure from the learning institution to the nuclear engineering program to the courses that make up the program. The institution defines its mission and education strategy thereby providing direction for the programs to develop objectives and outcomes. In the language of ABET, an objective is a statement that describes the expected accomplishments of graduates during the first few years after graduation. An outcome is a statement that describes what students are expected to know and able to do by the time they graduate. We define for each of the courses in the program course outcomes that map directly to program outcomes.

The primary constituency of the United States Military Academy is the Army. Our program objectives are developed to meet the needs of our primary constituency while contributing to the Military Academy's overarching academic program goals as detailed in the Academy's strategic paper called *Educating Future Army Officers for a Changing World*. The overarching goal of the academic program is "to enable its graduates to anticipate and to respond effectively to the uncertainties of a changing technological, social, political, and economic world." From this goal, the Military Academy derives a set of ten specific program goals that address Army needs and reflects the attributes that the Military Academy seeks to develop in every graduate. The needs of our constituency and the Military Academy's overarching goals are articulated by the Nuclear Engineering Program objectives as outlined in Figure 3.

1. Graduates can analyze and solve complex problems.

- **Graduates can apply their knowledge of mathematics, science, engineering, and the humanities to analyze and solve problems in nuclear and radiological engineering.**
- **Graduates can analyze problems with technical, social, political, and economic underpinnings; use appropriate technology to formulate effective courses of action; adapt methodologies even with incomplete or imperfect information; recommend or choose the best course of action.**
- **Graduates can solve problems in nuclear engineering and within the broader context of officership in the profession of arms.**
- **Graduates can creatively adapt problem-solving strategies and solutions to rapidly changing situations.**

2. Graduates can lead, manage, and execute.

- **Graduates can lead people, manage resources, prioritize activities, and execute projects within constraints and limitations to successfully complete selected courses of action and missions in the nuclear and radiation fields and in the Army.**
- **Graduates demonstrate the necessary leadership and teamwork skills to work in multidisciplinary team environments.**

3. Graduates can effectively communicate.

- **Graduates have the ability to communicate technical and non-technical information to supervisors, subordinates, peers, customers, and the general public.**
- **Graduates have the ability to communicate, orally and in writing, correctly and in precise terms, with each communication evincing clear, critical thinking.**

4. Graduates recognize their professional responsibilities.

- **Graduates internalize their professional responsibilities to society, the profession of arms, and the practice of engineering.**
- **Graduates demonstrate a desire to continue to grow intellectually by learning on their own and being willing to engage in and persist at complex tasks.**

Fig. 3. Nuclear Engineering Program Objectives

From these broad Nuclear Engineering Program Objectives, a set of ten program outcomes are developed. The outcomes are developed to ensure the program objectives and the ABET a-k criteria are accomplished in the nuclear engineering program. Figure 4 depicts the Nuclear Engineering Program Outcomes. Each course in the nuclear engineering program is matched against a set of these outcomes. Each course has a set of course outcomes that map to particular program outcomes. A course concept map is constructed and provides a graphical method to better understand the course topical coverage and how it relates to accomplishing the course outcomes. Course block objectives are then established that link into a set of coherent course-wide outcomes. Each concept map covers the technical, design, and lab components of each course. The technical concept map covers course block objectives that are linked primarily to accomplishment of program outcomes 1 and 2. The assessment of the accomplishment of outcomes 1 and 2 is the subject of the remainder of this paper.

Step 2: Selecting an Evaluation Instrument Set

As part of the course preparation process, embedded evaluation instruments for each course block objective are selected that will both:

1) evaluate the cadets' retention of previously learned concepts and procedures (*reinforcement*), and
2) evaluate the cadets' ability to synthesize multiple concepts and procedures (*extension*).

1. Apply knowledge of mathematics, science, engineering, humanities, and computing along with creativity skills to the solution of theoretical, practical and applied problems in nuclear and radiological engineering.
2. Apply atomic and nuclear physics and the transport and interaction of radiation with matter to nuclear and radiological systems and processes.
3. Demonstrate ability to measure nuclear and radiation processes.
4. Demonstrate the skills to plan, design, execute, and critically interpret results from experiments.
5. Apply professional and ethical considerations to the development of engineering solutions.
6. Demonstrate an appreciation of the roles and responsibilities of nuclear engineers and the issues they face in professional practice.
7. Communicate effectively with clear, critical thinking skills both orally and in writing.
8. Work effectively alone, in small groups, and as members of multidisciplinary teams using the engineering design process to design components or systems that meet desired needs or specifications.
9. Incorporate understanding of societal and global issues and knowledge of contemporary issues in the development of engineering solutions.
10. Demonstrate the ability to conduct independent inquiry and learning, and recognition of the need to continue to do so over a career in the military and beyond.

