Using ChatGPT for Concept Mastery in Thermodynamics

## Downloads

* [Download as Word Document (DOCX)](/downloads/teaching/thermodynamics-chatgpt.docx)

# Case Study: Using ChatGPT for Concept Mastery in Thermodynamics

## Course Context

**Course:** Engineering Thermodynamics II (ME 2304)  
**Level:** Sophomore  
**Enrollment:** 110 students  
**Prior Format:** Lecture-based with weekly problem sets and exams  
**Tools:** Equation solvers, property tables, simulation software  
**Faculty:** Dr. B, Associate Professor of Mechanical Engineering

## Implementation Challenge

Dr. B identified several challenges in teaching thermodynamics that AI assistance could potentially address:

1. **Conceptual Difficulty:** Students struggle with abstract thermodynamic concepts
2. **Problem-Solving Approach:** Difficulty in developing systematic problem-solving strategies
3. **Mathematical Barriers:** Varying levels of mathematical preparation impeding understanding
4. **Misconception Persistence:** Common thermodynamic misconceptions resistant to traditional teaching
5. **Individualized Support:** Limited office hours for a large enrollment course

## Implementation Goals

The integration of ChatGPT aimed to:

1. Provide on-demand conceptual explanations tailored to individual understanding levels
2. Help develop systematic problem-solving approaches for thermodynamic cycles
3. Bridge mathematical gaps without detracting from thermodynamic principles
4. Address common misconceptions with multiple explanation strategies
5. Extend instructional support beyond classroom and office hours

## Implementation Process

### Phase 1: Faculty Preparation (Winter break)

1. **Tool Exploration:**
   * Tested ChatGPT’s understanding of thermodynamic principles
   * Identified strengths in explanation and weaknesses in calculation
   * Developed prompts for common thermodynamic concepts
   * Created problem-solving templates for different thermodynamic systems
   * Documented common misconceptions and effective correction strategies
2. **Content Integration Planning:**
   * Identified key concepts for AI-enhanced explanation
   * Developed scaffolded problem-solving templates
   * Created conceptual checkpoints for self-assessment
   * Designed workflow integrating AI support with course materials
   * Established verification protocols for technical accuracy
3. **Assessment Adaptation:**
   * Redesigned homework to include AI-assisted and independent components
   * Created reflection prompts about conceptual understanding
   * Developed guidelines for appropriate AI use in coursework
   * Designed new assessment approaches focusing on conceptual understanding
   * Created rubrics valuing process explanation over final answers

### Phase 2: Initial Implementation (First three weeks)

1. **Student Introduction:**
   * Conducted 75-minute workshop on effective ChatGPT use for thermodynamics
   * Demonstrated example prompts for different learning scenarios
   * Established guidelines for appropriate AI assistance
   * Practiced critical evaluation of AI-generated explanations
   * Emphasized verification of calculations and principles
2. **Guided Integration:**
   * Assigned specific ChatGPT practice exercises with reflection
   * Provided feedback on students’ prompt strategies
   * Facilitated small-group comparison of different explanation approaches
   * Discussed how to recognize and address AI misconceptions
   * Gathered early feedback on perceived helpfulness
3. **Progressive Framework:**
   * Started with highly structured prompts and templates
   * Gradually reduced scaffolding as student proficiency increased
   * Developed class-sourced best practices for different concept areas
   * Created repository of effective prompts for different learning needs
   * Established peer support system for AI-enhanced studying

### Phase 3: Full Implementation (Throughout semester)

1. **Concept Mastery Support:**
   * Students used ChatGPT to explore alternative explanations for difficult concepts
   * Created concept maps with AI assistance to connect thermodynamic principles
   * Developed analogies and visualizations to reinforce understanding
   * Used AI to generate conceptual questions testing deeper understanding
   * Documented personal conceptual breakthroughs facilitated by AI explanations
2. **Problem-Solving Integration:**
   * AI served as problem-solving coach rather than solution provider
   * Students documented their problem-solving process with AI guidance
   * Used ChatGPT to analyze incorrect approaches and identify conceptual gaps
   * Practiced breaking complex problems into conceptual components
   * Compared AI approaches with textbook methods to develop critical thinking
3. **Metacognitive Development:**
   * Students maintained learning journals documenting their conceptual evolution
   * Reflected on how different explanation strategies affected their understanding
   * Identified personal learning preferences through varied AI approaches
   * Developed self-assessment skills by checking understanding with new scenarios
   * Created personalized study guides with targeted explanations

## Implementation Examples

### Example 1: Conceptual Explanation Chains

**Traditional Challenge:** Students often memorized equations without understanding the underlying principles, leading to difficulties when facing novel problems.

