

Holistic Energy Education for Nuclear Engineers

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Abstract

This paper introduces holistic energy education for nuclear engineers, integrating technical knowledge with social, environmental, and ethical perspectives to address complex, interdisciplinary challenges like climate change. Building upon existing frameworks of holistic and interdisciplinary education, holistic concepts were integrated into various nuclear engineering courses. Student feedback indicates significant improvements in understanding the broader implications of nuclear energy and its role in sustainable development. This adaptable framework aims to prepare nuclear engineers to develop innovative, sustainable, and socially responsible energy solutions and enhance public trust in nuclear technologies.

Introduction

Holism, from the Greek word *holos* meaning *whole, entire, total*, is the interdisciplinary idea that systems possess properties as wholes apart from the properties of their component parts. The concept can be summarized by the aphorism often attributed to Aristotle, “The whole is greater than the sum of its parts.”

Holistic principles have far-reaching implications across various fields, including medicine, psychology, ecology and engineering. Holistic engineering education integrates a comprehensive understanding of engineering principles with broader social, environmental, and ethical considerations.

Building on this concept, this paper introduces *holistic energy education* as a specialized form of holistic engineering education focused on energy systems. A holistic approach to energy systems emphasizes understanding the interplay between technical components, environmental impact, societal needs, and ethical considerations. While technical expertise is essential, considering environmental impacts, sustainability, and other overarching factors is crucial for developing innovative, sustainable, and socially responsible energy solutions. This comprehensive perspective ensures that energy solutions are not merely efficient and productive but are mindful of the broader contexts in which they operate, considering sustainability and social responsibility.

Addressing complex issues often requires multifaceted strategies, particularly when confronting wicked problems—those characterized by their complex, interconnected, and evolving nature. Climate change is a prime example of a wicked problem, with far-reaching impacts across environmental, economic, social, and political dimensions. This complexity underscores the need for holistic energy education to effectively tackle such challenges.

Nuclear energy has been explored alongside renewable energy as a solution to climate change. As a highly technical field, nuclear engineering requires a deep understanding of physics, chemistry, and engineering principles. However, nuclear energy is more than just a technical challenge; it encompasses complex environmental, social, ethical, and policy dimensions that must also be addressed. Hence, a holistic energy education approach is particularly essential for

nuclear engineering. This paper presents the integration of holistic energy concepts into nuclear engineering courses alongside technical nuclear engineering content.

The paper is structured as follows: a background section reviews the development and current state of holistic energy education and the need in nuclear engineering, then a section on the methodology used to incorporate holistic energy concepts in a variety of nuclear engineering courses, then a results and discussion section, and finally a section to conclude.

Background

Literature Review

There has been an argument for giving social science issues more prominence in engineering curricula, as a thorough understanding of the social world is crucial to successful engineering [1]. Holistic engineering education combines traditional engineering coursework with subjects like economics, sociology, psychology, business, and other disciplines, creating engineers who are capable of leading multidisciplinary teams and driving innovation [2]. In essence, holistic engineering education integrates *all* knowledge to some purpose [3]. The aim is to produce engineers who are capable of engineering in sustainable and socially responsible ways.

In response to concerns about engineers' readiness for future challenges, the National Academy of Engineering published a series of reports in 2004 and 2005 titled *The Engineer of 2020: Visions of Engineering in the New Century* that highlighted the necessity of transforming engineering education to address societal needs, recommending program restructuring, resource reallocation, and an emphasis on inclusion of social sciences and humanities [4]. The envisioned engineer of 2020 excels not only in math and science, but also understands the social, cultural, and economic impacts of their work, blending technical expertise with insights from social sciences and humanities.

Holistic energy education is a specialized branch of holistic engineering education focusing on energy systems. Holistic energy education covers topics such as renewable energy, energy efficiency, climate change, and energy policy, equipping future professionals with technical expertise, environmental awareness, risk assessment skills, and communication abilities. This approach aims to prepare students to address complex energy sector challenges with sustainable, economically viable, and socially equitable solutions.

Holistic energy education, integrated energy education, and interdisciplinary energy education have nuanced differences:

- Holistic energy education emphasizes a comprehensive approach, considering the entire system and the interactions between various elements within the energy sector. It focuses on seeing the big picture and integrating diverse perspectives, including technical, social, economic, environmental, and political aspects, to understand and solve energy-related challenges comprehensively.
- Integrated energy education suggests combining different disciplines or areas of study into a single, cohesive program or curriculum. It strives to remove traditional academic silos and bring together various fields such as engineering, economics, environmental

science, and policy, creating a unified educational experience that promotes collaboration and interconnected thinking.

