Using Artificial Intelligence Case Studies in a Thermodynamics Course

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Introduction

With the explosion of ChatGPT in the past year, it seems that Artificial Intelligence (AI) is everywhere, but engineering students may not realize its application beyond writing papers. The aim of this study was to build an AI teaching module that could be implemented into existing Mechanical Engineering Curriculum. Rather than teach students how to build neural networks or large language models, the module focused on how AI is utilized in Nuclear Power Plants. The module was then implemented into a Thermodynamics II course, directly following a unit on vapor power plants. The full course outline can be found in Appendix A, Table A1. Seven case studies from AI and Nuclear Energy Journals were selected and reviewed for use in the module. A Case Study Implementation Guide was developed by the instructor to assist the students with their navigation of difficult topics, but it was also intended for use by other instructors choosing to implement it into a Thermal/Fluids course. Students were also surveyed independently from the graded assignments. Using the survey feedback, the module can be revised and used as a model for integrating AI into other Mechanical Engineering courses across the curriculum.

Design of Case Studies

This work was part of a grant, "Advanced Computing through Experiential Education," from the Department of Education that established an AI Center at Norwich University. The AI Center mission is to conduct multiple forms and levels of research, deliver educational programming and create workforce development projects to meet the growing national and regional requirements for an advanced computing capable workforce. One of the outcomes for educational programming was to "Develop modules for one of your courses that demonstrates how AI/ML can be meaningfully applied to your discipline (e.g. approximately a week's worth of material for a semester course.)" With this outcome in mind, the Mechanical Engineering curriculum was examined for a course where applications in AI could be implemented. After surveying the literature and finding the expansive use of AI in Nuclear Power Plants as outlined by Lu et al [1], the best fit seemed to be in Thermodynamics II, where applications of thermodynamics is the primary focus. The course objectives as listed on the course syllabus are "To apply the basic ideas, concepts, and laws of thermodynamics. To learn how to apply the laws of thermodynamics to power and refrigeration cycles, combustion mechanisms, and mixture and flow processes. Development of thermodynamic relationships and equations of state." The course goals are:

1. To be able to use thermodynamics in engineering practice.
2. To understand vapor power plants.
3. To understand gas power systems.
4. To be able to model thermodynamically common types of refrigeration and heat pump systems.
5. To understand the behavior of ideal gas mixtures and psychrometrics.
6. To be able to analyze the chemical reaction of combustion of hydrocarbon fuels.
7. To provide a solid basis for subsequent courses in fluid mechanics and heat transfer.

With a week's time to implement the module, a group project with case studies was chosen as the mode for students to learn about AI in NPP. As a group they could divide the learning in order to delve into a new and complex topic.

Case Study Guide

Seven case studies were created for students to analyze, present back to the class, and to base written reports upon about their learning process. The topic areas of the case studies were the following application scenarios: Nuclear Fuel Management [2], Nuclear Data Processing [3], Autonomous Control for Fixed Procedures [4], Fault Detection and Diagnosis [5], Human-Machine Interaction [6], Emergency Alarming [7], and Decision-Making Assistance [8]. The students also researched nuclear power plant technology mentioned in the studies. A case study implementation guide for instructors was created to accompany the case studies. Table 1 lists a sample schedule and notes for the instructor on Case Study #1.

Table 1. Sample schedule for implementing the case study.

Time	Class I	Class II	Class III	Class IV
11:00	AI and NPP Pre-Test	Groups work on Worksheets, research, and presentations	-Assign Case Study Report, Teamwork Assessment as Homework	Presentations
11:10	Introduce NPP & AI Assignment		Presentations	
11:20	Provide background on NPP & AI (class notes)			Concept Mapping, Post-Test
11:35	Groups work on "Case Study Analysis" and "Independent Research" worksheets			

Case Study #1 – Nuclear Fuel Management [2]

The Problem

What is the best way to refuel a nuclear reactor?

Criteria for a successful solution

The nuclear reactor does not need to shut down to be refueled and power surges are avoided during on-power refueling.

Background and motivation of the case study

There are two options for refueling a nuclear reactor. The first option is to shut down the plant

and refuel. The disadvantage to this method is that backup power is needed, but this only occurs at 12, 18, or 24-month intervals. The second method is on-power refueling, which means keeping the reactor running while new fuel is added. This method needs to be carefully controlled due to the potential for power surges when adding a new fuel rod to a fuel assembly.

