

Generative AI in Chemical Engineering Education: Rebuilding Thermodynamics, Material and Energy Balances and Kinetics Courses with AI and Chemical Engineering Students' Perception of AI

Dr. Betul Bilgin, The University of Illinois at Chicago

Betul Bilgin is a Clinical Associate Professor of Chemical Engineering at the University of Illinois at Chicago (UIC). With a Ph.D. in Chemical Engineering from Michigan State University, Dr. Bilgin has extensive experience in both biotechnology research and engineering education. Since joining UIC, she has developed and taught various undergraduate courses, integrating innovative teaching methods and industry-relevant content to enhance student learning and engagement.

Dr. Bilgin's research focuses on engineering education, particularly in fostering professional identity among engineering students and integrating data science into the chemical engineering curriculum. She has received multiple awards for her contributions to teaching and mentoring, including the ASEE Ray Fahien Award and the UIC COE Harold Simon Award. Dr. Bilgin is also actively involved in professional service, currently serving as the Director of the Chemical Engineering Division for ASEE and participating in various initiatives to improve engineering education and student success.

Dr. Christopher V.H.-H. Chen, Columbia University

Christopher V.H.-H. Chen, Ph.D., is a Lecturer in the Discipline of Chemical Engineering at Columbia University. His teaching and research interests include the application of case- and problem-based approaches to STEM learning experiences; the promise and challenges of online learning and AI; how social and emotional interventions improve engineering education; and preparing graduate students as future change leaders within the academy.

Dr. Stephanie Butler Velegol, The Pennsylvania State University

Stephanie Butler Velegol is a Teaching Professor in Chemical Engineering at Penn State University. She pioneered the use of Flipped classes to increase active learning in the classroom and works on water treatment.

Generative AI in Chemical Engineering Education

Rebuilding Thermodynamics, Material and Energy Balances and Kinetics Courses with AI and Chemical Engineering Students' Perception of AI

Abstract

Artificial intelligence (AI) has the potential to transform how core engineering courses are designed and delivered. This study explores the complete redesign of three chemical engineering courses—Thermodynamics, Material and Energy Balances and Kinetics—using AI to generate the syllabus, course content, homework, quizzes, and case studies. The central objective is to assess how AI can be leveraged to create educational materials while also investigating students' evolving perceptions of AI's reliability and their confidence in using AI for problem-solving in engineering contexts.

Regarding student perspectives, sophomore and senior students at University of Illinois Chicago (UIC) were surveyed at the end of the semester to assess their current use of AI tools, including the types of AI they rely on, how reliable they find AI-generated answers, and how confident they are in the information they receive from AI. These perceptions were captured using a combination of Likert-scale and open-ended questions. The guiding research questions are: *How effective is AI in designing Chemical Engineering courses? What are students' perceptions of the reliability of AI and what is their confidence in using AI as an engineering tool?* The study adopted a survey-based approach to capture students' evolving perceptions of AI. The results offer an in-depth understanding of how students' perceptions of AI in chemical engineering setting.

Regarding faculty perspectives, three chemical engineering faculty from three different institutions used AI to design the syllabus, course materials, and assessments, providing a unique opportunity to explore the effectiveness of AI in the course development process. This work aims to provide a roadmap for future AI-driven course redesigns and offer insights into how AI influences both learning outcomes and students' confidence in using AI technology in professional settings. Preliminary case studies in Thermodynamics, Material and Energy Balance and Kinetics courses suggest that AI can enhance course material design by providing instructors with advanced problem-solving tools and real-time feedback mechanisms. However, challenges such as AI biases and content accuracy remain significant hurdles. This paper discusses the transformative potential of Generative AI in engineering education, with a specific emphasis on overcoming pedagogical challenges in teaching sophomore and junior chemical engineering courses.

Introduction

The integration of artificial intelligence (AI) in education has emerged as a transformative force, particularly in engineering disciplines where problem-solving complexity demands innovative teaching approaches. As generative AI technologies advance rapidly, their potential to revolutionize engineering education becomes increasingly apparent, especially in core chemical engineering courses that form the foundation of the discipline (Smith & Johnson, 2023). While AI has been widely discussed in educational contexts, its specific application in designing and delivering chemical engineering courses remains largely unexplored. This study investigates the comprehensive redesign of three fundamental chemical engineering courses—Thermodynamics,

Material and Energy Balances, and Kinetics— using AI tools for syllabus generation, content development, and assessment creation. The central goal is to evaluate the efficacy of AI in course development and to investigate the accuracy of AI generated content. Moreover, this study also aims to capture how students perceive and use AI as a learning tool in engineering contexts. Guided by the research questions: *How effective is AI in designing Chemical Engineering courses?* and *How do students perceive AI's reliability and develop confidence in using AI as an engineering tool?* this study adopts a survey-based approach to capture student feedback. The results provide insights into the opportunities and challenges of integrating AI into chemical engineering education, paving the way for future innovations in course design.

Literature Review

The application of AI in education, particularly in engineering, has garnered significant attention due to its potential to enhance student engagement and improve learning outcomes. Recent studies highlight the ability of generative AI tools to create dynamic course content, automate routine tasks, and provide real-time, adaptive feedback to students [1-3]. These features are particularly valuable in addressing the challenges of large class sizes and diverse student needs, making AI a promising tool for scaling high-quality education.

In chemical engineering education, where problem-solving and quantitative reasoning are integral, AI tools like ChatGPT and discipline-specific software have shown promise in assisting with complex calculations, modeling, and conceptual understanding. For instance, AI-driven platforms can simulate chemical processes and provide students with interactive learning opportunities, enhancing their grasp of core concepts [4-8].

However, the growing prevalence of AI tools across various sectors, including education, has sparked concerns about their influence on students' learning and academic outcomes. In response, some institutions have opted to ban the use of certain AI platforms in an effort to uphold traditional teaching methods and skill development. However, a more effective and forward-thinking approach lies in embracing these technologies while equipping students with the skills to use them responsibly, critically, and ethically.

While AI's technical capabilities are well-documented, students' perceptions and confidence in using AI tools remain underexplored. Research indicates that students' trust in AI tools is influenced by their prior experience, perceived reliability of AI-generated content, and the extent to which AI aligns with their learning goals [9-12]. Moreover, concerns about the accuracy of AI outputs and ethical considerations, such as potential biases in AI algorithms, have been raised by both students and educators [13-16].

Studies involving generative AI tools in STEM education suggest a mixed response: students appreciate the efficiency and accessibility of AI tools but remain cautious about over-reliance and the lack of critical evaluation skills when using AI-generated solutions. This highlights the need for educational interventions that not only incorporate AI tools but also teach students how to critically evaluate and effectively integrate these technologies into their learning.

Despite its potential, the adoption of AI in engineering education is not without challenges. Concerns about content accuracy, algorithmic biases, and the ethical use of AI in academic settings pose significant barriers. Additionally, faculty readiness and institutional support are critical factors influencing the successful implementation of AI-driven course redesigns. However, when effectively implemented, AI tools can enhance pedagogical practices, foster creativity, and improve educational equity by providing students with tailored learning experiences.

This study contributes to the growing body of literature by examining the dual role of AI in designing chemical engineering courses and capturing students' perceptions of its utility. By examining the experiences of sophomores and seniors at University of Illinois Chicago (UIC), this research offers a comprehensive view of how AI tools influence chemical engineering education.

Methods

This study adopts a mixed-methods approach, combining case studies and surveys to assess the effectiveness of AI in course design and to capture students' perceptions of AI as a tool for learning and problem-solving in chemical engineering education. Three faculty members from different institutions independently redesigned three core chemical engineering courses—Thermodynamics, Material and Energy Balances, and Kinetics—using AI. Concurrently, student perceptions of AI were investigated through surveys conducted with sophomores and seniors at UIC.

Participants

The faculty participants included three chemical engineering educators from three different institutions, each responsible for designing one of the target courses. The student participants consisted of sophomores (enrolled in Introduction to Thermodynamics course) and seniors at UIC. Even though seniors are not enrolled in the courses that are redesigned by the faculty members, their participation in the study brought another data point as a snapshot of graduating students' perspectives on AI. Survey was conducted at the end of Fall 2024 semester, and a total of 78 students participated in the survey, representing a diverse demographic and academic background. The gender distribution was similar across both courses, with approximately 58% male students, 35% female students, and the remainder identifying as nonbinary or preferring not to specify. The ethnicity distribution of all the participating students was ~30% Latinx, ~30% Asian, ~30% White and ~7% Black.