- Interdisciplinary energy education highlights the crossing and blending of multiple disciplines to address energy issues. This approach involves collaboration between different academic departments or fields, encouraging students and researchers to draw on methodologies, theories, and knowledge from various disciplines to tackle complex energy problems. It integrates insights from diverse fields without necessarily merging them into a single curriculum.

Interdisciplinary energy education has a longer history and is more established than holistic energy education. It gained prominence during the 1970s and 1980s energy crises when educators saw the value of integrating multiple academic disciplines to address complex energy issues. Programs combining fields like physics, chemistry, engineering, and environmental science were developed to equip students with a multifaceted understanding required to innovate and solve emerging energy problems. Consequently, interdisciplinary education became integral to engineering and science curricula, encouraging collaboration among different academic departments and promoting a pragmatic approach. The holistic approach is newer, emerging as the need for broader understanding of energy's societal and ethical implications became evident. While interdisciplinary education laid the groundwork, the holistic paradigm builds upon it by incorporating wider contextual elements, such as social and ethical considerations.

Climate Change and Nuclear Energy

In the energy field, perhaps no problem looms larger than climate change, a quintessential example of a "wicked problem." Wicked problems are complex issues deeply intertwined with environmental, economic, and societal challenges that require multifaceted approaches. Climate change exemplifies this complexity, with its intricate connections between environmental degradation, economic disparities, and socio-political dynamics. Addressing this challenge and related issues such as sustainable development, resource management, and energy security requires engineers to recognize that technical solutions must function within a broader context, integrating societal impacts and interdisciplinary considerations.

Nuclear energy has been explored alongside renewable energy as a solution to climate change [5]. As a highly technical field, nuclear energy demands a profound understanding of physics, chemistry, and engineering principles. The development, deployment, and management of nuclear energy systems encompass a variety of complex technical challenges, including reactor design, fuel cycle technology, and waste management. However, addressing nuclear energy challenges requires more than just technical expertise; these issues exist at the convergence of nuclear technology, policy, and societal interests, thereby exhibiting all the characteristics of wicked problems [6]. These problems include the need to balance safety concerns, regulatory requirements, economic feasibility, and public perception.

Moreover, the societal implications of nuclear energy are significant, as they involve public trust, ethical considerations, and long-term environmental impacts. The regulatory landscape is complex and varies significantly across different regions, adding another layer of intricacy to the implementation of nuclear solutions. Consequently, a holistic approach to energy education is

essential, particularly for nuclear engineering students. A holistic energy education not only equips students with the necessary technical knowledge but also integrates interdisciplinary perspectives that address the socio-political, ethical, and environmental dimensions of nuclear energy.

Examples of Holistic, Integrated, or Interdisciplinary Energy Education

Recognizing climate change and sustainability as some of the world’s most complicated problems, various institutions have implemented holistic, integrated, or interdisciplinary energy education. Some have chosen to do this via courses. The University of San Diego taught *An Integrated Approach to Energy* as a second-year course for engineering students in 2020 which the authors described as a “model of sociotechnical thinking—challenging studies with scenarios that were both technically demanding and required critical thinking about social implications” [7]. Baylor University’s Engaged Learning Group courses, which integrate technical knowledge with societal, political, and environmental dimensions, utilize a holistic approach to energy education [8]. These courses not only cover the scientific aspects of energy but also address its broader impacts. As shown in Table 1, some institutions have taken the approach of creating entire degree programs focused on energy.

Table 1. Degree programs focused on energy at various universities [9-13].

Degree name	Institution	Level
Integrated Energy Management	Central Washington University	B.S.
Energy Engineering	Pennsylvania State University	B.S.
Energy Policy and Management	Western Washington University	B.A.
Energy Science and Technology	Western Washington University	B.S.
Energy (Interdisciplinary)	Texas Tech University	M.S.
Energy and Resources	UC Berkeley	M.S./M.A./Ph.D.

Examples of holistic energy education approaches exist in nuclear engineering courses and other nuclear-related activities. At the University of Michigan, socio-technical topics have been included in a first-year design course, *Socially Engaged Design of Nuclear Energy Technologies* [14], and an elective, lecture-based course, *Nuclear Technology, Policy, and Society* [6]. The 2011 Advanced Summer School of Nuclear Engineering and Management with Social-Scientific Literacy at the University of California, Berkeley, held in the aftermath of the Fukushima Daiichi Nuclear Accident, emphasized the importance of combining nuclear science with social-scientific literacy and resulted in the organizers publishing a book on nuclear engineering education in the post-Fukushima era [15].

