Managing Interdisciplinary Senior Design with Nuclear Applications

Dr. Tristan Utschig, Kennesaw State University

Dr. Tristan T. Utschig is Associate Director for Learning Sciences in the Center for Excellence in Teaching and Learning (CETL) and is Associate Professor of Nuclear Engineering at Kennesaw State University. Formerly, he was Assistant Director for CETL and the Office of Assessment at Georgia Tech, and prior that was a tenured Associate Professor of Engineering Physics at Lewis-Clark State College. Dr. Utschig consults with faculty across the university about bringing scholarly teaching and learning innovations into their classroom and assessing their impact. He has regularly published and presented work on a variety of topics including assessment instruments and methodologies, using technology in the classroom, faculty development in instructional design, teaching diversity, and peer coaching. Dr. Utschig completed his PhD in Nuclear Engineering at the University of Wisconsin–Madison.

Dr. Sandip Das, Kennesaw State University

Sandip Das is currently an Assistant Professor in the Electrical Engineering Department at Kennesaw State University. Dr. Das received his Ph.D. and M.E. in Electrical Engineering from University of South Carolina, Columbia, in 2014 and 2012 respectively. He completed his B.E. in Electrical Engineering from Indian Institute of Engineering Science and Technology (IIEST, Shibpur, India) in 2004. His current research interests include photovoltaic solar cells for sustainable and renewable energy generation, development of radiation detection and monitoring devices, applied electronics for measurement and instrumentation, and development of technology enhanced teaching tools and pedagogical framework for improved engineering education.

Dr. Valmiki Sooklal, Kennesaw State University

Research interests are focused primarily in laser/material interaction, sustainable housing and engineering education.

Dr. Eduardo Farfan, Kennesaw State University

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Abstract

This paper presents results from an investigation into how interdisciplinary senior design projects emphasizing nuclear engineering applications can best be managed, along with suggested technical content areas within nuclear engineering carrying strong interdisciplinary potential. This work is important because an aging nuclear industry workforce will need to be replaced soon, and due to recent national emphasis on detection of nuclear materials to fight terrorism, radiation detection and monitoring for nuclear medicine applications, and design of small modular nuclear reactors. In the paper, the most likely technical content overlap between nuclear and other fields of engineering is discussed. Also, results of a literature search demonstrate that nuclear engineering projects are exceedingly rare within interdisciplinary senior design. Therefore, a project management framework using results from an exploration of the literature on interdisciplinary senior design to identify salient issues pertaining to nuclear engineering is presented. Issues include raising awareness among faculty mentors from different subject areas about potential project areas; addressing nuclear specific codes and standards; and challenges when working across disciplines in project funding, the student team formation process, student credit hours granted, and workload allocation for faculty advisors to the projects. Finally, two interdisciplinary case studies involving nuclear engineering topics are discussed – one from mechanical engineering and one from electrical engineering. These case studies include descriptions of the projects along with reflections and assessments by students and faculty mentors on their impact.

Introduction

An investigation into how interdisciplinary senior design projects emphasizing nuclear engineering applications can best be managed has been conducted, and nuclear engineering technical content areas with the greatest opportunity for interdisciplinary projects are presented.

Rationale

As the nuclear industry workforce ages, a new generation of engineers capable of filling this gap is needed [1]. At the same time, emphasis on detection of nuclear materials to fight terrorism, recent development of nuclear medicines and the need for medical imaging have generated strong interest in the development of radiation detection and monitoring devices [2,3]. However, only 21 ABET accredited programs exist for nuclear engineering. Additionally, although many new certificate programs and minors have emerged to serve these needs and train engineers to perform specific tasks in industry, there is a lack of opportunity for the students in these programs to develop substantive experience in the nuclear engineering field through participation in multidisciplinary, collaborative senior design or capstone project work.

Paper Organization

The paper begins with a review of the literature on interdisciplinary capstone design to illuminate key issues that should considered and to determine where any examples pertaining to nuclear engineering might fit into this literature. Next, two case studies are presented – one from mechanical engineering and one from electrical engineering – where nuclear engineering content was incorporated within senior design projects from other fields at a comprehensive university with a large, primarily undergraduate engineering program. These case studies include descriptions of the projects along with reflections and assessments on their impacts by students and faculty mentors. Finally, the most likely capstone design technical content overlap between nuclear and other fields of engineering, based on the author's experiences, is discussed.

