Bridging Simulation-Based Nuclear Engineering Education with the Needs of Veterans and Adult Learners in Online Environments

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Introduction

Engineering education is undergoing a transformation to meet the needs of diverse learners, including veterans and adult students transitioning from military service to civilian careers. This paper explores how simulation-based online nuclear engineering technology courses can provide flexible, relevant, and competency-driven learning experiences. In the words of Malcolm Knowles, often considered the father of modern Andragogy, *"If we know why we are learning and if the reason fits our needs as we perceive them, we will learn quickly and deeply."* [1] The vision statement of Excelsior states – "Excelsior University provides access to quality higher education through innovative online learning and exceptional student experience, serving as a model for addressing societal and workforce needs." One of the methods used to meet these statements in the Nuclear Engineering Technology program at Excelsior is through the incorporation of simulation-based learning into our asynchronous-online learning model.

Military students and veterans pursue higher education for a variety of reasons throughout their careers, both while serving on active duty and after transitioning to civilian life. Many active-duty personnel seek college credit to enhance their eligibility for promotion or to establish a pathway toward commissioning as officers. The author began his career as an enlisted Machinist Mate in the Naval Nuclear Power Program and later worked with Excelsior University—then the Regents Degree Program—to consolidate academic credits from multiple institutions along with evaluated prior learning from military training. This process enabled the completion of a Bachelor of Science degree, which contributed to the author's selection through a competitive review process for advancement to Chief Petty Officer and subsequently to Limited Duty Officer.

Drawing on more than two decades of naval experience counseling service members on professional development, the author has observed that off-duty education can play a meaningful role in career progression. For veterans, the combination of Naval Nuclear Power Program training and graduation from an ABET-accredited program such as Excelsior's Nuclear Engineering Technology degree provides a strong foundation for pursuing careers in the commercial nuclear sector, including Instant Senior Reactor Operator licensing pathways or technical leadership positions at nuclear power plants.

The needs of active-duty military members, veterans, and many workers at nuclear power plants are uniquely challenging. For instance:

- Naval and commercial nuclear environments use rotating shift schedules, duty rotations, 24/7 operations, and rapid schedule changes for unplanned maintenance.

- Training for operators, technicians, and supervisors is commonly:
    - Shift-work compatible (modules taken during low-workload periods)
    - Scenario-based with irregular timing
    - Integrated into qualification programs rather than semester-based cycles

Asynchronous simulation-based coursework directly addresses:

- Irregular work hours
- Long deployments
- High-tempo operations
- The need for modular, competency-based progression rather than weekly meeting times

Excelsior's online, asynchronous learning model has been designed to address the needs of adult learners. This is consistent with the Excelsior Mission - "Excelsior University provides educational opportunity to adult learners with an emphasis on those historically underrepresented in higher education. Excelsior meets students where they are — academically and geographically, offering quality instruction and the assessment of learning." Military and veterans are one of the underrepresented populations served by this program.

Background and rationale

Although this study focuses on nuclear engineering technology education, simulation-based pedagogy has been extensively developed across multiple engineering disciplines. To contextualize the present work, we review relevant research in mechanical engineering, electrical engineering (digital twins), and chemical/process engineering, along with established methods for assessing simulation effectiveness.

Simulation Pedagogy Across Engineering Disciplines

Simulation-based learning is widely used across engineering fields, providing students with controlled, risk-free environments to explore system behavior, practice problem-solving, and develop professional competencies. Research in mechanical, electrical, and chemical/process engineering offers insight into effective simulation design, instructional strategies, and methods for evaluating learning outcomes.

Mechanical Engineering Simulation Approaches

Mechanical engineering education frequently integrates simulation tools such as finite element analysis and computational fluid dynamics to help students validate designs, evaluate system performance, and iterate efficiently. Digital twins—virtual representations of physical systems—have enhanced these practices by allowing for real-time monitoring, fault prediction, and lifecycle-based design optimization. These simulation approaches support skill development, conceptual understanding, and decision-making in realistic scenarios. [2]

Digital twin–based instruction has been shown to align effectively with Bloom's taxonomy, supporting cognitive progression from basic knowledge to innovation and design. Studies demonstrate that low-, medium-, and high-fidelity digital twins can scaffold learning from foundational to advanced engineering tasks, enabling students to engage in meaningful problem-solving and system analysis at increasing levels of complexity. [3]

