Designing AI-enabled MEB Learning Activities

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Abstract

Material and Energy Balances (MEB) is often one of the first technical courses that undergraduates take in the chemical engineering major. Along with providing an introduction to the profession, the course serves an important role in orienting students to how chemical engineers think and solve problems. While MEB content has been roughly similar since at least 1990, some changes, such as greater inclusion of computer usage in calculations and analysis, have been seen in a survey of MEB courses conducted by the AIChE Education Division Survey Committee in Fall 2021.

With the release of ChatGPT in Fall 2022, and as the use of generative AI tools have become more pervasive amongst students, greater consideration is needed by engineering instructors in how to use and integrate these approaches into their own courses. Targeting MEB for the creation of AI-enabled teaching offers an opportunity to integrate AI early into the chemical engineering curriculum. Helping students build critical thinking skills and AI competencies (e.g., the limitations of AI)—or, generally, how to think *about* AI—at the beginning of their chemical engineering course requirements could help students better understand how they may leverage AI tools throughout their studies, and how AI is being used in the profession. Early disciplinary exposure to AI use may also help shape student perspective on AI and engineering, especially if a student's previous use of chatbots for studying were not productive. Additionally, the previous MEB survey was conducted before the release of ChatGPT, and would not have been able to capture how instructors for that course may have been leveraging generative AI.

To help address this gap, and as an example of how to intentionally integrate AI into a particular core course in chemical engineering, we are creating MEB activities that leverage commercially available chatbots, which could be used across course contexts, and reflecting on how AI has affected MEB. These learning activities—and other pedagogical materials—are designed to target a range of MEB concepts, learning objectives, and use cases (e.g., in-class or outside of class, one-off or continued use). This paper describes the types of AI-enabled activities we have created, and our reflections on implementing these activities in our classrooms. Our analysis will present strategies for designing homework problems, in-class activities, syllabus language, and other pedagogical materials that may be helpful to instructors who are considering using AI tools for teaching. By sharing a case of multiple instructors designing AI-embedded learning activities for a particular course, along with our observations as to how AI has impacted student learning and our own teaching, we hope our example can inspire other instructors to consider how they may try similar approaches to enhance learning by integrating AI intentionally.

Introduction

Material & Energy Balances (MEB) is often one of the first technical courses in the undergraduate chemical engineering curriculum, with most students taking the course in the first term of their second (i.e., sophomore) year [1]. This course is more than an introduction to the profession—it plays a foundational role in teaching students how chemical engineers think and solve problems. The AIChE Education Division Survey Committee has been tracking how schools in the US and Canada teach MEB, with the last survey taken in 2021. Their most recent paper shows that the content of MEB courses has been roughly similar since at least 1990, with some small changes, such as greater inclusion of computer usage in calculations and analysis [1]. Since the most recent MEB survey study was conducted prior to the release of ChatGPT in 2022, there has not been an opportunity to understand how AI has impacted how MEB is taught.

AI has been a disruptive force in engineering education, and higher education at large. With use of generative AI having become pervasive amongst college students [2], greater consideration is needed by engineering instructors in how to use and integrate these tools into their own courses, including what learning objectives ought to be targeted. (We note that we will use AI for generative AI as most applications of AI in MEB that we consider are generative AI.) Instructional considerations should go beyond just thinking *with* AI in the discipline to also consider how to think *about* AI. Thinking *with* AI includes engineering practice that can be augmented by offloading some tasks (e.g., coding, analyzing data, or designing) to AI. Anyaegbu and Dada presented many examples of thinking *with* AI (although not in those terms) in chemical engineering in a 2022 ASEE paper [2] predating ChatGPT. On the other hand, thinking *about* AI encompasses skills such as ethics of AI use, understanding the limitations and biases of models, and critical thinking–all of which are needed for engineers to think effectively *with* AI.

We will also note that we separate that our efforts in this paper differ from how AI or machine learning (ML) can be used for the practice of chemical engineering. For example, there are researchers who are developing bespoke AI models for addressing chemical engineering problems (such as the efforts of Venkatasubramanian *et al.* [3], who also has taught the longest running AI in Chemical Engineering course in the US for nearly 40 years [4]), and resources for instructors to help integrate ML and AI approaches in their courses [5]. Instead, our paper is more focused on how generative AI can be used to help improve chemical engineering education, and how to develop learning activities to help guide students towards better habits for using AI that support learning.

Targeting MEB for the creation of AI-embedded teaching offers an opportunity to integrate AI early into the chemical engineering curriculum; our goal is provide students an opportunity to develop critical thinking skills and AI competencies (i.e., how to think *about* AI) so they can more productively use AI tools through their college and professional careers. Early disciplinary exposure to AI could also help shape student perspectives on AI and engineering, especially if a student's previous use of chatbots for studying were not productive. Intentional integration of AI would also respond to students' feelings of being underprepared in AI use by graduation [6], and help allay faculty concerns that students would over-rely on the tool and prevent learning [7].