Course Redesign Process

Each faculty member utilized ChatGPT-4o as generative AI tools to redesign their respective courses. The AI-generated content included:

- Syllabus: Comprehensive course schedules, learning objectives, and assessment structures.
- Course Materials: Lecture notes and instructional content.
- Assessments: Homework problems, multiple choice and open-ended questions for quizzes, and case studies tailored to course objectives.

The faculty were encouraged to adapt and refine the AI-generated materials as necessary to align with their pedagogical goals and institutional standards. After redesigning the course, faculty

documented their reflections, including the advantages and challenges of using AI in course development.

Survey Design and Administration

To evaluate students' perceptions of AI, an end-of-semester survey was distributed. The survey consisted of:

1. Likert-Scale Questions: Students rated their agreement with statements regarding the reliability, accuracy, and utility of AI tools in their coursework.
2. Open-Ended Questions: Students elaborated on their experiences with AI tools, including specific examples of how they used these tools for problem-solving and their concerns or reservations.

Survey questions were designed to address the research questions by capturing:

- The frequency and types of AI tools students used (e.g., ChatGPT, Grammarly).
- Their confidence in the reliability of AI-generated answers.
- Their perceived usefulness of AI in solving complex engineering problems.

Data Analysis

Quantitative data from Likert-scale responses were analyzed using descriptive and inferential statistical methods to identify trends and differences between sophomores and seniors. The qualitative data from open-ended responses were thematically analyzed to uncover recurring themes, such as perceived benefits, challenges, and trust in AI. The study adhered to institutional ethical guidelines, ensuring voluntary participation and anonymity for all student participants. Informed consent was obtained from all participants prior to data collection.

Limitations

This study focuses on three courses and one institution for student surveys, which may limit the generalizability of findings. Additionally, the accuracy and adaptability of AI tools depend on the specific platforms used, which may vary in capabilities and performance. More advanced AI models, such as premium versions with access to specialized datasets, might yield improved results, reducing the need for extensive faculty revisions. While this study provides a snapshot of students' perceptions and use of AI, the rapidly evolving nature of AI technology poses a challenge to its longevity. By the time this research is published, advancements in AI tools may address many of the concerns and challenges identified here, potentially rendering some findings less relevant. This underscores the importance of continuously revisiting and adapting educational practices to align with the latest developments in AI.

Instruments

All the instructors used the prompts listed below in Table 1 to redesign their courses. To ensure consistency among instructors, the course redesign process relied solely on the specified AI prompts listed in Table 1. Additional resources, such as class notes, textbooks, or external content, were deliberately excluded to allow the AI to guide the development process independently. It should also be noted that instructors did not upload the textbook and rely on ChatGPT to use its own knowledge of the book (if any) to generate connections with book chapters. This approach provided a standardized framework for evaluating the capabilities and limitations of AI in course design for multiple courses in chemical engineering.

Table 1. Prompts for Rebuilding Chemical Engineering courses.

Syllabus Generation:
"Generate a syllabus for a [specific chemical engineering course, e.g., Introduction to Thermodynamics]. Include a course description, course objectives, weekly topics, grading policy, and required materials. Align the content with undergraduate chemical engineering standards."
Mapping with Book Chapters:
"Map the syllabus topics of a chemical engineering course on [specific subject] with chapters from the textbook [Textbook Title]. Indicate how each topic aligns with specific chapters, noting key sections or page numbers that cover essential concepts."
Lesson Plan Creation:
"Create a detailed lesson plan for each week of a chemical engineering course on [specific topic]. For each lesson, include learning objectives, a brief summary, instructional strategies, activities, and suggested readings. Each plan should fit a [class duration, e.g., 60- or 90-minute] session format."
Mapping with ABET Outcomes:
"Map the syllabus topics for a [specific chemical engineering course] to ABET student outcomes. List each topic and explain how it contributes to achieving specific ABET outcomes (e.g., apply knowledge of mathematics, engineering, communicate effectively, etc.)."
Learning Outcomes Listing:
"List specific, measurable learning outcomes for each chapter in a chemical engineering course on [specific subject]. Ensure each outcome reflects skills or knowledge that students should demonstrate by the end of each chapter."
Open-Ended Questions and Answers for Each Chapter:
"Generate three open-ended questions for Chapter [Chapter Number and Title] of a chemical engineering course. Each question should encourage critical thinking and application of concepts. Provide detailed answers or explanations for each question."
Multiple-Choice and Fill-in-the-Blank Quiz Questions and Answers:
"Create three multiple-choice and three fill-in-the-blank quiz questions for Chapter [Chapter Number and Title] in a chemical engineering course. Ensure that each question assesses key concepts from the chapter. Provide correct answers and explanations for each question."
Designing Real-Life Case Studies:
"Design a real-life case study related to [specific topic, e.g., thermodynamics, chemical reaction engineering] for a chemical engineering course. The case study should involve real-world applications of the topic and challenge students to apply theoretical knowledge to solve practical problems. Include guiding questions and potential solutions."

Based on their experiences, they provided one-page reflection to share the strengths and weakness of AI on redesigning CHE courses.

On the other hand, survey instrument (can be accessed via this [link](#)) designed for measuring student's perception is adapted from two instruments: AI Attitude Scale (AIAS-4) [17] and General Attitudes Towards Artificial Intelligence Scale (GAAIS) [18]. AIAS-4 scale has been used to evaluate attitudes toward AI in university students across various fields, including science and technology disciplines. GAAIS is validated for use in diverse contexts which

measures both positive and negative attitudes. In our context, we reduced the questions into 9 Likert-scale questions (Table 2) and three open-ended questions.

Table 2: List of Likert scale Questions.

Q1. I am confident in my ability to use AI tools for academic purposes.
Q2. I feel comfortable integrating AI tools into my learning process.
Q3. I understand how to critically evaluate the output of AI tools.
Q4. AI tools can help improve my understanding of chemical engineering concepts.
Q5. AI tools make it easier to solve complex problems in CHE courses.
Q6. I am confident in my ability to use AI tools for academic purposes.
Q7. I feel comfortable integrating AI tools into my learning process.
Q8. I understand how to critically evaluate the output of AI tools.
Q9. AI tools can help improve my understanding of chemical engineering concepts.

Open-ended questions were “What were your initial thoughts in the beginning of the semester about using AI tools for learning chemical engineering concepts? And have they changed to the end of the semester?”, “Please list all the experiences you had with using AI in this course. Either positive or negative. (homework, self-study, project, writing, etc.)” and “What are your concerns, if any, about relying on AI for academic purposed?”.

Results

Faculty Reflections on AI-Generated Course Materials

Faculty members who used ChatGPT to redesign their courses provided detailed reflections on the benefits and challenges of incorporating AI into the course development process. These reflections offer insights into how AI tools like ChatGPT can support syllabus creation, material design, and assessment development while revealing areas where human expertise remains essential.

1. *Syllabus Design:* Faculty noted that AI-generated syllabi were generally comprehensive, well-organized, and aligned with course objectives. For example, two faculty members appreciated how the syllabus provided measurable learning objectives and a grading scale, though it lacked sufficient details for associated projects. Another instructor remarked, “*The AI-generated syllabus was a great starting point, offering clear objectives and schedules. However, I needed to refine it to add specific activities and context relevant to my teaching style.*”
2. *Course Materials:* AI-generated lecture plans and instructional content served as valuable foundational resources. One instructor observed that the AI-generated materials helped prioritize essential concepts and suggested logical sequencing for topics. However, they found the content too generic for in-depth coverage, necessitating the use of additional resources like textbooks and prior course materials. As one faculty member reflected, “*I was able to directly use the learning objectives and did use some of the chatbot-developed problems as part of the lectures. However, I found that none of these materials were really deep or detailed enough to drive a full 75-minute lesson plan as a first-time instructor for kinetics.*”

3. *Assessment Design:* Faculty reported that AI-generated assessments, such as homework problems and quizzes, were helpful in providing basic questions but often lacked the complexity required for advanced learning. Issues such as unclear phrasing and incomplete understanding of core concepts, like recycle and accumulation in material balances, were identified. As one instructor noted, *“The language of the assessments does not align well what I teach in the class. It does not follow the instructional steps that I follow in the class, which makes students confused.”*