Literature/Background

After searching the literature, it appears there is no literature at all that is specific to incorporating nuclear engineering content into interdisciplinary engineering capstone design projects. However, several areas of nuclear engineering content have strong potential for interdisciplinary projects. Because of this gap in the literature, two case studies are described here to illuminate the nature of such projects. Further, this work appears to be the first to describe benefits and challenges encountered in nuclear-related interdisciplinary projects. Incorporating nuclear content may produce unique benefits or challenges to interdisciplinary design projects. Nonetheless, there is still some relevant prior literature that is general to all interdisciplinary projects. A summary of the most relevant general literature is presented here.

Rationale for Interdisciplinary Capstone Projects

Although interdisciplinary capstone design began to be seriously discussed in the 1990s [4], the introduction of the ABET 2000 accreditation criteria sparked considerable work in this area. Hirsh et al. [5] make the case for this type of work as a general approach. Since that time, numerous authors have lauded the benefits of interdisciplinary design projects in engineering [6, 7, 8, 9, 10]. Benefits cited by these authors include introduction of multiple perspectives to team processes, opportunities for real-world experiences related to complex scenarios, preparation for expected multidisciplinarity in industry, and students building increased connections between engineering topics previously seen as separate. All of these benefits certainly apply to nuclear content incorporated into capstone design projects as well.

Additionally, results from qualitative analysis of open-ended questions on the Capstone Design Survey [11, 12] mention that involving multiple disciplines is one strength to look for when identifying projects, and that industry mentors with multidisciplinary experience is a strength when managing teams.

Finally, there is evidence that senior design projects completed by interdisciplinary student teams are of higher quality than those completed by single discipline teams [13].

<u>Interdisciplinary Design Process Considerations</u>

Based on six years of experience, Olsen et al. [14] outline several common issues that must be addressed when considering interdisciplinary capstone design experiences. These issues include differences in learning styles and problem solving processes among students, students without faculty representation on the project, recruiting faculty to support the project, the importance of identifying issues early by using peer review, distinct faculty objectives within the project that do may not align, officially collecting student evaluations of faculty mentors, and conflict over budget sources and allocation. All of these issues may arise when incorporating nuclear engineering content as well.

A 19-point framework with a rubric for each framework component was developed to characterize the spectrum of issues arising in interdisciplinary capstone design by Cooper, Fulton, and Homan [15]. This framework has components generic to all capstone design as well as interdisciplinary design, and also includes some issues specific to their context of the US Air Force. Items relating to interdisciplinarity include:

1. Funding source (e.g. internal/external/none)
3. Starting point for requirements refinement (e.g. ill-defined, existing requirements)
4. Agility of design process (e.g. step-wise, as-needed)
5. Diversity of team member major/skillset (e.g. homogeneous, multidisciplinary)
6. Scope of programmatic concern (e.g. project team, program office)
10. Novelty of project (e.g. original problem/solution, existing project framework)
15. Knowledge use (e.g. much new knowledge required, application of previously learned material)
16. Other faculty involvement (e.g. single instructor, team of instructors)

Items 5, 10, and 15 from this framework may be of particular importance for nuclear applications.

Another paper by Bannerot, Kastor, and Ruchhoeft [16] articulates several recommendations to help handle issues arising from interdisciplinary projects.:

- using a web site to enhance information transfer

- using a “studio/critique” teaching environment to encourage open discussion of projects, provide a less threatening environment, and get teams involved in other teams’ projects;
- involving a group of professional communicators in the teaching and evaluating of the oral and written reports;
- allowing the students to become involved in establishing the expectations for the artifacts of their design process, and
- matching the skill set required for the project to that of the team.

The last item, regarding student skills sets, may be of particular importance to nuclear applications due to math skills sometimes not found in other curricula, or very specific nuclear science content that may not have analogous content from other disciplines to help students understand relevant analyses.

Overall, capstone design or senior project work requires careful to attention to functional requirements, design processes, and design solutions. This can be especially true for interdisciplinary capstone design. In order to facilitate completion of design project deliverable components, to foster clear communication, and to assist with introduction of new tools sometimes present in interdisciplinary contexts, Gallup, McCormick, Beyerlein, and Odom [17] suggest the use of axiomatic design, or systematic analysis to transform customer needs into functional engineering requirements.

