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Innovative Online Delivery of Nuclear Engineering Technology Courses Using Simulation-Based Learning

Dr. Richard Elliott Cole Ed.D., Excelsior University

Richard Cole is an accomplished educator with fifty years of experience in government and commercial nuclear operations. Starting as an instructor at the Naval Nuclear Propulsion Training Unit Idaho Falls in 1976, he has been part of numerous training organizations. He held numerous roles in nuclear operations and maintenance, both as an enlisted member and an officer, until his retirement in 1997. He then transitioned to the commercial nuclear industry and has worked at several nuclear plants. His experience and expertise include Instructional Design, Instructor Development, College Instruction, Training Program Evaluation, and Training Program Accreditation. He lives in Fruitland Park, Florida with his wife of 53 years.

Richard received his bachelor’s in science from Excelsior University and holds a Doctor of Education from Valdosta State University, specializing in Adult and Career Education. He has been an Adjunct Instructor at Excelsior since 2017 and joined the full-time faculty in 2024. Active in the American Nuclear Society for over 25 years, he was previously the Chair of the Executive Committee for the Operations and Power Division and is a member of the Education, Training, and Workforce Development Division.

Dr. Anveeksh Koneru, Excelsior College

Dr. Anveeksh Koneru is a Department Chair for Engineering Technology at Excelsior University, Albany NY. He served as the coordinator for the Engineering Summer Camp at the College of Engineering. His primary research includes thermoelectrics and photocatalysis. He is an active member of ASEE and engages in innovative teaching methods for student success and retention. He is a recipient of UT STARs award of $300,000 to set up computational laboratory at University of Texas of the Permian Basin.

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Introduction

Online engineering programs increasingly serve adult learners and working professionals who require flexible pacing, targeted practice, and authentic problem-solving opportunities. Simulation-based learning (SBL) has emerged as a strong fit for these needs, enabling hands-on, scenario-driven engagement without the cost and logistical constraints of physical labs. Large-scale reviews in higher education show that simulations, when paired with scaffolding and feedback, produce substantial learning gains across domains (average $g \approx 0.85$), and that instructional support can be tailored to learner prior knowledge to further improve outcomes. [1][2]

As part of continuous program improvement and consultation with the Industry Advisory Committee, Excelsior implemented a Pressurized Water Reactor (PWR) simulator through external grant funding. This realistic simulation environment allows students with varying levels of nuclear experience to observe how heat transfer, fluid mechanics, and regulatory practices manifest in commercial reactor systems. By integrating hands-on virtual learning, the simulator strengthens students' understanding of foundational engineering principles and supports their preparation for work in the commercial nuclear industry.

Concurrently, research on online engineering education documents growing adoption of asynchronous approaches that emphasize accessibility and structure for adult learners, while highlighting the importance of purposeful design to sustain engagement and feedback loops. This paper describes an asynchronous, simulation-forward model for nuclear engineering technology courses, focusing on how simulations are embedded, how students are assessed and supported, and how faculty are prepared to deliver high-quality experiences online. [3][4]

Background and rationale

Why simulation for nuclear engineering technology

Simulations allow learners to visualize and manipulate plant dynamics (e.g., thermohydraulics, reactor kinetics) and rehearse responses to operational transients in a safe environment. International agencies have long promoted PC-based simulators to support education and training—providing authentic interfaces and dynamic responses for multiple reactor types (PWR, BWR, PHWR), explicitly for classroom use. [5][6]

Alignment with adult learning and asynchronous delivery

Adult online learners benefit from structured, flexible course designs that integrate guided practice, immediate feedback, and peer interaction—elements that simulations can naturally support. Recent syntheses of adult online learning emphasize modular content and facilitated discussion as levers for persistence and depth of learning. [3][4]

Course design and simulation integration

Simulation ecosystem

Our curriculum integrates an HTML-based generic PWR simulator to support core concepts (heat transfer, fluid flow, reactor kinetics, balance-of-plant) through guided labs with parameter manipulation and real-time system response visualization. To broaden exposure to reactor technologies, we incorporate the IAEA educational BWR simulators (conventional BWR with active safety systems for systems-overview courses. These desktop simulators mimic plant control interfaces and typical transient scenarios suitable for instructional use. [5]

Modular structure and scaffolded activities

Each module follows a consistent pattern:

1. Concept Primer: Short multimedia overview and targeted reading.
2. Guided Simulation Lab: Structured steps with predict-observe-explain prompts and embedded checks for understanding.
3. Asynchronous Discussion: Reflection on observed dynamics, cross case comparison, and peer critique of troubleshooting approaches.
4. Low Stakes Quiz + Brief Reflection: Immediate feedback and metacognitive wrap-up.