Methodology

Educational Framework and Learning Theory Approach

In our approach to implementing holistic energy education for nuclear engineering students, we grounded our methodology in the constructivist learning theory to ensure a robust and effective learning experience. Constructivist learning theory emphasizes the importance of students

constructing their own understanding through active engagement and reflection [16]. To achieve this, we integrated interdisciplinary content and collaborative problem-solving activities that reflect real-world scenarios. This way, students learn in contexts that mimic professional practice, enhancing the relevance and applicability of the concepts they study. Our educational design also incorporates Kolb's experiential learning principles, which focus on learning through direct experience followed by reflective observation [17]. This practical approach allows students to engage deeply with the material and develop a practical and comprehensive understanding of holistic energy concepts.

The holistic energy material emphasizes accessibility and inclusivity for students from all backgrounds. Specifically, Universal Design for Learning (UDL) principles were employed to accommodate individual learning differences. To further promote inclusivity, modules cover the societal impacts and ethical dimensions of nuclear energy, particularly how energy policies and practices impact different communities. Classroom discussions are carefully moderated to ensure a variety of perspectives are heard, fostering a culture of inclusivity. Additionally, assignments have been designed to allow students to explore the sociotechnical aspects of nuclear energy in various contexts, enabling them to consider and respect the diverse viewpoints of peers from different backgrounds.

Integration of Holistic Energy Concepts into Nuclear Engineering Courses

The goal of providing nuclear engineering students with a holistic energy education poses a challenge for educators: how to teach a broad set of concepts without trivializing them. It is essential to avoid merely covering topics from various disciplines without linking them together meaningfully. The chosen approach integrates holistic energy concepts throughout various courses rather than isolating them in a stand-alone course. Embedding these ideas across multiple courses helps students continuously connect specialized nuclear engineering knowledge to holistic energy concepts.

A curriculum analysis of leading nuclear engineering programs was conducted to identify common nuclear engineering courses for integration of holistic energy. The analysis focused on avoiding topics unique to any single institution. Common identified topics included introductory courses on nuclear engineering, radiation interactions, radiation detection, thermal hydraulics, nuclear materials, reactor physics, the nuclear fuel cycle, and risk assessment. The following sections detail how holistic energy education was incorporated into selected courses.

Introductory and Fundamental Courses

Introductory or fundamental courses in nuclear engineering provide a foundational understanding of nuclear principles and technologies. These courses also tend to offer the greatest flexibility to try different modules of content. At the University of Florida there are separate Introduction to Nuclear Engineering and Fundamentals of Nuclear Engineering courses.

Introduction to Nuclear Engineering is a one-credit course with approximately 15 contact hours over the semester. The course now starts with an overview of the global energy landscape, highlighting different sources of energy. In the nuclear history module, additional content was

added to discuss the environmental and societal impacts of nuclear technologies, including a homework assignment to research a historical nuclear event and broader implications. The section on the nuclear fuel cycle and safeguards has been expanded to cover global nuclear policies and the role of international organizations in ensuring the safe and secure use of nuclear materials. In the portion covering engineering ethics, we integrated broader ethical considerations such as environmental justice and societal impacts to prepare students to think critically about the implications of their work.

Fundamentals of Nuclear Engineering is a two-credit course with approximately 30 contact hours. The beginning of the course delves deeper into the global energy production and consumption, analyzing the past, present, and future role of nuclear energy within the energy ecosystem, including its advantages and limitations, and opportunities for hybrid systems with renewables. From the start, students gain a sense of how nuclear power fits within a wider energy context. The section on nuclear reactors was expanded to include discussions on the sustainability and environmental considerations of reactor types and siting locations, including radioactive waste management. Finally, the course concludes with a dedicated energy systems module providing a comprehensive look at energy systems, integrating holistic concepts such as sustainable development, renewable energy sources, and the future of energy policy.