Fig 4. Nuclear Engineering Program Outcomes

Embedded evaluation instruments include homework, quizzes, examinations, design projects, laboratory work, experiments, and papers. Evaluation instruments such as quizzes, tests, and final examinations focus on reinforcement knowledge since they are typically in-class timed events. Evaluation instruments such as homework, design projects, laboratory exercises, and in-class board problems focus on extension knowledge since these are typically untimed events. Evaluation instruments are overlaid on the concept map to ensure that the course block objectives are evaluated at multiple times sequencing through reinforcement and extension evaluations. By ensuring our grades have pedagogical meaning, we use the distribution of grades on these evaluation instruments to assess cadet attainment of each course block objective.

Step 3: Assessing the Level of Attainment

The achieved grades (A, B, C, D, and F) on each evaluation instrument are plotted vs. number of cadets achieving these grades. A rubric defines the standards to assess the performance of cadets on each evaluation instrument. The rubrics allow us to assess cadet performance as:

- *suspicious* (most frequent grades are A and B),
- *acceptable* (most frequent grades are C or better, with less than 20% F's),
- *marginally acceptable* (most frequent grades are C or better, with more than 20% F's), or
- *unacceptable* (most frequent grade is D or F).

By assessing multiple embedded evaluation instruments against these rubric standards, an overall assessment is made of cadet accomplishment of the course block objectives.

Example

One of the course block objectives developed in a concept map of NE453, *Nuclear Reactor Design*, is to determine the critical state and critical dimensions of a reactor. This block objective was assessed against reinforcement and extension instruments through multiple embedded indicators such as several homework problems (Fig. 5), a course-wide quiz (Fig. 6), an examination (Fig. 7), a design project (Fig. 8), and finally a term-end examination (Fig. 9). As part of the end-of-course assessment meeting, the course director reviewed the grade

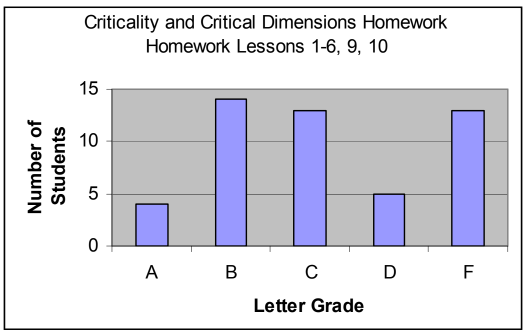

Fig. 5. Results from homework.

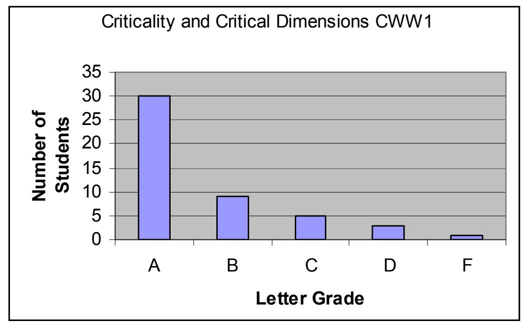

Fig. 6. Results from the course-wide quiz.

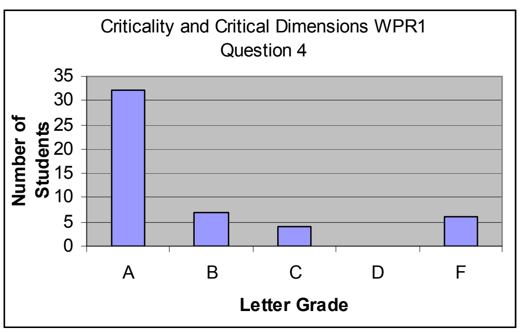

Fig. 7. Results from the examination.

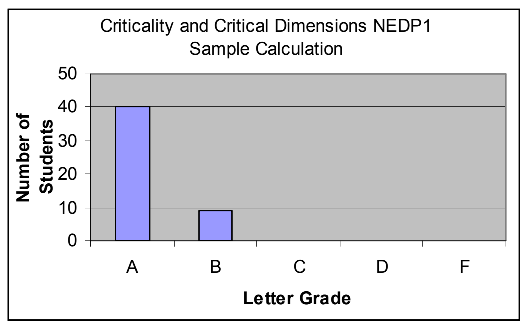

Fig. 8. Results from the design project.

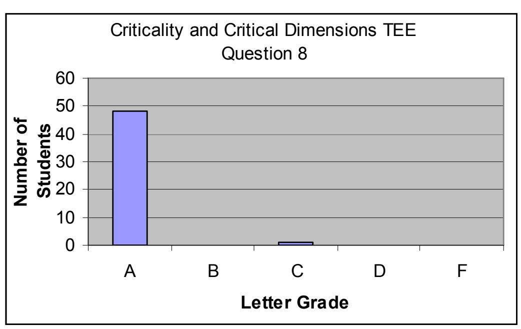

Fig. 9. Results from the term-end examination.

distribution of cadet performance on these homework problems. Based on the grade distribution on these homework problems, the course director assessed cadet attainment of this block objective as marginally acceptable. In like manner, an assessment of cadet attainment of this block objective was made based on their performance on the course-wide quiz, the examination, the design project, and the term-end examination. The course director then uses this assessment information to determine if changes should be made to the course. Similar assessment results from each course in the program are then used by the NE program director to measure NE program effectiveness.