Digital Twins in Electrical and Computer Engineering

Electrical and computer engineering programs increasingly incorporate industrial digital twins to teach system behavior, data integration, and real-time analysis. Digital twins allow learners to manipulate system parameters, observe system responses, and evaluate design alternatives in realistic virtual environments. Research also highlights the benefits of pairing digital-twin simulations with AI-supported mentoring tools that provide debugging assistance, adaptive scaffolding, and feedback on design decisions. Learning effectiveness has been evaluated using the Kirkpatrick Model, measuring learner reaction, skill acquisition, behavioral transfer, and performance outcomes. [3][4]

Chemical and Process Engineering Simulation Training

In chemical engineering education, process simulation tools such as Aspen HYSYS are central to developing design and analysis competencies. Recent pedagogical redesigns incorporate immersive blended learning models that combine simulation software, cooperative learning, MOOC content, and interactive problem-solving activities. Research demonstrates that this blended approach strengthens conceptual understanding, increases student motivation, and improves learners' ability to apply simulation outputs to authentic design problems. Performance data and reflective student analyses show improved design competency and confidence working with industry-standard simulation tools. [5]

Methods for Evaluating Simulation Effectiveness

Across engineering disciplines, several evidence-based frameworks and metrics have been used to evaluate simulation-based learning:

- **Performance and Design Accuracy:** Mechanical engineering studies assess simulation learning using error rates, design correctness, time-to-completion, and iterative improvement metrics [2]

- **Cognitive Skill Development:** Digital-twin research maps simulation tasks to Bloom's taxonomy and measures progression through understanding, application, analysis, and creation. [3]
- **Transfer of Learning to Workplace Tasks:** Chemical engineering simulations evaluate how students use simulation output in process design and troubleshooting tasks mirroring industry expectations. [5]
- **Kirkpatrick Four-Level Assessment:** Electrical engineering digital-twin studies use the Kirkpatrick Model to measure not only learning but also skill transfer and real-world behavioral changes. https://arxiv.org/html/2411.14433v1[3]

Collectively, these findings demonstrate that simulation-based instruction is well established across engineering fields and that robust assessment methods exist to evaluate learning outcomes, workplace relevance, and skill transfer. These cross-disciplinary insights inform the simulation design and evaluation strategies applied in the present study on nuclear engineering technology education.

Veterans and service members bring substantial technical expertise and strong leadership experience to the learning environment. Excelsior University recognizes the value of both military and commercial nuclear backgrounds through rigorous prior learning assessment, enabling students to accelerate degree completion without compromising academic integrity. Adult learning theory—particularly the principles of self-direction, relevance, and leveraging learners' existing experience—has long shaped Excelsior's educational model.

With an average student age of 35.7, and a Nuclear Engineering Technology program in which 43% of learners are active-duty personnel, 35% are veterans, and 12% are employed in commercial utilities, aligning course design with adult-learner needs is essential. Tailoring instruction to these experienced students supports engagement, enhances knowledge transfer, and reinforces the university's mission to serve working adults and military-affiliated learners.

Many military students intend to transition into the commercial nuclear workforce upon completing their service, while partner and veteran students often bring existing industry experience. This blend of backgrounds supports team-based learning, where mixed groups of military and commercially experienced learners collaborate on applied projects.

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.

For instance, in NUC211 the students conduct a group lab on Monitoring for Radioactive Material. In this lab exercise, the students conduct a search for potential radioactive sources. The searches are conducted with either instruments from the student's workplace for those students working in the nuclear field, or the student can purchase a simple radiation monitoring instrument available commercially. The students conduct their search and consolidate their results into a team-developed lab report. The challenge in this experiment is having access to actual sources of radioactivity outside of work environments. While there are common sources such as antiques crockery painted with Uranium-based pigments or smoke detectors with installed sources or antique watches with radium-based dials, these items can be limited in availability. While the school has been successful with currently available resources, this is an area where we are exploring the availability of Virtual Reality radiation measuring instruments for use in our labs. This could be particularly useful in a hybrid environment.

Course design and pedagogical framework

As many students in Excelsior's Nuclear Engineering Technology program are active-duty military or veterans, the asynchronous instructional model offers flexibility for learners balancing education with work and family responsibilities. Active-duty military personnel have duties that often require them to perform work in rotating shifts, daily duty responsibilities, and emergent duty requirements. Veterans are often employed in the commercial nuclear industry where they also have duties like active-duty personnel. As such, they need the flexibility of an asynchronous learning model.