Meta-analytic evidence indicates that scaffolding, worked examples for novices, and reflection phases for more advanced learners amplify simulation benefits—guiding our choice of supports and activity sequencing. [2][7]

Assessment strategy

Assessment balances procedural fluency (e.g., control actions, setpoint reasoning) and conceptual understanding (e.g., thermodynamic tradeoffs, feedback effects). Rubrics capture diagnosis quality, response prioritization, and safety margins. This mirrors broader educational guidance that SBL outcomes improve when task progression and support are tuned to learner readiness. [6][8]

Representative course implementations

a. Thermodynamics and systems courses

In thermodynamics, students connect first law and second law analyses to the plant heat cycle, then run targeted PWR simulator labs to observe turbine throttling, condenser performance changes, and feedwater perturbations.

The following is an excerpt from the module "**PWR Simulator and Regenerative Heat Exchanger".**

> This lab activity is designed to allow you to observe and analyze how one of the concepts from the Module 3 reading assignment applies to an operating nuclear power plant. In particular, the assignment is designed to illustrate the use of regenerative heat exchange in a nuclear plant system and will challenge you to analyze the effect on the plant resulting from a transient associated with the regenerative heat exchanger.
>
> Before you conduct the lab activity you must first read and understand the activity background information described below. The lab activity will require a basic understanding of the layout and function of the regenerative heat exchanger and letdown heat exchanger associated with the simulator plants Chemical and Volume Control System.
>
> ### *Deliverables*
>
> You will follow the instructions in the lab assignment to explore the cause/effect relationship of a transient associated with the regenerative heat exchanger. You are to complete and submit a lab report for the assignment. Your lab report should contain a discussion of the process of setting up the simulator, screenshots of the process of running the simulator and completing the instructions, and answers to the required steps embedded within. Your lab report should demonstrate your understanding and mastery of the technical material as well as proper written communication skills. Your answers should be clear and with proper units when required. Be sure that you are completely and directly answering the questions being asked.
>
> Background Information: Regenerative Heat Exchangers and the CVCS System
>
> The Regenerative Heat Exchanger
>
> You were introduced to regenerative heat exchangers in your Module 3 reading assignment. You should recall from your reading that a regenerative heat exchanger uses the fluid from a different area of the same system for both the hot and cold fluids. An example of both regenerative and non-regenerative heat exchangers working in conjunction is commonly found in the purification system of a reactor facility. The primary coolant to be purified is drawn out of the primary system, passed through a regenerative heat exchanger, non-regenerative heat exchanger, demineralizer, back through the regenerative heat exchanger,

and returned to the primary system. The picture below illustrates the basic layout of such a system.

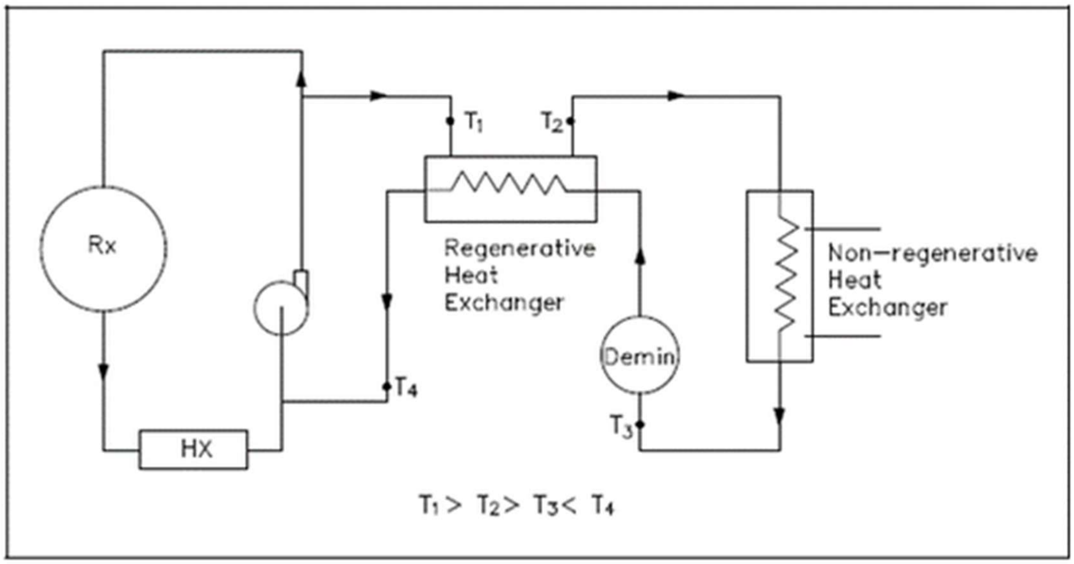

Figure 1: Regenerative Heat Exchanger

The excerpt is typical of the laboratory exercises conducted in the courses.