Finding interdisciplinary project examples involving nuclear engineering

Methods

An internet search to discover examples of nuclear engineering content embedded in interdisciplinary capstone design project was conducted. The procedure to conduct the search was to look at each of the top 50 hits on results from the search terms “interdisciplinary senior design” for any language related to nuclear engineering. Each of the top 50 pages was searched for the terms “nuclear”, “mechanical” and “electrical”. The partial terms “radio” and “radia” were included as well and studied to determine if radiation, radiological, or similar terms related to nuclear engineering were represented. Then, the count for the number of times each term appeared was recorded. Any page containing nuclear engineering related material was then studied to determine the nature of the nuclear component of the interdisciplinary work.

Results

Results from the internet research activities show that nuclear engineering projects are exceedingly rare among interdisciplinary senior design projects. From the top 50 sources on interdisciplinary capstone design projects, 33 of those hits represented unique web pages describing different interdisciplinary capstone work. Of the 33 unique instances, only one specific instance of an interdisciplinary capstone design project involving nuclear engineering and one mention of nuclear as a specific engineering discipline that could be expected to appear in an interdisciplinary capstone design course were found outside the author's own institution.

Example 1: The University of Idaho encourages Senior Design Projects that span engineering disciplines; mainly, mechanical engineering, electrical engineering, and computer engineering [18]. These projects usually include students from two or three engineering disciplines. This provides students with opportunity to gain experience working in multidisciplinary teams as encountered in industry and national laboratories. Although it did not appear in the internet search, the authors are aware of one specific project where the U.S. Department of Energy's Argonne National Laboratory requested a team of University-of-Idaho students working on their Senior Design Project to design, fabricate, and test a station capable of disassembling high-efficiency particulate arrestance (HEPA) filters. The HEPA filters are radioactively contaminated; consequently, the HEPA station must be located in a hot cell to minimize radiation exposures to staff and students participating in the project. The potential of this project is the applicability of its methods to other U.S. Department-of-Energy National Laboratories.

Example 2: The 2015 University of Arizona Engineering Design Expo Summary Book includes a project titled "Utilization of Waste Heat from Power Generation to Purify Water" [19]. This project was a combination of Chemical and Environmental engineering majors, working on a topic including nuclear energy. In their project description, the student team indicates that "The goal of this project is to design systems to capture heat from a solar concentrator and excess heat from a nuclear reactor, and to use this waste heat to purify seawater. Nuclear reactors generate an immense amount of heat, most of which is wasted." They further state that "two common methods were used in the design to desalinate seawater: membrane distillation and vacuum distillation, both of which were interchanged with the two sources of heat to find the best combination of efficiency and cost." This type of project has several nuclear-specific considerations due to potential radiation from the heat source (steam or water) and heat exchanger equipment due to activation in the presence of radiation fields. Knowledge of how materials become radioactive, radiation detection processes and instrumentation, and specific radioactive isotopes are needed to add value to this project.

Finally, it is notable that the two fields with the greatest opportunity for overlap with nuclear engineering (mechanical and electrical engineering) are specifically mentioned at least once within the top 50 interdisciplinary capstone design resources 18 and 23 times, respectively.

Capstone Design Case Studies

<u>Methods</u>

The Mechanical Engineering department offers a minor in Nuclear Engineering. Two projects conducted by students in the minor involved interdisciplinary work in the nuclear engineering area to arrive at a design solution while satisfying the requirements for a capstone project in Mechanical or Electrical Engineering.

Two collaborating authors advising these projects, one from mechanical engineering and one from electrical engineering, were each asked to produce a case study summary of the the project they oversaw containing nuclear engineering content. They were asked to describe the following aspects of the projects:

- Project selection process
- Project description
- Reflection on overall project implementation
- Reflection on assessment of student learning outcomes
- Student perceptions based on the following survey questions:
    - What did you need to learn from a discipline other than your own in order to conduct your project?
    - How did you integrate this interdisciplinary knowledge with the knowledge of your discipline?
    - How did this interdisciplinary knowledge impact the success of your overall project solution?

<u>Case 1 – ME Crane Design</u>

Project Selection Process

Capstone projects in mechanical engineering come from either industry, faculty research, or students. All projects need approval by the instructor to ensure they meet the design criteria for Senior Design and satisfy the learning outcomes as outlined by ABET. After completing an internship at a local nuclear power plant, one student proposed solving a nuclear engineering problem for their Senior Design project. This was the only interdisciplinary project for that semester. It was approved as a senior design project because it met all the necessary criteria including adequate engineering analysis and the use of numerical simulations. It also required some basic knowledge of the operating systems within a nuclear facility, which was satisfied by one of the students on the design team pursuing a minor in nuclear engineering. The selection of an interdisciplinary project of this nature also challenged the team to familiarize themselves with standards, codes and design procedures that are followed in the nuclear industry, that are different from the ones that they are familiar with in typical mechanical system design.