To support Excelsior's Bachelor's in Nuclear Engineering Technology (BSNET) program, Excelsior applied for and received a DOE grant in 2016 to develop and implement a Generic Pressurized Water Reactor (GPWR) simulator in our BSNET courses. In 2017, we implemented a Generic Pressurized Water Reactor (PWR) Simulator, powered by Curtiss-Wright Simulation & Modeling Technologies. The PWR Simulator has been integrated into seven of our courses. The HTML-based pressurized water reactor simulator provides interactive virtual labs covering heat transfer, fluid dynamics, reactor kinetics, and radiation control. Instructional strategies include modular content, embedded formative assessments, and peer-to-peer engagement. This allows students to experience the differences between the Naval Nuclear Reactor design and operation compared to a commercial nuclear power plant. Students are in a blended learning environment where students experienced in commercial reactor operations and maintenance can share their experience with active-duty personnel. This sharing of experiences is also of benefit to an increasing number of students who enter Nuclear Engineering Technology without previous nuclear experience. Based on projections for growth in the power needs of the nation, programs such as designed by Excelsior will be increasingly needed to meet the workforce needs to provide required power generation.

Simulator training is widely used in commercial nuclear power. All power plants are required to have a plant-referenced simulator for the initial training, qualification and periodic requalification and training of licensed operators [6]. Research was conducted related to simulator effectiveness for training operators during the implementation of the requirements for plant-referenced simulators and identified that the literature indicates simulation was an effective training methodology. [7] Recent initiatives such as the Navy's adoption of large-scale simulators represent significant advancement in the use of simulation for nuclear training. [8]

Simulation fidelity and information quality assessment

To ensure that Excelsior University's nuclear engineering technology curriculum provides students with realistic and workforce-relevant preparation, significant effort has been devoted to verifying the fidelity of the program's simulation tools. The WSC/Curtiss-Wright (WSC) simulation models used in the Generic PWR Simulator have an established reputation for accurately representing commercial reactor systems, incorporating thermodynamic behavior, reactor kinetics, and fluid-flow characteristics through robust internal modeling. Subject-matter experts from across the nuclear industry review and validate these models to confirm that simulator outputs align with expected plant responses before the scenarios are incorporated into coursework.

Students engage with these validated models through online laboratory activities in which they predict plant behavior using theoretical concepts from the curriculum and then compare their predictions to simulated plant data. This approach has proven especially beneficial for students with Naval Nuclear Power experience who are preparing to transition into commercial nuclear careers, as it helps them connect prior training to the operational realities of civilian power plants.

The simulations and scenarios used across the program are designed by instructors and developers with ten to fifty years of commercial and Naval nuclear experience. Their expertise ensures that the learning activities are both appropriately rigorous—promoting critical thinking—and authentically representative of real plant conditions, thereby supporting student engagement. As part of the program's continuous improvement efforts, Excelsior also benchmarks its simulated activities against International Atomic Energy Agency (IAEA) educational simulators [11]. While the IAEA BWR simulator is currently integrated into several courses, the university is actively pursuing grant funding to implement a Generic BWR simulator that will further enhance instructional flexibility and technological alignment.

Applied learning and capstone experience

Virtual labs replicate hands-on experiences, promoting applied learning without physical lab constraints. Our Generic PWR simulator allows the students to apply fundamentals learned in engineering courses to simulated reactor plant responses. For instance, in NUC245: Thermodynamics, one of the modules has the students learn thermodynamic properties through the expansion of the First and Second Laws of Thermodynamics. They study the equilibrium thermodynamics balance in a self-study session using the material supplied in the course. The text is the *DOE Fundamental Handbook: First Law of Thermodynamics (Vol3, 1992).*[9] After completing required reading, students review simulations of the properties they have learned and engage in an asynchronous discussion of simulations using PhET's collection of HTML Simulations (Version 2) from the University of Colorado Boulder [10]. The students then continue their application of the principles of thermodynamics by conducting a laboratory simulation using the online PWR Simulator hosted by Curtis-Wright.

Another application of simulation takes place in NUC350: Plant Systems Overview. In this course, students are exposed to the design of both Boiling Water Reactors (BWR) and PWRs. This course is particularly of value to the students with a Naval Nuclear background completely focused on PWRs. In addition to a review and discussion of the differences in design and operations of BWRs and PWRs, this course incorporates the IAEA Generic Boiling Water Reactor Simulator developed for the IAIA by Cassiopeia Technologies [9]. This design used in this simulator is like the Susquehanna Nuclear Power plant in Pennsylvania and allows students to observe normal operations and transients to become familiar with the unique attributes of a BWR. The students conduct labs with both technologies, better preparing them for the transition to a commercial environment where about one-third of the power plants in the United States are BWRs.

The students' final experience with a PWR simulator is during NUC 495: Capstone experience. In the capstone course, students perform two major exercises involving the PWR simulator. During the first exercise, students are assigned to develop a test of a safety-related pump in the PWR to verify operability per design specifications. This requires the students to utilize the simulator to develop an appropriate valve lineup, identify instrumentation to conduct the test, and determine appropriate instrumentation to use for collecting data. The draft procedure is then reviewed by the instructor using a rubric, and improvement opportunities are provided to the students.