Despite the advantages, faculty identified several challenges in relying on AI for course design:

- *Lack of Depth and Specificity:* AI-generated materials often provided only surface-level coverage of topics, requiring faculty to incorporate more detailed and rigorous content.
- *Conceptual Misunderstandings:* Certain questions generated by AI demonstrated a limited understanding of fundamental concepts, such as steady-state processes, which could confuse students if used without modification.
- *Customization Needs:* Faculty had to tailor AI-generated outputs to meet specific pedagogical goals, institutional standards, and ABET accreditation criteria.
- *Time investment and Efficiency:* Faculty reported significant variations in time efficiency when using AI for different aspects of course design. For syllabus generation, learning objectives, and basic course content creation, AI proved to be a time-saving tool. However, the development of assessment materials showed mixed results in terms of time efficiency. Faculty noted that creating and revising AI-generated open-ended questions and their solutions required more time investment compared to using textbook problems with existing solution manuals. Nevertheless, when developing original problems for courses, AI provided valuable starting points and ideation support. The interactive nature of AI tools emerged as a particular advantage, allowing faculty to iteratively refine prompts to achieve desired outcomes. Case study development emerged as an area of significant time savings, with AI dramatically reducing the time typically spent searching for appropriate cases online.

Overall, faculty found AI tools to be beneficial as a starting point but emphasized that human oversight and expertise were crucial for ensuring the quality and relevance of course materials. The following observations highlight this perspective:

- *“AI was incredibly helpful in breaking down complex concepts into manageable chunks, but its limitations became apparent when addressing higher-order thinking skills.”*
- *“A highlight is the application of the ABET criteria with the topics in the course. This is a great way to remind faculty how they can satisfy all the ABET requirements in the course.”*
- *“The details produced by the chatbot, however, were not enough to be used verbatim by a first-time instructor for the topic and were often too simple or straightforward for the level of student targeted in my teaching context. Some suggested problems and cases were used to start class activities, but additional materials were needed to fully create the lesson plans.”*

The faculty reflections underscore the transformative potential of AI in engineering education, particularly in simplifying initial stages of course development. However, they also highlight the importance of faculty adaptation and critical evaluation to address AI's current limitations.

Moving forward, combining AI's efficiency with faculty expertise can provide a robust framework for designing engaging, effective, and rigorous courses. For the readers' reference, the paper includes all three faculty reflections and sample prompt responses in the appendix.

Students' Perception and Use of AI in CHE

AI tool adoption rates were notably high across both cohorts: sophomores (Introduction to Thermodynamics) and seniors (Senior Design I). Among sophomores, 87.2% reported prior use of AI tools for academic purposes, while seniors showed a slightly higher adoption rate of 92.3%. This high adoption rate suggests that AI tools have already become deeply integrated into chemical engineering students' academic practices, regardless of their academic level. ChatGPT emerged as the dominant AI tool across both cohorts, though usage patterns differed significantly between the two groups. Sophomore students primarily employed AI tools for fundamental learning support, while seniors demonstrated more diverse and sophisticated applications.

Sophomores Usage:

1. Concept Understanding: Students frequently used AI to clarify complex thermodynamic concepts and equations.
2. Programming Support: Significant usage for VBA and MATLAB coding assistance.
3. Problem-Solving: Used AI tools to understand homework problems and verify solutions.
4. Study Aid: Creation of study guides and alternative explanations of textbook content.

Senior Usage:

1. Technical Writing: Extensive use for lab report writing and grammar checking.
2. Professional Communication: Email drafting and revision.
3. Advanced Problem-Solving: Integration with design projects and complex calculations.
4. Information Synthesis: Literature search and data gathering.
5. Code Development: More sophisticated programming applications.

Our comprehensive analysis of student perceptions reveals several key insights about how chemical engineering students at different academic levels view and interact with AI tools (Figure 1).

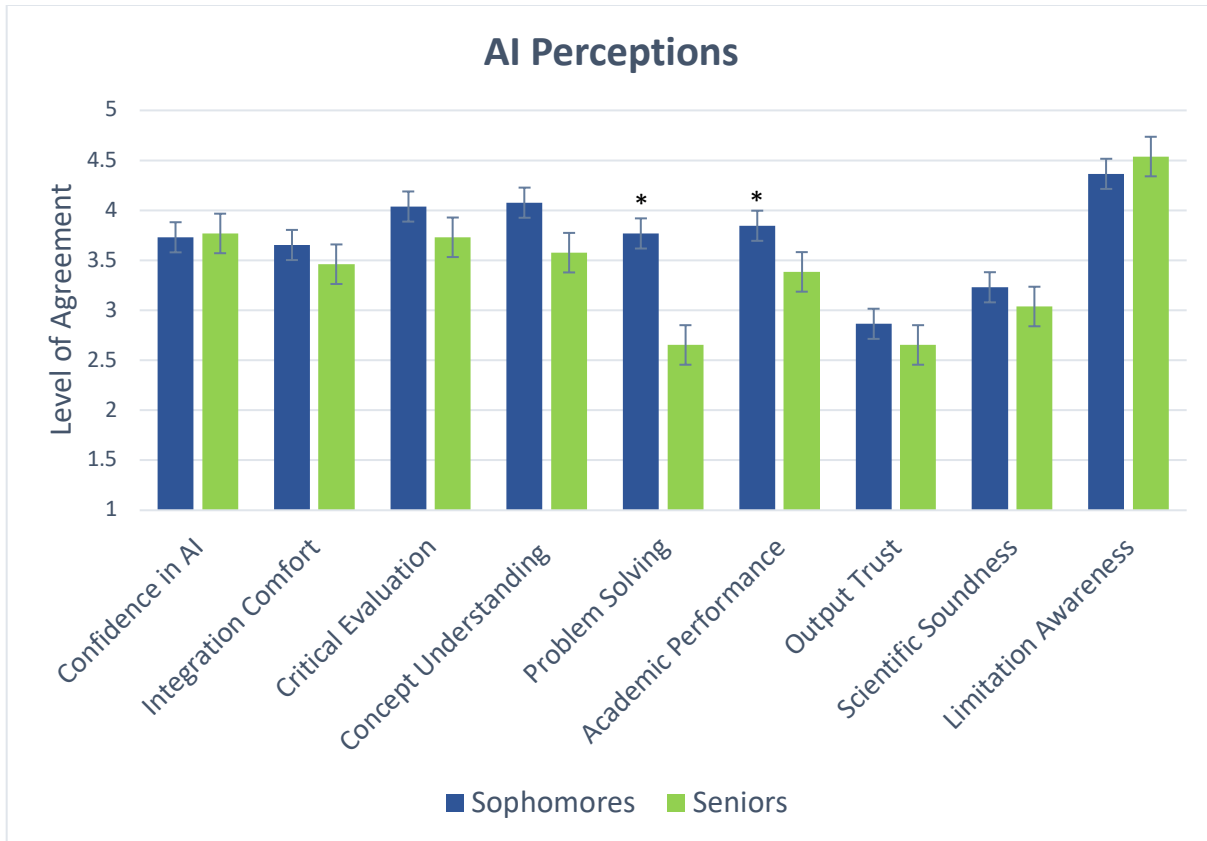


Figure 1: Students' Perception of AI Across Nine Aspects: Y-axis represents the Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Statistically significant data points are marked with an asterisk (*).

The data shows distinct patterns across nine key dimensions of AI perception and usage.