Some of the homework problems and the course-wide writ are reinforcement-level questions. The remaining homework problems, the examination, the design project, and the term-end examination are extension-level questions. As evidenced by the results, the cadets continued to improve in their reinforcement knowledge and extension capabilities in solving problems associated with this particular course block objective. At the end-of-course assessment meeting, the course director gave an overall assessment of acceptable for cadet attainment of this block objective. Assessment of cadet performance on the multiple embedded indicators must be tempered with discussion of why the results occurred. Such factors as rigor, outside influences on cadet time, program design, course design, etc., must be considered in making the final assessment of the attainment of course block objectives.

Step 4: Analyzing Results and Proposing Recommendations

We use the assessment of cadet attainment of block objectives in each course to evaluate the success of the entire NE program. For the purpose of assessing program outcomes, the evaluation of the individual cadet's performance is not important. However, the collective

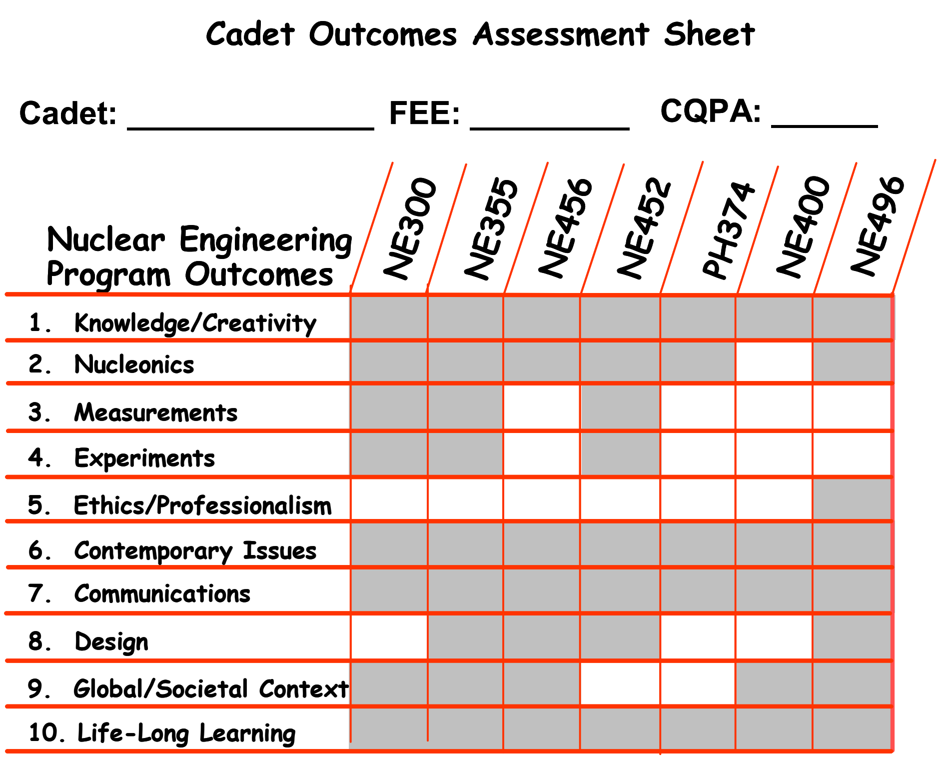

Fig. 10. Cadet Outcomes Assessment Sheet

performance can be used to assess the outcomes at the program level. This is accomplished at a semi-annual Program Assessment Meeting. At the program level, success in achieving each outcome is assessed based on a collective assessment utilizing the Cadet Outcomes Assessment Sheet (Fig. 10). The program assesses each of the outcomes based on the results of cadet assessments in multiple courses throughout the program (as indicated by the grey boxes in the Cadet Outcomes Assessment Sheet). Using this information, the NE program director and each course director decide on changes to the program to help ensure that cadets attain the program outcomes and objectives. Our four-step evaluation and assessment methodology helps to ensure that our program will graduate outstanding officers and leaders for our Army and that they meet our program objectives and the Academy's overarching goal.

Conclusions

A methodology for assessing attainment of outcomes in the nuclear engineering program in the Department of Physics at the United States Military Academy has been presented. This four-step process focuses on assessing accomplishment of program outcomes 1 and 2 through the use of concept maps leading to course block objectives. We then assess the accomplishment of the course block objectives through use of selected multiple evaluation instruments with specified rubric standards. These rubrics are based on the grade distribution of cadets achieved on the selected evaluation instruments. The assessment focuses on trends of performance with reinforcement and extension knowledge evaluation instruments. We then use this information to determine if we are meeting our program outcomes and objectives, and to adjust the program as needed.

Results, such as those shown in the example, provide a rigorous means to evaluate accomplishment of a course block objective. However, it is very important that grades have pedagogical meaning in order to use such an evaluation methodology. The methods we have developed to give meaning to grades, and the methods used to assess accomplishment of program outcomes three through ten, are the subject of a future paper.