In chemical engineering, some educators are integrating AI to teach students to think *with* the tool. For example, Tsai *et al*. [8] employed ChatGPT to allow students with limited programming experience to develop their own computational models towards solving problems, such as modeling a steam power plant and calculating its efficiency. Kong *et al*. [9] demonstrated how AI can be used to assist in the design of distillation columns in an interactive learning environment. ChatGPT and other Large Language Models (LLMs) are also being explored for use as virtual tutors for specific technical practices, such as training students in Good Manufacturing Practices at the masters level [10]. AI-supported self-paced learning of programming skills (MATLAB [11] and ODE modeling with Python [12]), helped students improve technical communication skills [13], and edited text, problem solved, and evaluated information in capstone design [14]. There are fewer examples, however, of helping students think *about* AI in chemical engineering, with one of the few examples in chemical engineering occurring in MEB, where students were tasked with interacting with a "novice" (intentionally-errant) chatbot to develop critical thinking skills [15]; and another where students are asked to co-create and critique novel course problems with AI [16]. Concurrent research is emerging on how AI can be used in qualitative research to probe student understanding of challenging chemical engineering concepts [17].

To help address this gap in helping students learn how to think *about* AI—and as an example of how to intentionally integrate AI into a particular core course in chemical engineering—we are creating MEB activities that leverage commercial chatbots, which could be used across course contexts. In particular, we consider how to use a "novice" chatbot for MEB to build student AI skills in the course. We have developed learning activities—and other pedagogical materials—designed to target a range of MEB concepts, learning objectives, and use cases (e.g., in-class or outside of class, one-off or continued use). Our paper will discuss the types of AI-enabled activities we have created leveraging various chatbots, and our reflections on developing these activities. Examples will include problems, in-class activities, syllabus language, and other pedagogical materials that may be helpful to instructors who are considering using AI tools for teaching. We also compare our different approaches across nine schools designing chatbot-enabled activities and strategies for AI integration into MEB. By sharing a case of multiple instructors designing learning activities for a particular shared course with a specific AI tool, we hope our example can inspire other instructors to consider how they may try similar approaches to enhance learning in their own courses with AI-embedded activities.

Methods
This paper synthesizes the experiences of nine MEB instructors from a diverse set of universities (located in the Midwest, Northeast, and South; R1 universities and smaller, regional undergraduate-focused colleges; public and private institutions). We are collaborating to eventually develop learning activities to leverage the MEB novice chatbot [15], and other pedagogical material that pertain to AI use in the course. The collaborating faculty members met to share activities, and discuss development of these AI-related MEB materials throughout Fall 2025 and Spring 2026.

For this paper, we collected and analyzed MEB syllabi and learning objectives; AI policy statements (course-, department-, and school-level when available); and AI-enabled learning activities and lesson plans. The authors then generated reflections—which included instructor- and observed student-use of AI in MEB; considerations that influenced how they integrated AI; and how AI has impacted the classroom beyond learning—and compared experiences designing AI-embedded activities for MEB. To prepare for collective use of the MEB novice chatbot, participating faculty used commercial chatbots that were available for free to them and their students. No data was collected directly from students regarding their experiences.

Results & Discussion
Overview of AI-enabled Learning Activities for MEB. Generative AI-enabled learning activities that were used by us (the instructors) during Fall 2025 could be broadly grouped into three general categories: (1) evaluate AI output; (2) compare solutions with AI; and (3) ideate with AI. Examples for each of these categories are shown in Table 1. The first two categories are similar but have important differences in the instructions to students, and target skills relating to thinking *about* AI. Both include a problem statement that students are required to ask the chatbot, and both ask students to assess whether they agree with the chatbot output. The difference lies in whether students are told to solve the problem themselves (often with explicit instructions as to what the student needs to have prior to comparison) before they assess the chatbot's response. These types of AI-enabled activities will work well with the MEB novice chatbot, because of trained bias towards common MEB student errors, but also can be used with any commercial chatbot. In fact, a variant of these problems is to ask students to compare multiple chatbot outputs and determine which of the most agree with and why, as one of the authors has done. These AI-enabled activities were used both within the classroom to spur discussion, and as part of homework assignments (both team and individual). Reflection questions (e.g., why do you agree or disagree with the chatbot) were also common features of these activities. Any questions used for this type of activity should be developed to trigger errors with AI, if possible, in order to help increase the likelihood students are critically thinking *about* AI as they engage in these exercises.