Nuclear reactor technology used in the case study
Advanced Heavy Water Reactor (AHWR), specifically Bhabha Atomic Research Center, India

AI used in the case study
Artificial Neural Network (ANN)

How AI was used in the case study
K-infinity values for 111 fuel rods were used as inputs to the ANN. The output was core excess reactivity and Maximum Channel Power (MCP). One quadrant of the reactor was used, and it was assumed that there was symmetry with the other 3 quadrants. If fresh fuel is put into location 1, there are then 110 locations for reshuffling and 110 simulations for refueling location 1. Because the fresh fuel can come in any of the 111 locations, the total number of simulations is then 111 x 110 (12,210). This input data set was then divided into two parts. One part was used to train the network, while the other set was not shown to the network and was used to validate the network's data. Several different networks were used as part of the study to reduce error and find the optimized network to use.

Final Outcome
The new refueling strategy resulted in improvement of cumulative discharge burn-up. By using the ANN, optimized fueling configurations were realized with short computational times of 2-3 minutes.

Further Application
This study allows for application of the ANN at other nuclear power plants where an AHWR is used. The ANN would take the inputs of that plant and help them with the best reshuffling scheme for refueling of the nuclear reactor.

Case Study Assignment

To complete the Case Study Review, students were placed into groups of 3-4, each assigned a different case study. To help the students engage with new topics, they were given two worksheets to complete with their group: Case Study Worksheet (Appendix, Table A2) and Independent Research Worksheet (Appendix, Table A3). The Case Study Worksheet asked them to complete tasks such as "Define the problem" and "Determine the criteria for a successful solution," and to answer, "What AI was used in this case study?". The Independent Research Worksheet helped the group identify what they needed to learn about the problem in the case study and develop a plan for acquiring that knowledge. The students were assessed in the following ways: pre- and post-test on content knowledge, group presentation, case study report, concept map, and teamwork assessment. The group presentation was a way to test their

knowledge without having them use AI to write a paper. The purpose of the case study report was to provide the student a way to summarize the process they used to learn about the case. By writing about the experience, they could reflect on their use of problem-solving and critical thinking skills. In the case study report, the students also reflected on how much their perception of AI changed from the beginning of the module to the end of it.

The assignment was introduced immediately following a unit on vapor power plants. The assignment, as given to students, is included below:

Each group will be given a real-world case study that involves nuclear energy and artificial intelligence. With your group, you will review the case study using a "Case Study Analysis" and "Independent Research" Worksheet. Your group will make a presentation on the case study to the class. The presentation should include the following:

1. Description of the problem the case study is trying to address
2. Background and motivation of the case study
3. Description of nuclear reactor technology, power plant, or other nuclear energy related topic assigned with your case study.
4. Description of the AI used in the case study
5. Description of how AI was applied in the case study
6. The final outcome of the case study

Throughout the presentation, be sure to define or describe any new terms your group came across that might need additional explanation.

Case Study Checklist

- Content Knowledge Pre-Test (not graded)
- Case Study Analysis Worksheet (Group)
- Independent Research Worksheet (Group)
- Presentation on Case Study (Group)
- Concept Map (Group)
- Case Study Report (Individual)
- Teamwork Assessment (Individual)
- Content Knowledge Post-test (Individual)

Student Feedback

After the case study unit was complete, the students were asked to complete a survey, included below, reflecting on their engagement with the case study.

Student Survey

	Difficulty Level			
	Not at all Difficult	**Somewhat Difficult**	**Mostly Difficult**	**Very Difficult**
1.Understanding the artificial intelligence content				
2. Understanding the nuclear power plant content				
3. Locating additional information about the artificial intelligence content				
4. Locating additional information about the nuclear power plant content				
5. Creating the presentation				
6. Writing the case study report				
7. Being part of a team				

For the following question, circle the response that most accurately reflects your experience. Please **circle only ONE number**.

	Strongly Agree	Agree	Disagree	Strongly Disagree
I learned more from the Case Study than I usually do from the work problems in my science, technology, engineering and/or math (STEM) classes.	4	3	2	1

Please specify which **ONE** of the following statements best corresponds to your experience.