Radiation Detection and Instrumentation

Radiation Detection and Instrumentation is a four-credit course with approximately 45 contact hours of lecture and 15 hours of laboratory. The introduction and radiation interactions review now include a contextual overview of the broader energy landscape, emphasizing the role of radiation detection within various energy systems. In the sections on counting statistics and error analysis, additional content was integrated to discuss the importance of accurate radiation detection in environmental monitoring and public health. Specifically, modules were added on the critical role of radiation detection in tracking radioactive contaminants in the environment, monitoring radiation levels near nuclear facilities, and its application in medical diagnostics and treatments. These additions focus on how accurate detection and error analysis can prevent false positives and negatives, which are crucial in identifying hazardous exposure levels and ensuring safety standards.

Risk Assessment and Economic Analysis

Risk Assessment and Economic Analysis is a three-credit course with approximately 45 contact hours. The course introduction now includes a comprehensive overview of the interconnected global energy landscape, emphasizing the importance of risk assessment and economic analysis across all energy systems. During fault and event tree analysis modules, students conduct comparative assessments of various energy systems, identify risks, and evaluate mitigation strategies. The economic analysis sections were expanded to cover the financial implications of integrating renewable energy sources, sustainable practices, and regulatory policies, ensuring students grasp the economic drivers of energy transition. Specific discussions now compare the economics of nuclear power plants with other renewable technologies, covering lifecycle costs and the benefits of co-locating energy sources. Additionally, sensitivity studies encompass

financial, environmental, and social factors, examining impacts of regulatory shifts, public perception, and technological advancements on risk and economic evaluations.

Results and Discussion

Student Feedback

To evaluate the necessity and impact of holistic energy education in nuclear engineering, student feedback was gathered through pre- and post-surveys. The pre-survey measured students' baseline knowledge and attitudes towards energy systems and the societal impacts of nuclear technology using Likert scale ratings from 1 (strongly disagree) to 5 (strongly agree) and open-ended responses. This provided a benchmark for assessing changes after course completion. A post-survey, administered at the conclusion of the course, asked the same questions to identify shifts in perceived knowledge and attitudes. The survey results, summarized in Table 1, indicate a significant improvement in students' perceived understanding of the broader context in which nuclear energy operates, including how nuclear energy contributes to sustainability and its sociotechnical challenges. Notably, the increase in scores from pre- to post-survey across all categories highlights the potential for holistic energy education to increase interdisciplinary knowledge among nuclear engineering students.

Table 1. Summary of Pre- and Post-Survey Results

Survey Question	Pre-Survey (Average Score)	Post-Survey (Average Score)
I feel confident in my technical understanding of nuclear energy and its applications.	4.2	4.4
Nuclear engineering education should include societal, policy, and interdisciplinary energy topics.	3.6	4.1
Nuclear engineering education should include how nuclear energy interacts with the broader energy landscape.	3.8	4.5
I understand how nuclear energy fits within the broader energy landscape and interacts with other energy sources.	3.2	4.1
I understand the importance of sustainability in energy system design and decision-making.	4.1	4.3
I understand how nuclear energy contributes to sustainable development.	3.8	4.3
I understand the how to use sociotechnical information (e.g., policy, public perception, environmental impact, and economics factors) in nuclear engineering decision-making.	2.8	3.7

The positive student feedback from the integration of holistic energy concepts into nuclear engineering courses indicates that continued efforts are worthwhile. Future efforts will focus on the refinement of holistic energy materials and development of an elective course that explores the societal impacts of nuclear technology.

Adaptability for Different Institutions and Disciplines

Recognizing the diversity in resources, demographics, and disciplines at various institutions, the holistic energy education framework is designed to be adaptable. Resource-rich institutions might include laboratory experiences, interdisciplinary projects, and industry partnerships. Conversely, institutions with limited resources could emphasize case studies and guest lectures to effectively convey holistic energy concepts. The modular structure allows for incremental implementation, enabling institutions to integrate holistic energy principles into one or two courses and expanding as resources permit. Practical exercises and flexible assignment topics further allow instructors to tailor material to their institution's focus areas and demographics, ensuring all students receive relevant education in holistic energy principles.

While this effort focused on integrating holistic energy education in nuclear engineering, holistic energy education can benefit numerous scientific and engineering disciplines within the energy sector. By integrating technical knowledge with environmental, social, political, and ethical considerations, students are better prepared to address discipline-specific sociotechnical challenges. This approach promotes interdisciplinary collaboration and equips students to develop innovative, sustainable solutions across the energy landscape.