b. Capstone team scenario

The capstone uses a multistage scenario where teams: (1) analyze plant indications; (2) propose immediate and longer-term actions; (3) run guided simulator trials to test hypotheses; and (4) present lessons learned and design recommendations to a simulated senior management panel. The design leverages evidence that complex, scenario-based SBL with structured feedback fosters advanced skills across higher education contexts. [2]

From the Capstone Course Syllabus:

> This capstone course integrates all fields of nuclear engineering technology. Students will draw on their knowledge of nuclear engineering technology and competencies to analyze reactor plant scenarios. The purpose of the course is to integrate the learning achieved in individual nuclear engineering technology courses taken, evaluated industry training, and naval nuclear power training to earn a nuclear engineering technology degree. The knowledge and competencies acquired in natural sciences, health physics and radiation protection, thermodynamics, heat transfer and fluid flows, reactor core fundamentals, and plant systems overview will be utilized to study the principles in nuclear engineering technology. Students will participate in a reactor plant simulation

experience that requires considering multiple theoretical concepts and applying those concepts to plant applications. An individual capstone project and a watch team capstone project will be developed and presented to the instructor.

Course Outcomes:

Upon completion of this course, students should be able to:

1. Apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the nuclear engineering technology discipline. (PO1)
2. Demonstrate an ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the nuclear engineering technology discipline. (PO2)
3. Apply written, oral, and graphical communications in broadly-defined technical and non-technical environments; and be able to identify and use appropriate technical literature. (PO3)
4. Conduct standard tests, measurements, and experiments and be able to analyze and interpret the results to improve processes. (PO4)
5. Function effectively as a member as well as a leader on technical teams, and apply project management techniques in team project activities. (PO5)
6. Demonstrate comprehension of currently applicable rules and regulations in the areas of: radiation protection, operations, maintenance, quality control, quality assurance, and safety. (PO6)
7. Demonstrate an understanding of and commitment to professional, ethical, and social responsibilities, including the impacts of culture, diversity, and interpersonal relations. (PO7)

There are Eight modules in the 15-week capstone course.

The modules utilizing the simulator are described below (Specific course links are for illustrative purposes only and may not be accessible from this paper.):

Module 1

In this module, you will be developing a test procedure to validate the operability of a pump. The pump and associated system are based on the plant simulator you will use for the course. The procedure will address the plant line-up for conducting the test as well as analysis of the test result, including an appropriate error analysis based on the instrument inaccuracies.

The module also includes activities to familiarize you with the plant simulator to be used throughout the course.

Order	Type*	Title and Description
M1.1	Engage	Learning: Required Readings
M1.2	Engage	Module Notes: Developing Tests to Establish Operability
M1.3	Engage	Module Notes: Overview of the Pressurized Water Reactor (PWR) Simulator
		Quiz: Agreement to Terms of Use
M1.4	Evaluate	Discussion: Discuss Issues associated with developing a test
M1.5	Evaluate	Assignment: Draft Test Procedure

Module 2 Continues from Module 1

Introduction

The module focuses on a demonstration of the student's mastery of selected thermodynamic and fluid mechanic principles. In this module, the student will conduct the test developed in Module 1. The student will document the results and based on an analysis of the results will determine whether the system satisfies the defined criteria.

In the industry, it is necessary to integrate multiple different aspects of nuclear technology in the performance of assigned duties. By conducting a test and analyzing results this assignment demonstrates selected performance indicators associated with developing and conducting experiments, mathematics, and operations and maintenance of plant systems. Once the analysis is complete it is necessary to identify how the results impact operability and what aspects of reportability may exist.

Regulations exist that identify what aspects of plant operation are reportable to the NRC. 10CFR50.72 and 50CFR50.73 are the most commonly referenced standards for reportability associated with the testing of systems, structures, and components important to safety. Discussion of the operability and any reportability requirement demonstrates elements associated with the understanding of regulatory requirements

Order	Type*	Title and Description
M2.1	Engage	Learning: Required Readings
M2.2	Engage	Module Notes: Linkage of Assignment to Program Outcomes

M2.3	Evaluate	Discussion: Regulatory Basis for Testing
M2.4	Evaluate	Assignment: Test Analysis and Report

Modules 4 through 7 includes individual and team assignments to demonstrate mastery of the course and program outcomes.