Table 1. Example generative AI-enabled MEB learning activities

AI-enabled Learning Activity Category	**Example AI-enabled Learning Activities for MEB**
Evaluate AI Output	[Homework Problem] Ask the chatbot the following question: "An insulated vessel contains 200 ml of water at 60 °C. Into the vessel 200 ml of an acid at 20 °C are poured. The contents of the vessel are then well mixed. If no heat is lost or gained through the walls of the container while the liquids are being mixed what will be the temperature of the mixture? Assume no chemical reactions take place." Review the chatbot's response and answer the following: A. On a 1-5 scale (5 = total agreement), do you agree with the chatbot? B. Why do you agree or disagree with the chatbot? C. On a 1-5 scale (5 = extremely confident), how confident are you in the chatbot's performance? Why? [15]
Compare Solutions with AI	[In-Class Activity] You have a 16 lb frozen turkey, with guests coming tomorrow. How do you thaw it quickly and safely? In pairs, come up with ideas. What does GenAI say? [Exam Problem] Students critique a ChatGPT solution to a basic energy balance problem that they had to solve independently. In this case, ChatGPT's solution made a ton of unnecessary assumptions, but it gets the same numeric final answer because the assumptions are "good enough."
Ideate with AI	[Lab Activity] You are tasked with building a swamp cooler. As you encounter problems when doing this hands-on project, you are encouraged to use AI to brainstorm potential solutions to these problems. [Project Milestone] Your team is required to design a hot air balloon which must meet design criteria and constraints, and to develop a mathematical model which will predict the balloon's performance. Use AI to brainstorm ideas for the design - within your team discuss how to prioritize these ideas. Videos related to chemical engineering course content from thermodynamics to separations have been translated into student-written, homework problems that reverse engineer the actions in the video. A new iteration brings together YouTube problems and Generative AI tools. Students are asked to be creative in picking a video as a team. Then, individually use a generative Ai tools to write and solve an appropriate problem. One final problem per team merges/combines/edits the best ideas. [16]

The final category, ideating with AI, are AI-enabled activities that help students think *with* AI in MEB. These types of activities included having the students co-create applications of MEB concepts (e.g., case studies or real life examples, experiments, or hands-on projects), co-develop project ideas [18], co-write homework or exam questions [16], or co-author code to perform process flow calculations with AI. Some instructors ask students to interact with chatbots similar to a Think-Pair-Share, where they engage with the chatbot as if it is another student in the course. These activities were more likely to be run in-class, with the AI-enabled activity effectively serving as a starting point for discussion and engagement, helping students overcome initial barriers to problem formulation, followed by group discussion to help students share how they can better *think with* AI as a partner or tool for engineering work. However, this category should be used with caution as creative ideation is important in the cognitive development of engineering students [19].

AI Policy Statements for MEB. Setting guidelines for students in the classroom is needed to ensure the students' AI use aligns with the instructor's expectations. University-recommended policy options include: (1) AI is encouraged to be used, (2) AI can be used in specified conditions, or (3) AI use is prohibited.

Having these statements for MEB are important, not only because guidance provided to faculty on generative AI from their institutions are highly varied (from our small sample of nine departments for this project, AI policies ran the gamut from default allowed to default banned, and no policy at all). Because MEB is often the first technical course in the major, acclimating students to how they may expect AI to be used in their studies and engineering practice is important to consider, and how we choose to (or not to) integrate AI into the course will affect how students decide to use AI as a tool for learning. As such, nearly all of our MEB syllabi include an AI policy statement (sometimes integrated with an academic policy statement) that generally allows AI use, with caveats. Nearly all statements include three parts: (1) a warning that AI should not displace learning and may be errant; (2) that AI will be disallowed on certain assessments (e.g., exams); and (3) that students will be required to disclose all AI use on submitted assignments. Excerpts from syllabus statements on AI that highlight each of these parts are shown in Table 2.

Although not common across the syllabi, some included a faculty AI disclosure statement, which communicates to students how instructors are disclosing their AI use to the class. This is often paired with a discussion of AI use on the first day of class to help students understand how these tools are pervading all parts of the teaching and learning process, and giving a chance for instructors to demonstrate appropriate use of AI in action. An example of such a statement is as follows:

> *Your instructor will use AI from time to time to generate course materials. This will be fully disclosed to you. AI will not be used to determine grades for your work. The creative impetus for any use of AI will come from your instructor.*