Conclusion

Nuclear technology is developed, constructed, and operated alongside other energy technologies, impacting society and the environment. A holistic perspective enables nuclear engineers to recognize their societal and environmental responsibilities, assess the long-term sustainability of nuclear energy, and engage with public concerns and regulatory landscapes. This comprehensive understanding is vital for developing responsible and innovative solutions that maintain public trust and ensure safety.

As the global energy landscape evolves, the ability to understand and innovate within the entire energy ecosystem will be a key differentiator for future nuclear engineers. Integrating holistic energy education into nuclear engineering programs and other energy-related disciplines will better prepare students to face the challenges and opportunities of the future energy landscape.

References

- [1] K. H. Sørensen, "The Role of Social Science in Engineering," *Philosophy of Technology and Engineering Sciences*, pp. 93–115, Jan. 2009, doi: 10.1016/B978-0-444-51667-1.50008-2.
- [2] D. Grasso and D. Martinelli, "Holistic Engineering," *Holistic Engineering Education: Beyond Technology*, pp. 11–15, 2010, doi: 10.1007/978-1-4419-1393-7_2.
- [3] J. Bordogna, E. Fromm, and E. W. Ernst, "An integrative and holistic engineering education," *J Sci Educ Technol*, vol. 4, no. 3, pp. 191–198, Sep. 1995, doi: 10.1007/BF02211836/METRICS.

- [4] National Academy of Engineering, "The Engineer of 2020: Visions of Engineering in the New Century," *The Engineer of 2020*, May 2004, doi: 10.17226/10999.
- [5] Q. Wang, J. Guo, R. Li, and X. ting Jiang, "Exploring the role of nuclear energy in the energy transition: A comparative perspective of the effects of coal, oil, natural gas, renewable energy, and nuclear power on economic growth and carbon emissions," *Environ Res*, vol. 221, p. 115290, Mar. 2023, doi: 10.1016/J.ENVRES.2023.115290.
- [6] A. Verma, A. Campbell, J. P. Duarte, and A. Liebscher, "Reckoning with the wicked problems of nuclear technology: pedagogical philosophy, design, and method underlying a course on nuclear technology, policy, and society," *Frontiers in Nuclear Engineering*, vol. 3, p. 1382695, Aug. 2024, doi: 10.3389/FNUEN.2024.1382695.
- [7] G. D. Hoople, D. A. Chen, S. M. Lord, L. A. Gelles, F. Bilow, and J. A. Mejia, "An Integrated Approach to Energy Education in Engineering", doi: 10.3390/su12219145.
- [8] K. Van Treuren and I. Gravagne, "Energy awareness efforts at Baylor university," *ASEE Annual Conference and Exposition, Conference Proceedings*, 2008, doi: 10.18260/1-2--3885.
- [9] "Energy Engineering Major | Penn State Department of Energy and Mineral Engineering." Accessed: Jan. 14, 2025. [Online]. Available: <https://www.eme.psu.edu/undergraduate/academics/undergraduate-programs/energy-engineering-major>
- [10] "Energy Studies | Western Washington University." Accessed: Jan. 14, 2025. [Online]. Available: <https://www.wvu.edu/majors/energy-studies>
- [11] "MSIS Energy | Programs | Graduate School | TTU." Accessed: Jan. 14, 2025. [Online]. Available: <https://www.depts.ttu.edu/gradschool/Programs/energy/>
- [12] "Program: Integrated Energy Management BS, Integrated Power Systems Specialization - Central Washington University - Modern Campus Catalog." Accessed: Jan. 02, 2025. [Online]. Available: https://catalog.acalog.cwu.edu/preview_program.php?catoid=60&poid=14154&returnto=3730
- [13] "Emmett Interdisciplinary Program in Environment and Resources." Accessed: Jan. 14, 2025. [Online]. Available: <https://eiper.stanford.edu/>
- [14] A. Verma and K. Snyder, "Integrating Community-Engaged Research and Energy Justice in Design Pedagogy: Reflections on a First-Year Undergraduate Design Course," *ASEE Annual Conference and Exposition, Conference Proceedings*, Jun. 2024, doi: 10.18260/1-2--47647.

- [15] J. Ahn *et al.*, “Reflections on the Fukushima Daiichi Nuclear Accident Toward Social-Scientific Literacy and Engineering Resilience”.
- [16] S. Olusegun, “Constructivism Learning Theory: A Paradigm for Teaching and Learning,” vol. 5, no. 6, pp. 66–70, doi: 10.9790/7388-05616670.
- [17] D. A. Kolb, *Experiential learning: Experience as the source of learning and development*. FT press, 2014.