In the next module, the students then use their procedure in the simulator to align the system(s), operate the components, collect data, analyze the data, and determine the operability of the safety-related pump. In most iterations of the scenario, the students find that the component does not meet the acceptance criteria. They are then required to provide ongoing actions regarding plant operations, regulatory requirements, and potential consequences. This allows the students to utilize the knowledge and skill from multiple prior classes in an applied simulation supported situation like what they might encounter in actual plant application.

In the final Capstone modules, students are placed into a situation where they act as a watch team in a nuclear plant. The team then runs a scenario in the simulator to diagnose a simulated plant event, brainstorm the potential consequences and implications of the event from a plant design standpoint, determine appropriate actions for the watch team to take, and propose system improvements that would mitigate or prevent the event from recurrence. As individuals, they propose a design recommendation, and as a team they present their findings to a mock senior management team, fostering leadership and systems thinking. In reflections at the end of the course, many students share that the use of the simulator in the Capstone course and working as a team is the most rewarding part of their experience in the course.

Faculty development and institutional support

Faculty training ensures confidence in simulation-enhanced andragogy. During the incorporation of the simulator in our courses, faculty were provided training on the operation of the simulator and the scenarios that were developed to support classes. Subject-matter experts from the nuclear industry are actively involved in simulator scenario development and improvement on an ongoing basis. Continuous improvement is supported through feedback loops and performance analytics.

Excelsior has supported faculty development and course improvement through the active participation of an Industry Advisory Committee (IAC) whose membership has included many senior members from the nuclear industry, a past president of the American Nuclear Society, and the Vice-president for Training of the largest nuclear utility in the United States. Several of the members of the IAC are also alumnus of the BSNET program and have had the opportunity to shape the program over time to support the relevance of our programs. They are highly supportive of the incorporation of realistic simulation in our programs.

Outcomes and student feedback

Student reflections indicate increased engagement and workplace relevance. Data suggests learning outcomes are comparable to previous online laboratory formats. Over time, student satisfaction has increased, and students are finding their education supports their career aspirations. Industry Advisory Committee members often monitor student performance through program assessment reviews and observation and comment on the performance of student teams in their Capstone presentations. These evaluations help ensure we both continue to meet ABET Accreditation standards and the needs of students and employers.

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. [12][13]

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 and future directions

Scaling the program effectively requires the creation of modular simulation-scenario repositories, ongoing faculty training, and a structured framework to support continuous improvement. Each simulator scenario is carefully developed and validated to ensure that students engage with realistic and instructionally sound laboratory experiences. Scenario development follows a collaborative model that brings together subject-matter experts with commercial nuclear plant experience and the technical specialists from the WSC simulation team. This partnership ensures that every scenario is both technically accurate and sufficiently rigorous to challenge students’ analytical and cognitive skills. Guided by feedback from faculty and the Industry Advisory Committee, new scenarios are periodically created and validated to provide students with continually updated and appropriately challenging learning experiences.

Instructor selection also emphasizes professional expertise. Faculty members are chosen for their nuclear industry experience and academic preparation, including one full-time faculty member with more than fifty years of combined Naval and commercial nuclear experience. Capstone instructors typically have over thirty years of industry experience, and newer instructors are periodically added to maintain alignment with current industry standards and evolving technologies. The full-time faculty member’s active involvement in the American Nuclear Society further supports the program’s readiness to incorporate emerging reactor technologies.

Excelsior University conducts regular faculty meetings to review course quality and relevance. Each trimester, selected Capstone student teams present their projects to faculty and members of the Industry Advisory Committee. These reviews provide insight into program consistency while offering an opportunity for industry experts to provide timely feedback. One outcome of this collaborative process is the initiative to acquire a fully functional BWR simulator and to expand simulation resources to include small modular and micro-modular reactor designs as these technologies become increasingly relevant to the industry.

Conclusion

The nuclear industry is projected to grow significantly over the next twenty-five years a electric demand increases. The nation's current nuclear reactor fleet employs approximately 100,000 people. That number is anticipated to rise to 375,000 by 2050 with the deployment and commercialization of advanced reactors.[14] Simulation-based asynchronous courses can bridge gaps in engineering education for military-affiliated learners, fostering innovation, flexibility, and inclusivity. Using realistic simulations, Naval Nuclear Operators and students new to nuclear power are better prepared to make the transition to the commercial nuclear workforce and related positions at the National Laboratories. Excelsior intends to expand the use of simulation-based learning in our programs.

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