**ChatGPT-Enhanced Approach:** Students used a series of progressively deeper prompts to build conceptual understanding of entropy.

**Prompt Sequence Example:**

Initial Prompt:  
"Explain the concept of entropy in thermodynamics at a sophomore engineering level."  
  
Follow-up Prompt:  
"I'm struggling to understand how entropy relates to available energy. Can you explain   
the connection between entropy, availability, and irreversibility using a simple example   
of a heat engine?"  
  
Deepening Prompt:  
"I think I understand the basics now. Can you help me understand how to determine if a   
process will occur spontaneously by analyzing entropy generation? Please use the example   
of heat transfer between two bodies at different temperatures."  
  
Application Prompt:  
"Now I'd like to apply this understanding to a refrigeration cycle. How does entropy   
help us analyze the performance and limitations of a vapor-compression refrigeration system?"

**Learning Enhancement:** Students created personal “explanation chains” for difficult concepts, documenting how their understanding evolved through multiple explanation approaches.

### Example 2: Problem-Solving Coach

**Traditional Challenge:** Students often jumped directly to equations without systematic problem analysis, leading to errors and confusion with complex thermodynamic cycles.

**ChatGPT-Enhanced Coaching:** Instead of seeking solutions, students used ChatGPT as a Socratic coach to develop systematic problem-solving approaches.

**Problem-Solving Template:**

I'm working on solving a problem about a Rankine cycle with reheat. Rather than solving   
it for me, I'd like you to act as a coach who helps guide my problem-solving process.  
  
Here's the problem: [student inserts problem statement]  
  
Please help me by:  
1. Asking me questions about how I should approach this systematically  
2. Guiding me to identify the key states in the cycle I need to analyze  
3. Helping me recall relevant principles and equations without simply stating them  
4. Pointing out potential conceptual misunderstandings in my approach  
5. Suggesting how to verify my results for reasonableness  
  
I'll share my thinking at each step, and you can provide guidance to keep me on track.

**Implementation in Assignments:** Weekly problem sets included a “process portfolio” component where students documented their problem-solving approach, including: - Initial problem analysis - AI coaching interactions - Key decision points and conceptual realizations - Verification of results - Reflection on approach effectiveness

### Example 3: Misconception Confrontation

**Traditional Challenge:** Common thermodynamic misconceptions often persisted despite traditional instruction.

**ChatGPT-Enhanced Approach:** Students actively engaged with misconceptions through structured exploration.

**Misconception Analysis Assignment:** > For this assignment, you will explore common misconceptions in thermodynamics using ChatGPT as a learning tool: > > 1. Select two misconceptions from the provided list that you find personally challenging > 2. For each misconception: > - Generate an explanation of why the misconception seems intuitively correct > - Ask ChatGPT to provide multiple perspectives challenging this misconception > - Request real-world examples that clearly demonstrate why the misconception is false > - Develop a conceptual test that would help someone determine if they still hold the misconception > > 3. Create a brief (2-minute) explanation video of each misconception and its correction that could help fellow students > 4. Reflect on how your understanding changed through this process

**Misconception Prompt Example:**

I'm trying to deeply understand a common misconception in thermodynamics: "Heat and   
temperature are the same thing."  
  
1. First, explain why this misconception seems intuitively reasonable to many students.  
  
2. Then, provide three different explanations (using different approaches or analogies)   
 for why heat and temperature are distinct concepts.  
  
3. Give me a concrete example that clearly demonstrates the difference between heat and   
 temperature in a way that's impossible to confuse.  
  
4. Suggest a simple experiment or thought exercise I could use to test whether someone   
 truly understands the distinction.