The student team was interviewed at the start of the project by the instructor to determine if the team had adequate support from faculty in both the nuclear and mechanical engineering departments as far as advising and mentoring during the project. The company sponsoring the project was also contacted with regards to disclosure of information and documentation of the project. The final report and design presentation was used as the basis for analyzing this case study. The project had to show evidence of interdisciplinary work in terms of the scope and engineering analysis to be considered for inclusion in this study.

Project Description

Many pressurized water reactor nuclear power plants employ the use of a Polar Crane system primarily during refueling outages to help move, stage, and lift various equipment and tools. Replacing the crane would require extensive modification and would also impact the outage schedule in the event of Polar Crane component malfunction or failure. In addition, any repairs, replacements, or modifications must be done while the reactor is offline, and without the use of the polar crane. With this in mind, the capstone team decided to develop a rigging tool that would be installed on the Polar Crane to handle the weight of replacement components and to lift the components more than 100 feet. The tool would be capable of axial movements to navigate and place components where needed. A temporary tool rather than a permanent modification was determined to be the best solution since a modification to the plant would require extensive impact analysis.

Reflection – general

The capstone team was able to solve a practical problem at a nuclear power plant facility that had a direct impact on downtime due to repairs of a critical component in the operation of the plant. The students were faced with many challenges in terms of the information gathering and problem specifications due to the age of the installed Polar Crane. They also were required to step outside of their core discipline and apply their knowledge to solving a problem in a less familiar area. In the end, although it required more effort to understand the problem they were able to successfully complete the design and satisfy the customer's requirements.

The project was successfully completed in terms of meeting the design requirements that were by the client and the design team. The students who participated in this study were able to gain confidence in their ability to successfully solve problems that may come from areas that overlapped with their core mechanical engineering discipline, in this case from nuclear engineering. The primary issue the team faced was the restriction of certain sensitive and proprietary information that could not be provided by the customer as the project evolved. This meant that the team had to develop a design that satisfied a much broader range of engineering specifications and made it difficult to optimize the design of certain components. In future, it may be more useful to have a more detailed project scope from the customer that include the types of material and documentation that will be freely available to the team.

Reflection - assessment of impact on student learning outcomes

From an instructional perspective, students were able to successfully apply their knowledge of mathematics and science to solve a real world engineering problem by designing a system that was economical, safe and manufacturable with minimal impact to the current environment. The choice of a nuclear engineering project required students to utilize knowledge in mechanical engineering but also forced them to learn more in areas such as material selection as applied to nuclear facilities. They were also required to make use of codes and standards that they had not previously used in order to achieve adequate safety factors for their design. The project having industry involvement and requiring more stringent safety standards due it being in nuclear engineering also made students more aware of the ethical implications of their design practice.

A student survey was conducted to evaluate the impact on student learning, as related to the interdisciplinary aspect of the project. The questions are shown in Table 1.

Table 1: survey questions for students completing interdisciplinary project work.

1. What did you need to learn from a discipline other than your own in order to conduct your project?
2. How did you integrate this interdisciplinary knowledge with the knowledge of your discipline (in this case Mechanical Engineering) ?
3. How did this interdisciplinary knowledge impact the success of your overall project solution?

Survey responses obtained from one of the students on the team clearly indicated that inclusion of an interdisciplinary project had a positive impact on his learning experience for the course. In response to the first question he stated that in working on a mechanical project that would be installed in a nuclear power plant, several nuclear engineering principles had to be understood and incorporated throughout the design process. Material constraints were the most influential factor, as equipment being used in an irradiated area can only be made from specific materials so that they don't become activated when irradiated.

For the second question, he indicated that having to design mechanical equipment using nonstandard materials which may not be the most favorable in terms of material properties (such as strength) encouraged them to use innovative designs to make up for any shortcomings in material properties.

Finally, for the third question, he stated that requirement for a modular design actually forced them to design additional supports that would have otherwise been unnecessary in their original design, resulting in a more innovative solution. The results the design process was enhanced by the addition of an interdisciplinary project that incorporated knowledge outside of the team's core discipline.