1. **Confidence and Integration (Questions 1-2)**
 - Overall confidence and comfort levels were similar between groups (3.70 for sophomores' vs 3.81 for seniors)
2. **Critical Thinking and Evaluation (Questions 3-4)**
 - Sophomores demonstrated higher scores in perceived ability to critically evaluate AI outputs (4.03 vs 3.73)
 - Sophomores also showed more optimism about AI's ability to enhance concept understanding (4.02 vs 3.57)
3. **Problem-Solving and Performance (Questions 5-6)**
 - Notable gap in problem-solving perception (3.76 for sophomores vs 2.65 for seniors)
 - Sophomores showed more optimism about AI's impact on academic performance (3.83 vs 3.38)
4. **Trust and Scientific Validity (Questions 7-8)**
 - Both groups showed relatively low trust in AI outputs (2.87 vs 2.65)
 - Moderate confidence in scientific soundness (3.23 vs 3.04)
5. **Awareness of Limitations (Question 9)**
 - Both groups showed high awareness of AI limitations
 - Seniors demonstrated slightly higher awareness (4.54 vs 4.36)

T-tests performed on the data revealed statistically significant differences ($p < 0.05$) in:

- Problem-solving perception
- Academic performance expectations

We also conducted a gender-based and ethnicity-based analysis of the survey data but did not observe any statistically significant differences across these groups. However, a few notable trends emerged:

- *Confidence in AI Use*: Male students across both courses reported slightly higher confidence in using AI tools, with an average score of 4.1 compared to 3.8 for female students.
- *Consistency Across Metrics*: Female students demonstrated more consistent scores across various aspects of AI use, suggesting a balanced approach to integrating AI into their learning processes.
- *Critical Evaluation Skills*: Female students outperformed their male counterparts in critical evaluation of AI outputs, scoring an average of 4.2 compared to 3.9 for males.
- *Trust in AI Outputs*: Male students expressed slightly higher trust in the accuracy and reliability of AI-generated outputs, with an average score of 3.1 compared to 2.8 for female students.

These observations indicate subtle gender-based differences in how students perceive and utilize AI tools, particularly in their levels of trust and critical evaluation skills.

While the quantitative survey results provide a broad understanding of students' perceptions of AI in chemical engineering education, the open-ended responses offer deeper insights into their experiences, challenges, and evolving attitudes toward AI tools. Analysis of student feedback demonstrates a clear evolution in their understanding and usage of AI tools, while also highlighting persistent concerns about their impact on learning outcomes.

1. *Evolution of Student Perspectives*: Students' initial attitudes toward AI tools showed considerable variation, with many expressing initial skepticism that later evolved into measured acceptance. As one student noted, *"I was apprehensive at first but overtime became more comfortable. I am still skeptical of any information i get from it but i do trust myself to evaluate what it gives me."* This evolution reflects a broader pattern of students developing more nuanced perspectives about AI's role in their education.

Many students who initially resisted using AI tools came to view them as valuable supplementary resources. One student captured this transition: *"I considered it cheating but then I learned to use the information as a guidance to develop my own thought process rather than something that gave me answers."* This shift from viewing AI as a potential threat to seeing it as a learning aid was common among respondents.

2. *Practical Applications and Limitations*: Students reported using AI tools across various aspects of their chemical engineering education, with notably different levels of success across different applications. For conceptual understanding and self-study, AI proved particularly valuable. Students frequently used it as a supplementary explanation tool,

with one student explaining, *"all positive, used it as a tutor to help explain problems and concepts when I got stuck on hw or reading the textbook."*

However, students consistently identified limitations in AI's capabilities, particularly regarding complex mathematical calculations. One student observed, *"ChatGPT can barely do math,"* while another noted, *"I couldn't use AI on actual assignments as often times the formulas and values were wrong or not complex enough for the question."* This recognition led many students to develop strategic approaches to AI usage, focusing on conceptual understanding rather than numerical solutions.

Writing and documentation emerged as areas where AI tools proved consistently helpful. Students reported positive experiences using AI for grammar checking, writing assistance, and literature research. One student noted, *"It is very good at navigating the web and finding papers. The more specific you can be the better."*

3. *Emerging Concerns and Challenges:* Despite the benefits, students expressed significant concerns about AI's impact on their education. The potential for overreliance emerged as a primary concern, with one student admitting, *"My ability of doing my hw has decreased and i feel dependancy on chat gpt for studies."* This concern about dependency was frequently coupled with worries about the depth of learning, as another student noted, *"we might not truly understand the concept of the problem."*

The accuracy and reliability of AI-generated information remained a persistent concern. Students repeatedly emphasized the importance of verification, with one noting, *"You should not 100% trust the outcome made by AI unless you double check by yourself."* This awareness of AI's limitations led many students to develop more sophisticated approaches to using these tools, often involving cross-referencing with traditional sources and careful verification of AI-generated information.

4. *Strategic Integration and Future Implications:* Students developed increasingly sophisticated strategies for effective AI usage throughout the semester. Rather than using AI as a primary source of information, many adopted it as a supplementary tool for clarification and verification. One student described their approach: *"I would ask if my approach to problem solving is right or wrong. I always ask for answers to questions after solving it by myself first."*

The need for clear institutional guidelines emerged as a consistent theme. Students expressed desire for *"clear expectations (as explicit as possible) from schools and professors on AI usage"* to avoid unintentional academic misconduct and ensure appropriate use of these tools. This suggests a need for educational institutions to develop comprehensive policies regarding AI usage while maintaining academic integrity.

The student perspectives reveal a complex relationship with AI tools in chemical engineering education. While initial skepticism has largely evolved into strategic acceptance, students maintain a sophisticated awareness of both the benefits and limitations of these tools. Their experiences suggest that AI can serve as a valuable educational resource when used

appropriately but requires careful integration to avoid potential pitfalls such as overreliance and superficial learning. The findings indicate a need for clear institutional guidelines and educational frameworks that help students leverage AI tools effectively while maintaining the depth and rigor essential to engineering education.

Discussion

The survey revealed evolving attitudes toward AI usage in chemical engineering education, along with distinct patterns in its application and associated concerns. Analysis of student responses to open-ended questions revealed a notable shift in attitudes toward AI throughout the semester. Many students reported initial skepticism about AI's role in chemical engineering education but developed a more nuanced perspective as the semester progressed. This evolution typically moved from viewing AI as potentially problematic for learning to recognizing its value as a supplementary educational tool. However, this acceptance was consistently tempered with awareness of AI's limitations and potential risks to learning outcomes.

Students reported diverse applications of AI across their coursework, with usage patterns varying between lower-level (Introduction to Thermodynamics) and upper-level (Senior Design I) courses. In lower-level, students primarily employed AI for basic concept understanding, homework assistance, and problem-solving support. In contrast, senior students demonstrated more sophisticated use cases, including research assistance, technical writing support, and literature review facilitation. This distinction suggests that AI usage patterns may mature as students' progress through their academic careers.

The survey identified several consistent concerns across both courses regarding AI usage in academic settings. Primary among these was accuracy and reliability, particularly in complex mathematical calculations and problem-solving scenarios. Students frequently reported instances of incorrect calculations or misleading information from AI tools, leading to a general consensus that verification against traditional sources remains essential. This finding suggests that students are developing critical evaluation skills in their interaction with AI tools.

A significant theme emerged regarding the impact of AI on learning outcomes. Students expressed concern about the potential for over-reliance on AI to diminish independent thinking and problem-solving abilities. This concern was particularly acute regarding exam preparation and performance, as students recognized the disconnect between AI-assisted learning and traditional assessment methods. However, students who reported positive experiences typically described using AI as a clarification tool rather than a primary source of learning, suggesting the emergence of effective usage patterns.

The data revealed several factors associated with successful AI integration into chemical engineering education. Students who reported positive experiences typically employed AI as a supplementary tool rather than a primary resource, maintained rigorous verification practices, and actively combined AI insights with traditional learning methods. These students often described AI as most valuable for concept clarification and initial problem-solving guidance, while emphasizing the importance of independent verification and understanding.

Risk factors identified in the survey included over-reliance on AI for problem-solving, unverified acceptance of AI outputs, and using AI as a replacement for fundamental understanding. Students in both courses demonstrated awareness of these risks, with many developing personal strategies to maintain academic integrity and ensure deep learning while leveraging AI's benefits. This awareness suggests a growing sophistication in students' approach to AI integration in their studies.

The findings indicate that successful integration of AI in chemical engineering education requires a balanced approach that leverages AI's capabilities while maintaining focus on fundamental understanding and skill development. Students' responses suggest that clear guidelines on appropriate AI usage, combined with training in effective verification methods and critical evaluation skills, could enhance the educational value of AI tools while mitigating potential risks to learning outcomes.

Conclusion

This study explored the use of generative AI tools, such as ChatGPT, in the redesign of three core chemical engineering courses—Thermodynamics, Material and Energy Balances, and Kinetics—and examined students' perceptions and use of AI in their academic practices. The findings highlight both the opportunities and challenges of integrating AI into engineering education. Faculty reflections revealed that AI tools were particularly effective in streamlining the initial stages of course development, providing comprehensive syllabi, learning objectives, and basic assessments. However, these tools often lacked depth, specificity, and contextual relevance, underscoring the necessity of faculty expertise to refine and adapt AI-generated materials. Faculty members emphasized that while AI tools can serve as valuable starting points, their outputs require careful validation and customization to align with course goals and pedagogical standards.