1. How easy was it for you to follow the Case Study?
   ____ Not at all easy to follow

   ____Somewhat easy to follow

   ____Extremely easy to follow

2. What did you like most about completing the Case Study? Why?
3. What did you like least about completing the Case Study? Why?
4. Describe any concepts that were difficult for you or your group to understand. How did you overcome that barrier individually or as a team?
5. How can we improve the Case Study?
6. What other topics would you like to explore in a Case Study format?
7. Did this project change your perception of what artificial intelligence is? YES NO
   If yes, how? If no, why?

8. What did the case study inspire you to learn more about?

Table 2 shows the numerical results for the questions on Difficulty Level.

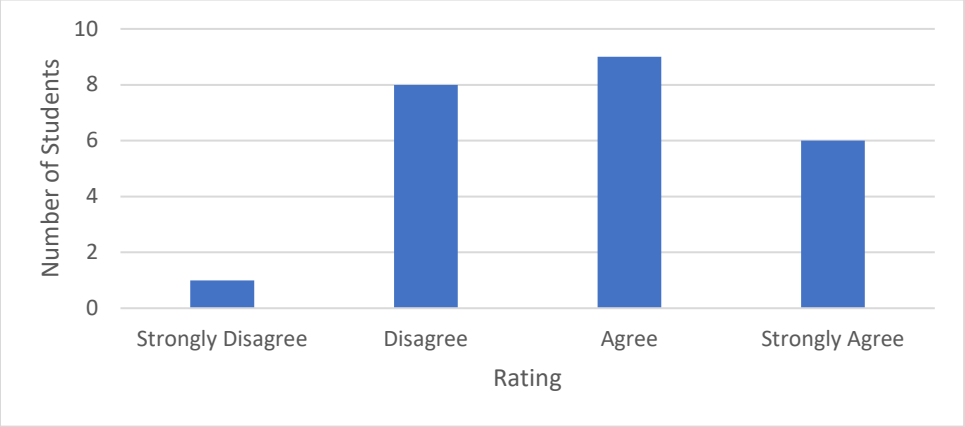
Table 2. Numerical Averages of Perceived Difficulty Level.

Question	Average
1	2.1
2	1.8
3	1.7
4	1.5
5	1.3
6	1.4
7	1.1

Not at all difficult = 1, Somewhat difficult = 2, Mostly difficult = 3, Very difficult = 4.

These results indicate that the students overall found the case study assignment to be not at all difficult, with being part of a team being the least difficult for them. The AI content was found to be somewhat difficult, as will be further illustrated through students' comments in the section on "What they didn't like about the case study?".

The numerical average for the question "I learned more from the Case Study than I usually do from the work problems in my science, technology, engineering and/or math (STEM) classes" was 2.8 with the distribution seen in Figure 1.

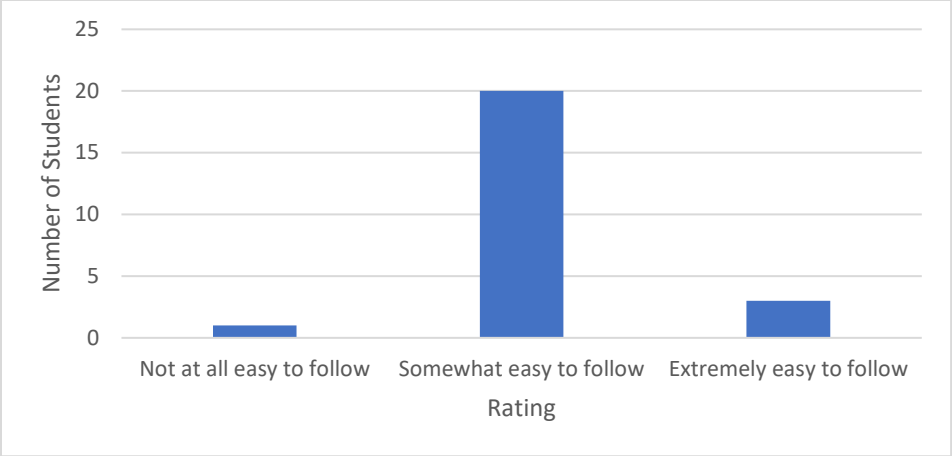


Strongly Disagree = 1, Disagree = 2, Agree = 3, Strongly Agree = 4

Figure 1. Student Responses for Learning more from Case Study.