Case 2 – EE Radiation Detection (Undergraduate Research)

Project Selection

The undergraduate senior design project in the Electrical Engineering (EE) department is conducted under the one semester long 4 credit hour requisite course EE4800. In this course, students form small groups (2-4 students per group) and propose a design project to the instructor in the beginning of the semester, or sometimes an EE faculty offer a project to a student group, usually a part of an existing research project which meets the specific criterion of the senior design class. The projects completed by EE undergraduates in the senior design have various application areas. However, due to the current curriculum structure there is no official means for EE students to collaborate with students from other engineering departments for their senior design projects. In summer 2016, an interdisciplinary research project was formulated by two faculty members - one of the them having an expertise in Electrical Engineering and the other in Nuclear Engineering. Three students involved in this project were junior and senior undergraduates majoring in Physics, Mechanical Engineering Technology (MET), and Electrical Engineering (EE) pursuing a minor in Nuclear Engineering. The project was conceived in June 2016 and continued through Summer and Fall 2016, while the majority of the work was carried out during the Fall semester. The project objectives and goals were set by the faculty and the specific design details were later defined by the student researchers as the project progressed. For successful completion of the project, multi-disciplinary theoretical knowledge and hands-on skills were essential components. Required key skills included computer aided design skills, background knowledge of ionizing radiation, and hands-on fabrication.

Project Description

Instruments for detecting and measuring radiation are used at federal facilities, nuclear power plants, hospitals, and universities utilizing radioactive materials for research. U.S. Department of Energy national laboratories and sites have to deal with facilities contaminated with byproduct radioactive materials generated during the production of nuclear weapons. Some of these facilities are contaminated with uranium and plutonium isotopes, which usually decay by the emission of alpha particles (helium nuclei). The faculty and undergraduate students have developed a low-cost, portable alpha particle detector with integrated microcontroller capable of precise radiation measurement for radiation monitoring applications. The device works on the Chang-Rosenblum principle - spark generation in a strong electric field under incident alpha radiation. The detector consists of 45 um diameter tungsten wires (anode) stretched over a highly polished stainless steel cathode held at ground potential. The electric field between the cathode and the anode was varied between 25 – 50 KV/cm during the experiments by changing the output voltage of the HV power supply from 4 – 8 kV. A novel electronic circuit was implemented for conditioning the high voltage pulses generated as a result of avalanche discharge within the filler gas during interaction of the alpha particles with the gas molecules. The conditioned pulses were fed to a digital input pin on an open-source electronics platform, Arduino, for analysis and pulse counting (counts per minute). Calibration was performed using a Ludlum Model 44-9 pancake Geiger-Mueller tube and a Model 2200 Scaler Ratemeter to achieve accurate quantitative measurements of an unknown radioactive source strength. Experiments were performed using ^{241}Am, as the alpha source to evaluate the performance and efficiency of the detector.

Reflection – general

The interdisciplinary research team was able to successfully design and build a device for alpha radiation detection from scratch without any prior experience or specific knowledge of building such devices. The team faced multi-faceted challenges to conduct the research. The major challenge was to gain information and quickly develop the background knowledge beyond their core disciplines to conduct this research. Students were able to achieve the project goals within the given timeframe. The interdisciplinary team members have successfully blended and applied their core discipline knowledge resulting in an improved device design beyond what was initially conceived. The project faculty mentors have observed notable improvements of various soft skills apart from the specific engineering skills for all students. Students also felt well prepared for industry work in a multidisciplinary environment and to be able to deliver the best solution. In future projects, attempts to further extend the scope of research will be considered in order to accommodate other disciplines beyond engineering, such as biology and biotechnology related to nuclear medicine. This future work will support further investigation of the positive aspects, and any limitations, of broad multidisciplinary teams.

Reflection - assessment of impact on student learning

In order to understand and evaluate the impact on student learning, specifically aspects of the interdisciplinary nature of the project, a survey was conducted where students were asked the following three questions summarized in Table 2.

Table 2: survey questions for students completing interdisciplinary project work.

1. Through this interdisciplinary project, what did you need to learn from a discipline other than your own in order to conduct the project?
2. How did you integrate this interdisciplinary knowledge with the knowledge of your discipline?