The survey results provided a nuanced understanding of students' perceptions of AI. While many students initially approached AI tools with skepticism, they gradually recognized their potential as supplementary resources for learning. Students in lower-level courses primarily used AI for concept clarification and homework assistance, whereas upper-level students employed it for more sophisticated tasks, including research and technical writing. However, concerns about accuracy, over-reliance, and the potential impact on critical thinking and independent problem-solving were prevalent across both groups.

The study also identified key success factors for effective AI integration. Students who used AI as a supplementary tool, verified outputs independently, and combined AI insights with traditional learning methods reported positive experiences. Conversely, over-reliance on AI and uncritical acceptance of its outputs were associated with negative outcomes, highlighting the importance of fostering critical evaluation skills.

References

- [1] E.A. Alasadi and C.R. Baiz, "Generative AI in education and research: Opportunities, concerns, and solutions," *J.Chem.Educ.*, vol. 100, pp. 2965–2971, 2023.
- [2] J.H. Orduño-Osuna, E.I. Cota-Rivera, M.E. Raygoza-L, R. Jimenez-Sanchez, G.M. Limón-Molina, M.E. Bravo-Zanoguera, A. Mercado-Herrera and F.N.M. Rico, "Exploring the Challenges and Applications of Generative AI on Engineering Education in Mexico," *Facilitating Global Collaboration and Knowledge Sharing in Higher Education with Generative AI*, pp. 259–286, 2024.
- [3] A. Owoseni, O. Kolade and A. Egbetokun, "Enhancing Personalised Learning and Student Engagement Using Generative AI," in *Generative AI in Higher Education: Innovation Strategies for Teaching and Learning*, Springer, 2024, pp. 123–150.
- [4] W. Chiu, "Pedagogy of emerging technologies in chemical education during the era of digitalization and artificial intelligence: A systematic review," *Education Sciences*, vol. 11, pp. 709, 2021.
- [5] M.R. Dobbelaere, P.P. Plehiers, R. Van de Vijver, C.V. Stevens and K.M. Van Geem, "Machine learning in chemical engineering: strengths, weaknesses, opportunities, and threats," *Engineering*, vol. 7, pp. 1201–1211, 2021.
- [6] F. Caccavale, C.L. Gargalo, K.V. Gernaey and U. Krühne, "FermentAI: Large Language Models in Chemical Engineering Education for Learning Fermentation Processes," in *Computer Aided Chemical Engineering*, Elsevier, 2024, pp. 3493–3498.
- [7] R. Andika and Z.A. Putra, "Teaching programming to chemical engineering students," *ASEAN Journal of Science and Engineering Education*, vol. 2, pp. 51–60, 2022.
- [8] M. Tsai, C.W. Ong and C. Chen, "Exploring the use of large language models (LLMs) in chemical engineering education: Building core course problem models with Chat-GPT," *Education for Chemical Engineers*, vol. 44, pp. 71–95, 2023.
- [9] S. Zhan and L. Wang, "Integrating Generative AI in Higher Education: Challenges, Opportunities, and Innovations in Assessment Practices within Electrical Engineering," .
- [10] P.M. Simelane and J. Kittur, "Use of Generative Artificial Intelligence in Teaching and Learning: Engineering Instructors' Perspectives," *Computer Applications in Engineering Education*, vol. 33, pp. e22813, 2025.
- [11] E. Er, G. Akçapınar, A. Bayazıt, O. Noroozi and S.K. Banihashem, "Assessing student perceptions and use of instructor versus AI-generated feedback," *British Journal of Educational Technology*, 2024.
- [12] L. Labajová, "The state of AI: Exploring the perceptions, credibility, and trustworthiness of the users towards AI-Generated Content," 2023.

- [13] S. Akgun and C. Greenhow, "Artificial intelligence in education: Addressing ethical challenges in K-12 settings," *AI and Ethics*, vol. 2, pp. 431–440, 2022.
- [14] A. Adel, A. Ahsan and C. Davison, "ChatGPT promises and challenges in education: Computational and ethical perspectives," *Education Sciences*, vol. 14, pp. 814, 2024.
- [15] B. Memarian and T. Doleck, "Fairness, Accountability, Transparency, and Ethics (FATE) in Artificial Intelligence (AI), and higher education: A systematic review," *Computers and Education: Artificial Intelligence*, pp. 100152, 2023.
- [16] O. Bulut, M. Beiting-Parrish, J.M. Casabianca, S.C. Slater, H. Jiao, D. Song, C.M. Ormerod, D.G. Fabiyi, R. Ivan and C. Walsh, "The rise of artificial intelligence in educational measurement: Opportunities and ethical challenges," *arXiv Preprint arXiv:2406.18900*, 2024.
- [17] S. Grassini, "Development and validation of the AI attitude scale (AIAS-4): a brief measure of general attitude toward artificial intelligence," *Frontiers in Psychology*, vol. 14, pp. 1191628, 2023.
- [18] A. Schepman and P. Rodway, "Initial validation of the general attitudes towards Artificial Intelligence Scale," *Computers in Human Behavior Reports*, vol. 1, pp. 100014, 2020.

APPENDIX A

Faculty Reflections

Reflections on Kinetics Course

Course Context

This 3-week kinetics module sits within a bridge series of courses to our chemical engineering MS program for non-chemical engineers (typically chemistry undergraduates), which is taken within the first term of graduate school for these students. This module is one of the last modules students take, building on material and energy balances, thermodynamics, and transport modules students had taken earlier in the series. Students participate in six lectures and three recitation sessions (all 75 minutes) and complete two homework assignments to demonstrate competency in the concepts in the module. As the module is very short, the lectures and problems focus entirely on core kinetics concepts required for the students to access the graduate kinetics course required for the MS.

Instructor Reflection on ChatGPT for Module Design

ChatGPT 4-o mini (the free version) was a useful companion in helping to down select for the most important concepts to cover and to order them in a way that would be digestible and helpful for students. I was able to use the module-level learning objectives (edited) that ChatGPT had given to develop a syllabus-like overview for the 3-week module, and topics for the six lectures. I found it helpful to see how ChatGPT produced a full semester (15-week) course plan that was then converted to a 6-session format, and to see that the chatbot did not directly follow the order of chapters from the textbook to guide the lectures.

The lecture plans, sample activities, and problems that were produced by the chatbot were helpful in developing high level, relatively easy problems that students could engage in in-class. I was able to directly use the learning objectives and did use some of the chatbot-developed problems as part of the lectures. However, I found that none of these materials were really deep or detailed enough to drive a full 75 minute lesson plan as a first-time instructor for kinetics. As such, though I used the chatbot's suggestion for high level structure of the module, I drew on Fogler's Chemical Reaction Engineering textbook and its associated web resources, along with the course materials from previous module instructors to get more detailed plans, slides, and problems to use in the classroom.

The homework/exam questions that the chatbot produced seemed to be generally correct, but not particularly complex or broken into parts in the way that I want students to practice the concepts presented in the lectures. These, again, could serve as the basis for problems that I could have used for the module. I opted to instead use the homework problems of the previous instructor as a means of assuring that students were gaining the same competencies as the previous batch of students.

All-in-all, I found that using the chatbot was helpful as a starting point, helping to suggest learning objectives for the individual lectures and overall module, along with providing kernels of problems that could have been used for homework or exams. The details produced by the chatbot, however, were not enough to be used verbatim by a first-time instructor for the topic, and were often too simple or straightforward for the level of student targeted in my teaching

context. Some suggested problems and cases were used to start class activities, but additional materials were needed to fully create the lesson plans.

Reflections on Materials and Energy Balance Course

I put the prompts in for a Material Balances class. The syllabus was well done and covered the material from the book. It even put together a decent grading scale including a project. It did not include anything about the project in the syllabus though. Interesting that it skipped to chapter 9 for some of the lessons, but the flow made sense.

The lecture description was a little vague but did include guided problem solving and an activity (no specificity about type of activity). It only laid out 5 weeks, but I am sure you could ask it to continue for the other weeks. I liked that it encouraged interaction with the students in class.