## Assessment Strategy

### Evolving Assessment Approach

#### Before AI Integration: Traditional Assessment

* Weekly problem sets focusing on numerical solutions (40%)
* Midterm and final exams with calculation-heavy problems (50%)
* Participation and quizzes (10%)

#### After AI Integration: Concept-Focused Assessment

* Weekly problem sets with both process documentation and solutions (25%)
* Concept mapping and misconception analysis assignments (15%)
* Explanation development assignments (15%)
* Modified exams with conceptual and application focus (35%)
* Learning portfolio documenting conceptual evolution (10%)

### New Assessment Components

1. **Explanation Quality Evaluation:**
   * Students’ ability to generate clear explanations of thermodynamic concepts
   * Multiple representation approaches (verbal, mathematical, graphical)
   * Ability to tailor explanations to different knowledge levels
   * Recognition of conceptual connections between topics
2. **Problem-Solving Process Documentation:**
   * Systematic approach to thermodynamic problems
   * Identification of relevant principles before equation application
   * Clear state identification and assumption justification
   * Reasonableness checks and result verification
   * Reflection on alternative approaches
3. **Conceptual Understanding Demonstrations:**
   * Creation of novel examples illustrating thermodynamic principles
   * Development of conceptual questions testing understanding
   * Identification of potential pitfalls or misconceptions
   * Ability to transfer concepts to unfamiliar scenarios

## Potential Outcomes and Considerations

### Expected Benefits

* Deeper conceptual understanding beyond equation manipulation
* More systematic and principled problem-solving approaches
* Greater student autonomy in learning and self-assessment
* Increased engagement with theoretical foundations
* Better preparation for advanced thermodynamics applications
* Stronger connections between mathematics and physical principles
* Development of explanation skills valuable for engineering communication

### Potential Challenges

* Risk of over-reliance on AI for conceptual understanding
* Technical errors in AI-generated thermodynamic explanations
* Difficulty ensuring students engage deeply rather than superficially
* Additional time required for process documentation
* Balancing conceptual focus with necessary quantitative skills
* Managing varying levels of AI proficiency among students

## Faculty Implementation Considerations

### Key Implementation Strategies

1. **Explanation before calculation** emphasis in all aspects of the course
2. **Multiple representation requirement** for concept demonstrations
3. **Process documentation** as a core component of assessment
4. **Guided prompt development** to ensure effective AI interactions
5. **Verification protocols** for ensuring conceptual and technical accuracy

### Important Considerations

1. **Clear boundaries** for appropriate AI use in different assessment contexts
2. **Technical fundamentals** must still be mastered independently
3. **Conceptual integration** should be emphasized over isolated topics
4. **Metacognitive development** is as important as content mastery
5. **Progressive autonomy** in AI interaction supports long-term learning

### Future Refinement Directions

If implementing such an approach, consider: 1. Developing discipline-specific prompt libraries for thermodynamic concepts 2. Creating a structured misconception database with effective correction strategies 3. Implementing peer-teaching components using AI-enhanced explanations 4. Adding more real-world applications to reinforce conceptual understanding 5. Creating advanced metacognitive frameworks for self-directed learning

## Resources Developed

1. **Thermodynamics Concept Prompt Library:** Structured prompts for key thermodynamic principles
2. **Problem-Solving Templates:** Frameworks for different thermodynamic systems and processes
3. **Misconception Database:** Common errors with multiple correction approaches
4. **Process Documentation Templates:** Structured formats for showing problem-solving thinking
5. **Verification Checklists:** Technical accuracy guides for different topic areas

## Implementation Advice

### For Faculty Considering Similar Integration:

1. **Start with conceptually challenging topics** where multiple explanations add value
2. **Emphasize process over answers** in all assessment components
3. **Create clear documentation requirements** to make thinking visible
4. **Develop verification habits** from the beginning of implementation
5. **Build a progressive framework** that gradually transfers responsibility to students

### Pedagogical Considerations:

1. **AI works best as a supplement** to strong foundational instruction
2. **Balance conceptual and quantitative** components throughout
3. **Encourage student-generated examples** to deepen understanding
4. **Use AI to bridge diverse learning preferences** and preparation levels
5. **Foster metacognition** through regular reflection on learning processes

*This case study was developed as part of the “Strategies for Integrating Generative AI in Engineering Education” workshop materials in collaboration with Claude-3.7 Sonnet.*