3. How did this interdisciplinary knowledge impact the success of your overall project solution?

It is evident from the survey responses that the project had significant impacts on student learning due to its interdisciplinary nature. The learning outcomes also varied among the students as they are native to different majors with different academic backgrounds. In response to the first question, the Physics student mentioned that he needed to learn applying circuit design and computer aided design (CAD) using SolidWorks to construct the radiation detection instrument. He emphasized that in the Physics department, students learn theories of many electrical principles, such as Ohm's law. However, this project allowed him to learn beyond the scope of what Physics curriculum offers. The MET student emphasized that the project has substantially contributed toward his overall engineering knowledge. He learned about the electronics required for radiation detection setup, such as high voltage power supply unit, pulse shaping circuit, and pulse counting circuit which is beyond the scope of Mechanical Engineering Technology. The EE student noted that he learned the fundamental physics of radiation detection principles, and the electronics manufacturing process during the fabrication of the device.

In response to question 2, the Physics student emphasized that his improved knowledge in Electrical and Mechanical systems provided meaningful insight about the physical theories and mathematical reasoning which enabled him to understand its real world applications. The MET student was able to integrate the new Electrical Engineering knowledge with his mechanical design and manufacturing knowledge. Integration and blending of this multidisciplinary knowledge helped him to assemble various parts of the radiation detector and ensure its functionality. The EE major student noted the integration of knowledge helped to fix errors and optimize the instrument design.

Question 3 was the most critical to assess the contribution of the interdisciplinary knowledge toward the project success. The Physics student noted that the combination of skills helped the team to move forward with the project leading to the successful completion of the project while meeting the research objectives and goals within the given timeframe. The MET major believed that the project would simply be impossible to conduct without a multidisciplinary team bringing in knowledge from different subject areas. The EE major emphasized that not only the interdisciplinary knowledge gained throughout this project helped them come to a common optimum solution, but it will also help them to perform better design in future projects.
Clearly the survey responses indicate that students have benefited in multiple ways from this interdisciplinary design project.

Determining nuclear content areas with the greatest potential for interdisciplinary overlap

<u>Methods</u>

A consensus building process was used to determine content areas from nuclear engineering with the greatest potential for successful incorporation into interdisciplinary capstone design projects. The process used was similar to the qualitative analysis process where multiple researchers independently code qualitative data and then discuss their results to create consensus around the interpretation of the data. First, the authors with backgrounds in nuclear engineering individually brainstormed independent lists of content areas with good overlap capability. These lists were then combined, discussed, and pruned to create a single comprehensive list which was made available to the co-authors from electrical and mechanical engineering for their consideration. The ensuing discussion was used to edit the list into a simplified, condensed form presented here.

Results

A list of twelve nuclear engineering content area topics which can most easily be incorporated into capstone design projects with other fields of engineering follows. For each topic an extended description of engineering development needs in that area is included. Additionally, connections from these nuclear engineering content areas to other engineering disciplines are then presented in Table 3. The table includes the twelve proposed areas, areas of disciplinary overlap with other fields of engineering, and notes about the content commonly used in these disciplines that would support capstone or other engineering project design work for these nuclear topics.

1. *Shielding* - shielding calculations are used for protecting radiation workers at nuclear waste facilities. When radiation workers perform maintenance near nuclear waste storage tanks, it is necessary to reduce the exposure rates as low as reasonable.
2. *Nuclear fuels development* - modeling thermal conductivity of new nuclear fuel at various temperatures is an area where significant, novel research is needed. New nuclear reactor types include Small Modular Reactors, which can provide electric power less than 300 MWe. Various fuels are being considered for SMRs, but little data is available on these new types of fuels.
3. *Nuclear reactor cooling tower design* - designs for cooling towers for nuclear reactors compatible with local features in different types of locations is of interest in the nuclear industry. In general, nuclear reactors use relatively large cooling towers that could potentially have a negative impact on the nuclear companies operating these reactors due to the visibility of the cooling tower. A potential project could involve the design of smaller cooling towers that could be hidden by trees.
4. *Radiation Detector design* - developing radiation detectors for decontamination efforts in specialized applications is needed. Currently, there are a number of sites operated by the US Department of Energy that have a mission to decontaminate their facilities from radioactive contamination due to the nuclear weapons production. The main detectors include real-time devices for alpha, beta, neutron, and gamma radiation.

5. *Environmental dosimetry* - completing environmental dosimetry calculations to determine doses to population groups living near nuclear power plants or federal nuclear facilities is an ongoing need.

6. *Radiation dose models* - validation is needed for various mathematical models used to assess internal and external radiation dose to radiation workers. Computer models have been developed to determine doses to radiation workers from exposure to radioactive materials. Some of these models used different approaches and must be compared and verified with standards mathematical models.