A highlight is the application of the ABET criteria with the topics in the course. This is a great way to remind faculty how they can satisfy all the ABET requirements in the course. The table at the end is particularly helpful. It did a nice job with the learning objectives using measurable words like describe, apply, solve, analyze, differentiate, explain, evaluate. Of course, I would use more specificity in mine, but it is a good start.

I had mixed feelings on the open-ended questions. Question 1 was a little too vague (how does a PFD help?) but I really did like question 2 (what is the purpose of a purge stream). It seemed to really understand the trade off from the purge itself. I don't really like question 3. This question is about degrees of freedom. Although this can be helpful for creating questions, it is typically not a concept I would focus on.

There were problems with the multiple-choice questions and open ended with the concepts of recycle and accumulation. First - Question 3 in the multiple choice asked the purpose of the recycle. The answer was "to reduce waste and improve process efficiency" However, another option was "To increase the production of the desired product" and that could also be true. Second - it doesn't understand the use of accumulation. Question 2 of the multiple choice asked what term(s) from the material balance equation are always zero in a steady-state process. It should be Generation and Consumption AND Accumulation, but it only said Generation and Consumption. In addition, question 4 of the open ended asked for the term representing changes in material within the system in a steady-state process. There should be no term for change in material, but it said accumulation. This is very confusing for students.

The open-ended question mentioned the Haber Bosch process. This is a great example that I use in my class and would be helpful for a first-time faculty member to know about.

Reflections on Introduction to Thermodynamics Course

Context

I redesigned the course "*Intro to Thermodynamics*", the first course in a two-class thermodynamics sequence. It is a sophomore-level course and serves as an introduction to the

chemical engineering department. Over the 16-week semester, I teach the first and second laws of thermodynamics for pure substances. Classes are held twice a week in 75-minute lectures, with students taking three midterms, completing weekly homework assignments, and working on a semester-long project.

AI in Course Preparation

I entered the course textbook name into ChatGPT, and it provided an excellent foundation for syllabus creation. It organized the course content week-by-week and aligned it with chapter objectives and learning outcomes. This feature is particularly helpful for faculty teaching a course for the first time, as it saves significant time and effort. As one advantage, it *"mapped the ABET outcomes and chapters"* effectively, offering a strong starting point for curriculum alignment with accreditation standards. However, while the AI-generated lecture plan included activity suggestions and reading assignments, it lacked timing details and external references beyond the textbook and it required further refinement to fit my specific teaching style and classroom activities. Similarly, while it created a lecture outline, the outline needed additional depth. These limitations could likely be addressed by providing more detailed and specific prompts.

For quizzes and activities, ChatGPT generated multiple-choice and fill-in-the-blank questions that were straightforward and suitable for tools like Kahoot. However, these questions were fairly basic and lacked the depth needed for more complex understanding. It may help to enter prompts explicitly requesting conceptually rich or "conceptware" questions to improve the quality of the generated assessments. Open-ended questions were primarily conceptual and did not include calculation-based problems unless explicitly prompted. Once prompted, the calculation-based questions were adequate but still fairly simple, while the conceptual open-ended questions required further refinement. Also, the language of the assessments does not align well with what I teach in the class. It does not follow the instructional steps that I follow in the class, which makes students confused. When I prompted the AI for calculation-based problems, the results were somewhat better but still basic. Real-life case study prompts yielded textbook-style problems rather than references to real-world news or industry cases. This gap underscores the need for careful prompting and refinement when designing higher-order assessments.

Overall, ChatGPT generates responses that serve as a great starting point for a wide range of applications, including syllabus design, lecture planning, and assessment creation. AI was incredibly helpful in breaking down complex concepts into manageable chunks, but its limitations became apparent when addressing higher-order thinking skills. Importantly, my students have shared that they use ChatGPT to design self-study questions by entering my practice exam questions and requesting similar problems. This highlights the need for instructors to understand how to guide AI tools effectively to generate richer content. As educators, we should disseminate best practices for prompting and guiding AI, not only for personal use but also to help students maximize its potential for learning.

APPENDIX B

Sample Prompt Responses

Prompt 1: Generate a syllabus for a Material Balances. Include a course description, course objectives, weekly topics, grading policy, and required materials. Align the content with undergraduate chemical engineering standards.

Course Syllabus: Material Balances

Course Description

This course introduces the fundamental principles and techniques of material balances, a cornerstone of chemical engineering. Students will learn to systematically analyze and solve problems involving the conservation of mass in chemical processes, including reactive and non-reactive systems. Applications include chemical production, energy generation, environmental systems, and biological processes.

Course Objectives

By the end of this course, students will:

1. Understand and apply the law of conservation of mass to process systems.
 2. Develop the ability to formulate and solve material balance problems on single-unit and multi-unit processes.
 3. Analyze and solve reactive and non-reactive systems, including recycle, bypass, and purge operations.
 4. Interpret and utilize process flow diagrams.
 5. Understand the role of physical properties and phase behavior in material balance calculations.
 6. Develop foundational skills for chemical process design and analysis.
-

Weekly Topics

Week	Topic
1	Introduction to Material Balances: Basic Principles and Definitions
2	Units, Dimensions, and Process Variables
3	Single-Unit Non-Reactive Systems: Basics and Problem-Solving Strategies
4	Multi-Unit Processes: Process Flow Diagrams and Problem Analysis
5	Introduction to Energy Balances: Tie-ins with Material Balances
6	Reactive Systems: Stoichiometry and Extent of Reaction
7	Material Balances on Reactive Systems (Single-Unit)
8	Midterm Exam and Review
9	Recycle, Bypass, and Purge Operations
10	Systems with Phase Changes: Vapor-Liquid and Liquid-Liquid Equilibria
11	Material Balances on Environmental and Biological Systems
12	Introduction to Process Simulations and Computational Tools

Week	Topic
13	Case Studies and Advanced Problem-Solving
14	Course Review and Final Project Discussions
15	Final Exam

Grading Policy

Component	Weight
Homework Assignments	20%
Quizzes	10%
Midterm Exam	25%
Final Exam	30%
Final Project	10%
Class Participation	5%

Grading Scale:

A: 90–100% | B: 80–89% | C: 70–79% | D: 60–69% | F: <60%

Required Materials

1. **Textbook:** *Elementary Principles of Chemical Processes* by R.M. Felder and R.W. Rousseau (latest edition).
 2. Scientific Calculator (with unit conversions).
 3. Access to process simulation software (e.g., Aspen Plus or ChemCAD).
 4. Notebook for problem-solving and notes.
-

Course Policies

1. **Attendance:** Attendance is mandatory. Participation in discussions and problem-solving sessions is encouraged.
2. **Late Submissions:** Assignments turned in late will incur a penalty unless prior arrangements are made.
3. **Collaboration:** Students are encouraged to collaborate on homework but must submit individual work.
4. **Academic Integrity:** Plagiarism and cheating are strictly prohibited and will result in disciplinary action.

Prompt 2: Write me learning objectives for an undergraduate chemical engineering kinetics course.

Sure! Here are some learning objectives for an undergraduate chemical engineering kinetics course:

1. ****Understand Fundamental Concepts**:** Students will be able to describe the basic principles of chemical kinetics, including reaction rates, rate laws, and the impact of concentration, temperature, and catalysts on reaction rates.

2. **Mathematical Modeling**: Students will develop the ability to formulate and solve mathematical models of chemical reactions, including both elementary and complex reactions, using differential rate equations.
3. **Experimental Techniques**: Students will gain proficiency in designing and conducting experiments to measure reaction rates, as well as analyzing and interpreting kinetic data using appropriate statistical methods.
4. **Reaction Mechanisms**: Students will learn to propose and evaluate reaction mechanisms, differentiating between molecularity, elementary steps, and overall reaction orders.
5. **Catalysis and Surface Reactions**: Students will understand the principles of catalysis and its effects on reaction rates, including enzyme kinetics and heterogeneous catalysis.
6. **Arrhenius Equation and Temperature Effects**: Students will apply the Arrhenius equation to analyze the temperature dependence of reaction rates and understand the significance of activation energy.
7. **Software Applications**: Students will become familiar with using computational tools and software for simulating chemical reactions and analyzing kinetic data.
8. **Critical Thinking and Problem Solving**: Students will develop critical thinking skills to analyze complex kinetic scenarios, propose solutions, and communicate their findings effectively.
9. **Interdisciplinary Connections**: Students will appreciate the relevance of chemical kinetics in various fields such as materials science, biochemistry, and environmental engineering.
10. **Ethical and Safety Considerations**: Students will recognize the importance of ethical practices and safety measures in conducting chemical research and experiments.