Module 4: Team Project Assignment

Introduction

The module focuses on the application of team skills in the conduct of a scenario associated with an operational challenge. The scenario will involve conducting a scenario on the software plant simulator. The module will focus on developing a team charter that identifies the roles and responsibilities associated with conducting the assignment, as well as identifying any potential decision that may be anticipated in the conduct of the evolution. The team will submit a team charter and a team report. In a subsequent module, the students will submit a team presentation outlining the roles assigned, potential decisions, and the ethical and societal attributes that may come into play in the decision-making process.

Order	**Type***	**Title and Description**
M4.1	Engage	Learning: Required Readings
M4.2	Engage	Module Notes: Team Project Instructions
M4.3	Engage	Module Notes: Ethical versus Legal
M4.4	Evaluate	Discussion: Ethical considerations in decisions
M4.5	Evaluate	Assignment: Team Project - Team Charter
M4.6	Evaluate	Assignment: Team Project – Brainstorming Report

Module 5: Conducting the Exercise

Introduction

The scenario assigned in Module 4 will be conducted using the software plant simulator. The team will discuss the results of the simulation and document any decision made. The team will develop a presentation that identifies the potential decisions, documents the decision made, and analyzes the ethical and societal implications of the decision. Included in the presentation is an analysis of the potential radiological impact of the event and any decision made as well as discussions of system interactions and applicable scientific principles. The DRAFT presentation will be submitted to the course instructor for comment prior to scheduling the formal presentation to the instructor and fellow students.

Order	Type*	Title and Description
M5.1	Engage	Learning: Required Readings
M5.2	Engage	Module Notes: Analysis of an event
M5.3	Evaluate	Discussion: Potential Design Changes
M5.4	Evaluate	Assignment: Decision Analysis Report
M5.5	Evaluate	Assignment: Team Project – Draft Presentation

Module 6: Design Change Recommendation

Introduction

The module explores the students' understanding of the design of the simulated facility and the processes associated with designing changes to the facility. In this module, each student will develop a proposed design change that could have improved the response or results of the event simulated in Module 5. The recommendation will include an analysis of the technical, regulatory, and radiological considerations. The analysis will also include an analysis of the projected cost associated with the implementation of the change and an estimate of subsequent operation and maintenance costs.

Order	Type*	Title and Description
M6.1	Engage	Learning: Required Readings
M6.2	Engage	Module Notes: Cost Analysis
M6.3	Evaluate	Discussion: Analyzing Cost
M6.4	Evaluate	Assignment: Design Recommendation

Module 7: Team Presentation and introspective Assessment

Introduction

This module focuses on the completion of the formal team presentations assigned in Module 5.

Order	**Type***	**Title and Description**
M7.1	Engage	Learning: Required Readings
M7.2	Engage	Module Notes: Team Presentation
M7.3	Evolve	Considerations in Making a Presentation
M7.4	Evaluate	Assignment: Team Project – Presentation and Defense

Overall, the Capstone allows students an opportunity to gain additional familiarity with the operations and regulation of a commercial nuclear reactor. As our student population consists of military, veterans, and partners from the nuclear industry, they have an opportunity to share experiences and expectations for their future careers.

Compliance and industry relevance

While our educational simulators are generic (not plant referenced), the curriculum design is informed by industry practice and regulation that rely on simulators for operator training and requalification (e.g., NRC NUREG1021 sets expectations for operating tests administered on full scope, plant referenced simulators). For academic programs, IAEA frameworks help classify and select suitable PC-based basic principles simulators for instruction. [9][10]

Faculty development and change management

We implemented a faculty onboarding sequence covering: (1) simulation operation and scenario banks; (2) facilitation of asynchronous discussions; and (3) assessment calibration using shared rubrics and exemplar artifacts. Research on adult online learning underscores the importance of structured interaction and feedback in asynchronous settings—guiding our emphasis on facilitation techniques and timely responses. [4][3]

Outcomes and reflections

Course analytics and student reflections indicate increased engagement and perceived workplace relevance of simulation tasks, especially in troubleshooting and system analysis. These perceptions align with meta-analytic findings that simulation plus scaffolding can produce large learning gains relative to traditional methods, if guidance is adapted to learner prior knowledge and task complexity. [2][7]

Avg. of Q1. "Overall, I am satisfied with this course."			
Course	**2023**	**2025**	**% Increase 2023 - 2025**
NUC 211	6.60	6.73	1.97%
NUC 245	6.67	6.70	0.45%

NUC 246	6.20	6.29	1.45%
NUC 250	5.18	5.83	12.55%
NUC 260	6.28	6.07	-3.34%
NUC 330	6.00	6.39	6.50%
NUC 350	6.37	6.42	0.78%
NUC 495	5.97	6.39	7.04%
All Sim Courses	**6.13**	**6.32**	**3.10%**