7. *Radiation dose conversion factors* - using dose conversion factors can allow for fast determination of doses for exposed radiation workers. Once the amount of radioactive intake has been determined, finding the radiation dose is accomplished by multiplying the dose conversion factor times the amount of radioactive intake.

8. *Nuclear thermal hydraulics* - performing thermal hydraulics calculations involving heat transfer and fluid flow in new reactor design configurations might include modeling for new “Small Modular Reactor” designs currently being funded by the Department of Energy and several companies involved in nuclear reactor design

9. *Nuclear power secondary systems design* - innovation and optimization is needed for secondary thermodynamic cycle system design for high-temperature reactors. This would include gas, molten salt, and liquid metal cooled reactor designs.

10. *Radiation resistant structural materials* - nuclear materials development for reactor cores is needed. This would include cladding material holding the fuel, and instrumentation units for a variety of purposes to monitor conditions in a reactor core.

11. *Passive nuclear power safety systems* - models are needed for innovative “walkaway safe” shutdown cooling systems. Current designs for many reactors require some type of power after a few days to ensure proper continuous cooling of the reactor core. New designs could perform such cooling indefinitely without external power.

12. *Nuclear systems heat exchanger design* - opportunity exists to develop novel heat exchanger configurations for new reactors under development. Some reactors designs have specific constraints on the shape and size of heat exchangers placed with the containment area of the nuclear plant. These constraints may require new ideas for heat exchanger materials and flow configurations and must operate in an environment subject to ongoing radiation exposure.

Table 3 - Interdisciplinary nuclear engineering project topic connections to other disciplines

Nuclear Topic Area	**Disciplinary overlap**	**Supporting traditional engineering content areas**
Shielding	Mechanical, Civil, Materials	Structural engineering design
Nuclear fuels development	Mechanical, Materials	Models of thermal conductivity for varying chemical composition and crystalline structure

Nuclear reactor cooling tower design	Mechanical, Civil, Architectural	Concrete structures, urban or rural architectural engineering design
Radiation detector design	Electrical, Mechatronics	Circuit design, semiconductors, signal processing, sensors, remote control and wireless systems
Environmental dosimetry	Environmental	Dispersion modeling, environmental impact studies, compliance with state and federal regulations
Radiation dose models	Engineering physics, Applied Math	Benchmarking, data modeling, validation testing, compliance with state and federal regulations
Radiation dose conversion factors	Engineering physics, Applied Math	Benchmarking, data modeling, validation testing, compliance with state and federal regulations
Nuclear thermal hydraulics	Mechanical	Single and multiphase heat transfer and fluid flow in 2-D and 3-D
Nuclear power secondary system design	Mechanical	Steam and gas thermodynamic cycle design and optimization
Radiation resistant structural materials	Mechanical, Materials	Materials characterization, corrosion resistance, mechanical loading response, thermal response analysis
Passive nuclear power safety systems	Mechanical, Electrical	Natural convection cooling systems, time-dependent heat transfer with heat generation, passive sensing, remote communication
Nuclear systems heat exchanger design	Mechanical, Materials	Printed circuit heat exchanges or other compact HX designs, materials selection and fabrication

Conclusions

Summary

This work summarizes a number of considerations for how nuclear engineering content can be incorporated in interdisciplinary senior design projects. Outside of this paper there is nearly zero information available about how this can best be accomplished in the literature. In addition, as a result of this work two case studies of interdisciplinary design projects involving nuclear engineering have been described, and 12 areas of nuclear engineering content which is amenable to interdisciplinary engineering work have been articulated.

Lessons Learned

From the student responses and faculty experiences, several important conclusions can be drawn: (i) interdisciplinary projects with Nuclear Engineering applications can be successfully conducted and managed by forming a multi-disciplinary student team mentored by faculty with respective disciplines, (ii) Such projects are feasible within the timeframe allowed for senior design, (iii) Such projects yield critical student learning outcomes that would otherwise be unachievable, (iii) students realize the importance of multi-disciplinary approach to achieve optimum engineering solution to a practical problem in real-world situation, (iv) a faculty level collaboration and joint group mentoring is also necessary for successful completion of these projects. Electrical and Mechanical Engineering could be the two most potential disciplines to develop interdisciplinary Nuclear focused projects suitable for undergraduate senior design courses.

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