These results would indicate that using a case study method worked for more than half of the students, while 9 would have preferred to learn the traditional way with lectures and solving problems.

Figure 2 illustrates students' responses to "How easy was it for you to follow the Case Study?". While their comments on the survey indicated a sense of frustration with learning the AI content, 20 students did find the layout of the case study to be somewhat easy to follow.



Not at all easy = 1, Somewhat easy = 2, Extremely easy = 3.

Figure 2. Student Responses for Ease of Following Case Study

Because one of the main goals of the case study was to expose students to AI in an application that they were already studying, they were asked, "Did this project change your perception of what AI is? If yes, how? If no, why?" Out of the 22 respondents, 15 answered "Yes", while 7 said "No". A few comments from the "Yes" group are as follows:

- "I did not understand how much of a role AI had on technology and innovation, other than ChatGPT."
- "Used to think it was just an algorithm used for social media didn't know algorithms can be used to solve and run real world problems."
- "It made me think of AI as more of a tool that can make things run more efficiently."

From the "No" respondents:

- "It did not change the perception, but rather helped to expand my knowledge."
- "I already know a lot about AI in general, so no perceptions were changed."

Even if students' perceptions were not changed, students were inspired to learn more about AI and nuclear power plants. When asked, "What did the case study inspire you to learn more about?", 12 respondents said they wanted to learn more about AI, and 15 stated more about NPP. Here are some of their comments:

- "If nuclear power plants can be fully managed by AI to avoid human errors."
- "AI in general what its capable of."
- "Using nuclear as a complete replacement for fossil fuels. Making nuclear energy 'infinitely' safe using AI safeguards."

Since this was a pilot group for the case study, the students were asked what they liked the most, the least, and what could be improved with the case study. Here are some comments about what they liked the most:

- "Working together as a team to gather the information, learning about the nuclear power was really interesting, nuclear power and AI has come a long way, and it was also interesting reading/researching the history about it."
- "I liked learning about how modernized AI is being incorporated into NPP and real-world applications. This is because it is interesting to see how technology is evolving."
- "The part I liked most was gaining an understanding of how and why AI is beneficial."
- "I enjoyed the topic and learning more about upcoming technology. I enjoyed the topic because I thought it was practical to mechanical engineering students approaching graduation. Helped me understand more fields of engineering I can explore."

Overall, the students liked learning about Nuclear Power Plants and the ways AI was applied to help them run better.

When asked about what they liked least, the students listed a wide variety of things that they didn't like. Here are some of their comments about what they liked least:

- "Some of the vocabulary and topics were confusing at first. After the presentations completed I felt more comfortable and wanted to do more research."
- "I felt rushed through my understanding."
- "I enjoyed learning about the AI however it was hard to learn the complexity of AI as well as learning how a nuclear plant works."
- "I didn't like how we kind of jumped into the case study with little or no knowledge of this topic, since I didn't know some of the topics, and I would have to adjust to it by taking the time to learn it."

As for improvements, students suggested that more background knowledge be provided on AI and NPP before having them review the case studies. Here are some of their comments about improvements:

- "Give more of an introduction or lecture into what types of power plants there are and how AI works, then let us work in teams on specifics and in-depth power plants and their use of AI."
- "To give a more in-depth presentation about AI beforehand so we have more background to go off of."
- "Have reference notes to what each type of AI does readily available."

Recommendations for Future Case Studies

Based on implementing these case studies into a Thermodynamics II course and the students' feedback, there are some recommendations for future use of the case studies. It is recommended that the schedule should be modified to add an additional day for providing background on AI and NPP. This background information could also come from a well-produced video on each topic area that the students could reference as they work through the case studies. Instructors could also create a "Case Study Guide" for students, where they would receive a tutorial on their specific case study. While the Content Knowledge Pre- and Post- Tests were helpful to see what they didn't know and what they learned, they were not really helpful in the overall learning

outcomes and induced more stress for the students. It is recommended to use a Pre- and Post-Test for assessment, but not in their grade. Additionally, the Concept Mapping process was not particularly useful in this case study assessment and felt like busy work to the instructor and students.

From the original Case Study Checklist, the Worksheets, the Presentation, the Case Study Report, and the Teamwork Assessment should be kept. The Worksheets were useful guides that the team could use to work together to engage with the difficult content. The Case Study Report was useful for the instructor to see what each student had contributed individually. The Presentations turned out well and gave the students a chance to speak in a technical fashion about a complex concept.