These objectives should provide a comprehensive framework for the course, ensuring that students gain a solid foundation in chemical kinetics.

Prompt 3. Create a detailed lesson plan for each week of a chemical engineering course on material balances. For each lesson, include learning objectives, a brief summary, instructional strategies, activities, and suggested readings.

Lesson Plan Creation (Week 1 Example)

Topic: Introduction to Thermodynamics

Learning Objectives:

- Define thermodynamics and its scope in chemical engineering.
- Understand the concepts of energy, work, and heat transfer.

Summary:

An introduction to thermodynamic systems and processes. Discussion of energy forms and the laws governing energy transformations.

Instructional Strategies:

- Lecture with PowerPoint slides.
- Interactive discussions using real-world examples (e.g., power plants).
- Short in-class exercises on identifying thermodynamic systems.

Activities:

- Group discussion on common thermodynamic systems.
- Problem-solving practice on defining systems and surroundings.

Suggested Readings:

- Moran & Shapiro, Chapter 1: Sections 1.1-1.4.

Prompt 4. Map the syllabus topics for a Material balances to ABET student outcomes. List each topic and explain how it contributes to achieving specific ABET outcomes (e.g., apply knowledge of mathematics, engineering, communicate effectively, etc.).

Below is a mapping of syllabus topics for a **Material Balances** course to **ABET student outcomes** (as specified in the current ABET accreditation criteria). Each topic is aligned with specific ABET outcomes to demonstrate how it supports achieving them.

ABET Student Outcomes (for reference)

1. **Problem-Solving:** Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
 2. **Engineering Design:** Ability to apply engineering design to produce solutions that meet specified needs.
 3. **Communication:** Ability to communicate effectively with a range of audiences.
 4. **Ethics and Responsibility:** Ability to recognize ethical and professional responsibilities in engineering situations.
 5. **Teamwork:** Ability to function effectively on a team.
 6. **Experimentation and Data:** Ability to develop and conduct appropriate experimentation, analyze data, and use engineering judgment.
 7. **Lifelong Learning:** Ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
-

Syllabus Topics and Mapping

1. Introduction to Material Balances

- **ABET Outcome 1:** Students identify key principles of engineering and mathematics (e.g., conservation of mass).
 - **ABET Outcome 7:** Introduces the importance of self-directed learning to build foundational knowledge in chemical engineering.
-

2. Process Flow Diagrams (PFDs)

- **ABET Outcome 1:** Students interpret and analyze process systems using flow diagrams.
- **ABET Outcome 3:** Communicating process information visually and in writing.

- **ABET Outcome 5:** Encourages teamwork in interpreting complex diagrams during collaborative problem-solving sessions.
-

3. Material Balances for Single-Unit Systems

- **ABET Outcome 1:** Application of mathematical and engineering principles to solve steady-state and unsteady-state balance problems.
 - **ABET Outcome 6:** Solving real-world examples using measured or provided data (e.g., flow rates, compositions).
 - **ABET Outcome 7:** Encourages iterative problem-solving and applying theoretical knowledge to new problems.
-

4. Multi-Unit Systems

- **ABET Outcome 1:** Extending problem-solving skills to multi-unit systems by breaking down complex systems into simpler components.
 - **ABET Outcome 5:** Promotes collaboration when working in teams to solve problems involving multiple units and processes.
-

5. Recycle, Bypass, and Purge Systems

- **ABET Outcome 1:** Problem-solving for recycle, bypass, and purge systems involves applying mathematical and chemical engineering principles.
 - **ABET Outcome 2:** Encourages the design of systems that optimize resource use and minimize waste.
 - **ABET Outcome 4:** Discusses ethical considerations in optimizing energy and material use in chemical processes.
-

6. Reactive Processes

- **ABET Outcome 1:** Students solve problems involving reaction stoichiometry and material balances for reactive systems.
 - **ABET Outcome 2:** Applications of reaction systems are tied to process design and efficiency.
 - **ABET Outcome 6:** Hands-on analysis of reaction data to determine material requirements for processes.
-

7. Combustion and Chemical Reactions

- **ABET Outcome 1:** Combustion problems reinforce the application of principles of chemistry, mathematics, and engineering.
- **ABET Outcome 4:** Ethical discussion about sustainability, environmental impact, and reducing carbon emissions.

- **ABET Outcome 7:** Promotes understanding of the evolving role of combustion technologies in engineering.

8. Phase Changes and Vapor-Liquid Systems

- **ABET Outcome 1:** Students apply thermodynamics and phase equilibrium principles to solve vapor-liquid problems.
- **ABET Outcome 6:** Uses real-world data to evaluate equilibrium conditions, promoting experimentation skills.
- **ABET Outcome 2:** Tied to the design of processes involving distillation, evaporation, or condensation.

9. Industrial Applications of Material Balances

- **ABET Outcome 1:** Students analyze real-world problems and apply core material balance concepts.
- **ABET Outcome 3:** Case studies require effective communication of results in oral and written forms.
- **ABET Outcome 4:** Discussions of industrial safety and sustainability link to professional and ethical responsibilities.
- **ABET Outcome 5:** Students work in teams to propose solutions for industrial process challenges.

Summary Table

Syllabus Topic	ABET Outcome 1	ABET Outcome 2	ABET Outcome 3	ABET Outcome 4	ABET Outcome 5	ABET Outcome 6	ABET Outcome 7
Introduction to Material Balances	✓						✓
Process Flow Diagrams (PFDs)	✓		✓		✓		
Single-Unit Systems	✓					✓	✓
Multi-Unit Systems	✓				✓		
Recycle, Bypass, and Purge Systems	✓	✓		✓			
Reactive Processes	✓	✓				✓	
Combustion and Chemical Reactions	✓			✓			✓
Phase Changes and Vapor-Liquid Systems	✓	✓				✓	
Industrial Applications	✓		✓	✓	✓		

Explanation:

This mapping shows how a Material Balances course contributes to achieving the broad range of ABET outcomes. It ensures that students acquire essential engineering skills, such as problem-solving, teamwork, communication, and ethical responsibility, while also grounding them in the principles of chemical engineering. Let me know if you'd like me to elaborate further or tailor it to a specific syllabus!

Prompt for Homework Question Design and Answer: Generate three open-ended questions for each chapter of Kinetics book. Each question should encourage critical thinking and application of concepts. Provide detailed answers or explanations for each question.

Session 1: Introduction to Chemical Kinetics

****Homework Question**:**

Define the term "reaction rate" and explain how it can be affected by changes in concentration and temperature. Provide an example of a chemical reaction where you observe these effects.

Session 2: Rate Laws and Mathematical Modeling

****Homework Question**:**

Given the following experimental data for the reaction $2A + B \rightarrow C + D$, $(A \rightarrow B)$:

[A] (mol/L)	Rate (mol/L·s)
0.1	0.02
0.2	0.08
0.3	0.18

Determine the rate law for the reaction and calculate the rate constant (k) .

Session 3: Reaction Mechanisms

****Homework Question**:**

Propose a possible mechanism for the following overall reaction: $(2A + B \rightarrow C + D)$. Justify your steps and specify the elementary reactions, including their molecularity.

Session 4: Catalysis and Enzyme Kinetics

****Homework Question**:**

Discuss the difference between homogeneous and heterogeneous catalysis. Provide an example of each type of catalysis and explain how the catalyst affects the reaction rate in your examples.

Session 5: Temperature Effects and the Arrhenius Equation

****Homework Question**:**

Using the Arrhenius equation, calculate the activation energy (E_a) for a reaction if the rate constant (k) doubles when the temperature increases from 300 K to 350 K. Assume $(R = 8.314 \text{ J/(mol·K)})$.

Session 6: Data Analysis and Computational Tools

****Homework Question**:**

You are given kinetic data for a reaction over a range of temperatures. Use a software tool (such as MATLAB or Python) to plot the natural logarithm of the rate constant (k) versus $(1/T)$ (where (T) is the temperature in Kelvin). Analyze the slope to determine the activation energy (E_a) .