Figure 1

While specific measures related to the simulator are not currently collected, student satisfaction with simulation-based courses in the Bachelor of Science in Nuclear Engineering Technology program at Excelsior University has generally increased between 2023 and 2025 (Figure 1). Across all simulation courses, the average score on the 7-point Likert satisfaction item ("Overall, I am satisfied with this course") rose from 6.13 to 6.32, representing a 3.10% increase over the three-year period. Several individual courses showed more pronounced gains, particularly NUC 250 (+12.55%), NUC 495 (+7.04%), and NUC 330 (+6.50%), suggesting meaningful improvements in the student experience within these simulation-supported courses. Other courses remained consistently high with minimal fluctuation, indicating sustained satisfaction where simulation has already been well integrated. Overall, the upward trend suggests that simulation-based learning continues to positively support student satisfaction across the program.

Student	2023	2025	% Inc. 2023 - 2025
Discussions	61	68	11%
Actions	135	153	13%

Figure 2

Figure 2 summarizes average weekly student engagement in simulation-based courses within the Bachelor of Science in Nuclear Engineering Technology program at Excelsior University. Between 2023 and 2025, average weekly **discussion participation increased from 61 to 68 posts per student**, an **11% increase**, while average weekly **course actions increased from 135 to 153 actions per student**, a **13% increase**. These increases occurred alongside notable program growth, with course takers rising from **303 students in 2023 to 379 students in 2025**. Despite serving a larger student population, students continued to engage frequently and increasingly with both discussion-based and required course activities. The sustained and rising averages suggest that students in these simulation-supported courses are consistently interacting with course materials and learning activities on a weekly basis.

Below are actual comments taken from end of course surveys that support students views on the simulations within our nuclear courses at Excelsior University:

- *“Enjoyed this class overall! Always enjoy the plant simulators and the discussions that we have!”*
- *“Fantastic class with the utilization of simulators to accomplish the goals of the lab activities. I thoroughly enjoyed the simulator and the activities provided the ability to discuss Integrated Plant Operations relating my experience with the class format.”*
- *“Overall the course was great and really enjoyed the simulator activities.”*
- *“The PWR simulator was fantastic, easy to use, and easily understood.”*
- *“The use of simulators increased the class effectiveness and was a fantastic learning aid.”*
- *“I enjoyed access to the Generic PWR Simulator the most, EXCELLENT tool!”*
- *“I thoroughly enjoyed this course. The PWR simulator was a very interesting tool and Dr. Koneru is a wonderful and very understanding instructor.”*
- *“Overall this course is useful, interesting, and quite informative. The 3KeyStudent Simulator is a phenomenal tool and the learning activities are very useful.”*
- *“The simulator was the easy to use, it provided indications I would expect from my practical experiences.”*
- *“The simulators were helpful to experience different reactor types.”*

Recommendations for scaling

1. Modular Simulation Repositories: Curate reusable labs mapped to outcomes (e.g., kinetics ramp, loss of feedwater heating, isolation transients). International resources (IAEA simulators and manuals) can seed libraries and support rapid adoption. [5][6]

2. Faculty Training Models: Provide orientation and in-course instructions in simulation integration and asynchronous facilitation; use exemplar scenarios and calibrated rubrics. Evidence suggests that structured support and adaptive scaffolding improve results across learner profiles. [7][8]

3. Iterative Feedback Loops: Collect learner analytics (attempt paths, time-on-task) and mid-course reflections; refine prompts, balance guidance vs. autonomy, and adjust task progression based on data. [8]

Conclusion

Simulation-based learning provides a viable, scalable pathway to deliver authentic, practice-oriented nuclear engineering technology courses asynchronously. With modular design, embedded formative checks, and facilitated discussions, online simulation labs can bridge theory and practice and produce outcomes comparable to traditional labs—especially when scaffolding and progression are tuned to learner needs. This model supports broader institutional goals of flexibility, accessibility, and workforce relevant problem solving in digital environments. [1][2]

The school of technology has established the following Mission and vision. Mission – The School of Technology leads in providing students an ethically centered, multidisciplinary, and multimodal technical education through innovative learning that meets the future-focused needs of industry and society. Vision – The School of Technology cultivates the next generation of leaders by blending technical expertise with practical wisdom and ethical insight. Through innovative programs, hands-on experiences, and industry collaborations, we empower learners across disciplines to thrive in today's technological landscape. We foster a culture of excellence where everyone can contribute and thrive, fully equipped to meet the challenges and opportunities of tomorrow. The ongoing use of simulation technology supports these tenants.

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