Conclusions

This module was a unique twist in a Thermodynamics course that with modifications could be used again in the same course. The model of using Case Studies to introduce students to AI could work well in other courses in Mechanical Engineering, Engineering, or other disciplines. Students in Higher Education should be informed of the many applications AI has, so that they can make decisions about how to engage with it, and further improve upon it. It was inspiring to see how many students were more interested in both AI and NPP because of the Case Study Assignment.

References

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Appendix

Table A1. Course Outline

Lecture #	Topic	Activity
1	Introduction to Syllabus, Review of Thermo I	
2	Vapor Power Systems (Ch. 8)	
3	Vapor Power Systems (Ch. 8)	
4	Vapor Power Systems (Ch. 8)	
5	Vapor Power Systems (Ch. 8)	HW #1 due
6	Vapor Power Systems (Ch. 8)	
7	Nuclear Power Plants and Artificial Intelligence	
8	Nuclear Power Plants and Artificial Intelligence	HW #2 due
9	Nuclear Power Plants and Artificial Intelligence	Presentations
10	Nuclear Power Plants and Artificial Intelligence	Presentations
11	Nuclear Power Plants and Artificial Intelligence	Presentations, Case Study Report, Teamwork Assessment due
12	Refrigeration (Ch. 10)	
13	Refrigeration (Ch. 10)	
14	Refrigeration (Ch. 10)	
15	Review for Exam #1	HW #3 due
16	Exam #1	
17	Gas Power Systems (Ch. 9)	
18	Gas Power Systems (Ch. 9)	
19	Gas Power Systems (Ch. 9)	
20	Gas Power Systems (Ch. 9)	HW #4 due
21	Gas Power Systems (Ch. 9)	
22	Gas Power Systems (Ch. 9)	
23	Gas Power Systems (Ch. 9)	HW #5 due
24	Gas Power Systems (Ch. 9)	
25	Gas Power Systems (Ch. 9)	
26	Gas Power Systems (Ch. 9)	HW #6 due
27	Review for Exam #2	
28	Exam #2	
29	Ideal Gas Mixture (Ch 12.1-12.5)	
30	Ideal Gas Mixture (Ch 12.1-12.5)	
31	Ideal Gas, Psychrometrics (Ch. 12.6-12.10)	
32	Psychrometrics (Ch. 12.6-12.10)	HW #7 due
33	Psychrometrics (Ch. 12.6-12.10)	
34	Chemical Reactions (Ch. 13)	
35	Chemical Reactions (Ch. 13)	HW #8 due
36	Chemical Reactions (Ch. 13)	
37	Chemical Reactions (Ch. 13)	
38	Chemical Reactions (Ch. 13)	HW #9 due
39	Review for Exam #3	
40	Exam #3	
41	Final Review	
42	Final Review	

Step I. Case Study Analysis

When learning a new and complex topic, it can be beneficial to ask questions along the way to guide your learning. The table below will help you by first giving space to define the problem as presented in the case study. Then think about what the criteria would be for a successful solution. Next, review the background and the motivation for the case study. Since all of the case studies involve nuclear power plants and artificial intelligence, review the case studies to see what was used in each of these areas. Lastly, determine the final outcome for this case study. Once you have the basics of the problem, it is time to take a deeper dive with the Independent Research Worksheet.

Table A2. Case Study Analysis Worksheet.

Define the problem:				
What was the criteria for a successful solution?	**What was the background of this case study? What was the motivation for this work?**	**What nuclear reactor technology was used in this study?**	**What artificial intelligence was used in this case study?**	**What was the final outcome for this case study?**

Step II. Independent Research

- Independent Research involves identifying what you need to learn about the problem and then developing a plan to acquire that knowledge.
- Given what you know about the problem from the Case Study Analysis phase, make a list of what you need to learn. Be very specific!
- Then divide up the learning with your team members, set deadlines, and develop an action plan for how you and your team will acquire the knowledge and skills needed to understand the problem.

Table A3. Independent Research Worksheet

What do we need to learn? Be specific.	Divide up the learning: Who will do what?	How much time do we have to complete the research?	What is our action plan for acquiring the knowledge we need?