These questions should reinforce the key concepts covered in each session while encouraging critical thinking and application of the material. Let me know if you need any further adjustments or additional questions!

for each of the above homework questions, could you write me the answer?

Sure! Here are the answers to the homework questions for each session:

Session 1: Introduction to Chemical Kinetics

****Answer**:**

The reaction rate is defined as the change in concentration of a reactant or product per unit time. It can be affected by:

- ****Concentration**:** An increase in the concentration of reactants generally leads to an increase in reaction rate due to more frequent collisions.
- ****Temperature**:** Increasing the temperature provides reactants with more kinetic energy, resulting in more effective collisions, thus increasing the reaction rate.

****Example**:** For the reaction $(2H_2 + O_2 \rightarrow 2H_2O)$, increasing the concentration of (H_2) will increase the rate at which water is produced. Similarly, raising the temperature will also speed up the reaction.

Session 2: Rate Laws and Mathematical Modeling

****Answer**:**

To determine the rate law, we can use the method of initial rates:

1. From the data:

- For $[A] = 0.1 \text{ M}$, Rate = 0.02 M/s
- For $[A] = 0.2 \text{ M}$, Rate = 0.08 M/s
- For $[A] = 0.3 \text{ M}$, Rate = 0.18 M/s

2. We can assume the rate law is of the form $(\text{Rate} = k[A]^n)$.

3. Taking the ratio of the first two experiments:

$$\frac{0.08}{0.02} = \left(\frac{0.2}{0.1}\right)^n \implies 4 = 2^n \implies n = 2$$

4. Thus, the rate law is $(\text{Rate} = k[A]^2)$.

5. To find (k) using the first set of data:

$$0.02 = k(0.1)^2 \implies k = \frac{0.02}{0.01} = 2 \text{ M}^{-1}\text{s}^{-1}$$

2. We can assume the rate law is of the form $\text{Rate} = k[A]^n$.

3. Taking the ratio of the first two experiments:

$$\frac{0.08}{0.02} = \left(\frac{0.2}{0.1}\right)^n \implies 4 = 2^n \implies n = 2$$

4. Thus, the rate law is $\text{Rate} = k[A]^2$.

5. To find k using the first set of data:

$$0.02 = k(0.1)^2 \implies k = \frac{0.02}{0.01} = 2 \text{ M}^{-1}\text{s}^{-1}$$

Session 3: Reaction Mechanisms

****Answer**:**

One possible mechanism for the reaction $(2A + B \rightarrow C + D)$ could be:

1. $(A + B \rightarrow AB)$ (fast, elementary step)
2. $(AB + A \rightarrow C + D)$ (slow, rate-determining step)

****Justification**:**

- The first step forms an intermediate (AB) quickly, which then reacts with (A) in the rate-determining step. The overall stoichiometry matches the balanced equation.

Prompt: Create three multiple-choice and three fill-in-the-blank quiz questions for Thermo class. Ensure that each question assesses key concepts from the chapter. Provide correct answers and explanations for each question.

Multiple-Choice and Fill-in-the-Blank Questions (Chapter 1 Example)

Multiple-Choice:

1. Thermodynamics primarily deals with:
 - a) Kinetics of chemical reactions
 - b) Energy and its transformations ☒
 - c) Chemical bonding
 - d) Motion of fluids

Fill-in-the-Blank:

1. The first law of thermodynamics is also known as the law of _____.
Answer: Energy Conservation

Prompt: Design a real-life case study related to material balances for a chemical engineering course. The case study should involve real-world applications of the topic and challenge students to apply theoretical knowledge to solve practical problems. Include guiding questions and potential solutions.

Case Study: Optimizing Recycle and Purge Streams in an Ammonia Synthesis Plant

Background

Ammonia synthesis is a critical process in the chemical industry, primarily used in fertilizer production. The Haber-Bosch process produces ammonia by reacting nitrogen (N_2) and hydrogen (H_2) gases under high pressure and temperature in the presence of a catalyst. However, not all the reactants convert into ammonia in a single pass through the reactor. To improve efficiency, unreacted reactants are recycled back into the system.

However, impurities such as argon (Ar) enter the system with the nitrogen feed. Since argon is inert and does not react, it can accumulate in the recycle loop and reduce the efficiency of the process. To avoid this, a purge stream is introduced to remove a fraction of the recycle gas.

Objective

The goal of this case study is to design and analyze the ammonia synthesis process, focusing on optimizing the recycle and purge streams to balance efficiency, reactant recovery, and impurity removal.

System Description

- **Inputs:**
 - N_2 : 50 mol/s
 - H_2 : 150 mol/s
 - Ar : 1 mol/s (impurity in the feed)
 - **Reactor Output (Single Pass):**
 - 40% of N_2 reacts with H_2 to form ammonia (NH_3).
 - **Recycle Loop:**
 - Unreacted N_2 , H_2 , and Ar are recycled back to the reactor.
 - **Purge Stream:**
 - Removes a fraction of the recycle stream to prevent Ar buildup.
 - **Stoichiometry:**
 - $N_2 + 3H_2 \rightarrow 2NH_3$
-

Tasks for Students

1. **Mass Balance on the Reactor:**

- Perform a material balance around the reactor to calculate the molar flow rates of NH_3 , N_2 , H_2 , and Ar leaving the reactor.
- 2. **Recycle Loop Analysis:**
 - Write material balances for the recycle loop to determine the composition and flow rates of the recycle stream.
- 3. **Purge Stream Optimization:**
 - Calculate the minimum purge flow rate required to keep the mole fraction of Ar in the recycle stream below 2%.
- 4. **System Efficiency:**
 - Determine the overall conversion of N_2 and H_2 in the system, considering both the reactor and the recycle loop.
- 5. **Economic and Environmental Considerations:**
 - Discuss the trade-offs between maximizing reactant recovery and minimizing energy use and waste generation.

Guiding Questions

1. What are the molar flow rates of N_2 , H_2 , NH_3 , and Ar leaving the reactor in the first pass?
2. How does the recycle loop affect the overall conversion of N_2 and H_2 ?
3. What is the relationship between the purge rate and the accumulation of Ar in the system?
4. How can the purge stream be adjusted to minimize N_2 and H_2 losses while maintaining an acceptable level of Ar ?
5. What operational changes could improve the energy efficiency of the system without compromising production?

Solution Outline

1. **Reactor Material Balance:**
 - Reactor input: N_2 : 50 mol/s, H_2 : 150 mol/s, Ar : 1 mol/s.
 - Reactor output:
 - N_2 reacted = $0.4 \times 50 = 20 \text{ mol/s}$
 - H_2 reacted = $3 \times 20 = 60 \text{ mol/s}$
 - NH_3 produced = $2 \times 20 = 40 \text{ mol/s}$
 - Remaining N_2 : $50 - 20 = 30 \text{ mol/s}$
 - Remaining H_2 : $150 - 60 = 90 \text{ mol/s}$
 - Ar remains unchanged: 1 mol/s
2. **Recycle Loop Material Balance:**
 - Write balances for N_2 , H_2 , NH_3 , and Ar in the recycle stream considering the purge fraction (PPP).
3. **Purge Rate Calculation:**
 - For steady-state conditions, the mole fraction of Ar in the recycle stream is:
$$x_{\text{Ar}} = \frac{\text{Purge flow rate of Ar}}{\text{Recycle flow rate} + \text{Purge flow rate of Ar}}$$
 - Solve for the purge rate (PPP) to ensure $x_{\text{Ar}} < 0.02$.
4. **Overall System Efficiency:**
 - Overall conversion of N_2 :
$$\text{Overall conversion} = \frac{\text{NH}_3 \text{ produced}}{\text{Total } \text{N}_2 \text{ fed to the system}}$$

- Consider both single-pass and overall conversions with recycle.
 - 5. **Economic and Environmental Trade-Offs:**
 - High purge rates reduce ArArAr buildup but lead to loss of N₂ and H₂.
 - Optimizing the purge stream improves sustainability by reducing waste and energy consumption.
-

Expected Outcomes

- Students will calculate the flow rates and compositions of all streams in the process.
 - They will determine the optimal purge rate to balance reactant recovery and impurity removal.
 - They will understand the impact of operational decisions on process efficiency and environmental performance.
-

This case study challenges students to integrate material balance calculations with practical considerations, fostering critical thinking and application of engineering principles to real-world problems. Let me know if you'd like to expand any section!