Table 2. AI Policy Statement Excerpts for MEB

AI Policy Statement Part	MEB AI Policy Statement Example Excerpt
Warning that AI should not displace learning and may be errant	ChatGPT and other generative artificial intelligence (AI) programs are promising tools. Some of these systems can even provide some reasonable responses to questions related to topics in chemical engineering and suggest possible solutions to a problem. When used well, AI can be a powerful tool to enhance understanding of a topic or even write and refine programming code. *However, the goal of this course is for every student to learn to "think like a chemical engineer," not, "write effective prompts to get ChatGPT to solve chemical engineering problems."* The work submitted for this course must demonstrate that you, the student, understand core chemical engineering concepts. Generative AI can be used to help master your understanding of topics, but it can't replace your understanding.
AI will be disallowed on certain assessments	***Unauthorized Assistance***: Do not use AI to access unauthorized materials or solutions during examinations, quizzes, or other assessments. Any form of unauthorized assistance is a violation of academic integrity
Disclosure of AI use on submitted assignments	We recognize that ChatGPT (and other AI) can be a powerful tool to help you with writing and reviewing content – and we are OK with you using it, to some extent. Whatever work you present as your own ***should be your own work.*** That is, you should be solving your own homework problems, and if you use one of these tools to help you write, we ask that you **acknowledge your use of them**. Please keep in mind that like any tool, ChatGPT (or other tools) has flaws. It is **not guaranteed to be correct,** so you must be careful when using its output.

Faculty Observations on Students' Use of AI in MEB. Within the classroom, beyond AI-enabled activities led by instructors, we have directly observed students using AI. This includes use cases similar to instructor-led activities where students *think with* AI (e.g., breaking down a problem, generating code for calculations, or getting them started on a problem), but also include use of AI for translation, defining concepts, and finding useful data (e.g., heat capacities, densities, molecular weights). Anecdotally, for out-of-class homework assignments, students seem to rely primarily on a mix of in-person (e.g., study groups, and teaching assistant and faculty office hours) and online resources (e.g., LearnChemE materials, and solution platforms such as Chegg or Course Hero), which would include AI chatbots. Because many textbook problems already have complete, worked solutions available through solution platforms, it may still be likely that students find them to be more reliable than AI for routine homework completion—albeit a likely academic integrity infraction. In a more troubling use-case, some students were found to use AI to address open-ended, short-answer questions where they are asked to interpret or contextualize numbers from a problem, engineering skills they are likely learning for the first time in MEB. In required AI statements with assignments, many students have disclosed use of AI for helping them make their writing more concise or clear and for checking their work, but none have written they use AI to completely solve the problems in their entirety.

Faculty Reflections on Grading and Assessment. Generative AI has generally encouraged instructors to revisit their assessment practices [20], and that is no different for MEB. Many of us still use traditional, in-class exams where AI (and often the Internet) are not allowed, despite other changes to grading and assessment within our courses. For example, a distinctive feature of several instructors' course assessments is the use of group quizzes or exams [21,22]. During these assessments, students are explicitly encouraged to use all available resources, including classmates, course notes, the internet, and sometimes the instructor. In one case [21], the instructor observed that early in the semester students frequently attempted to use AI during these quizzes. However, after approximately two to three weeks, a noticeable shift occurred, with students moving away from AI and instead relying more heavily on course-specific resources, peer collaboration, and direct interaction with the instructor. This transition suggested to that instructor that students recognized the limitations of AI for real-time problem solving and the greater efficiency of leveraging their immediate learning environment. Such a transition requires sufficiently complex or open-ended tasks that AI cannot yet solve.

Another instructor has made it a priority to incorporate AI output in their exams and quizzes to have students critically think about what the output says, whether it's accurate, and how it could be improved. This technique has had several advantages—it allows the instructor to probe more deeply into students' understanding, and it subtly encourages students to be critical of AI output.

Because AI potentially provides students the answers (e.g., full solutions) to problems, several instructors have reconsidered how to assess out-of-class work, shifting to assignments that are graded on completion and requiring students to write reflections on their learning process. In addition to mitigating the incentive to offload thinking to AI for their homework to attain a desired grade (instead of *thinking with* AI on the assignment), grading homework for completion also helps to encourage student metacognition and struggle with the assigned exercises.

Because policing student use of AI, in the context of academic misconduct, is difficult, we have found that addressing these cases require patience and a neutral discussion to avoid creating unnecessary barriers in communicating with students. Deliberate avoidance of an accusatory tone (or explicit accusations) can be helpful. The guidelines for AI use in academics are still changing at many universities and may be different across institutions—and even departments—creating a greater need for students to learn appropriate AI use in MEB early in their engineering studies.

Faculty Reflections on the Impact of AI on Classroom Culture. While it has always been an integral aspect to effective teaching practice, our previous examples show how the presence of AI places a primacy of curating a positive classroom culture. We have needed to help our students to see the value of what they are learning, more than before ChatGPT's arrival. We have also had to emphasize how we (as instructors) are there to support student learning and success (i.e., we are all on the same team with a shared purpose of learning—à la *Start with Why* [23]). This is especially important given the large prerequisite STEM classes students have taken where they may have used unproductive habits in regard to AI and that may have been more punitive in policing students' AI use. As MEB is often the transition into chemical engineering and its disciplinary culture, MEB is an important place to instantiate these values.

With the advent of AI, addressing long-standing tensions in university classrooms around uncertainty, authority, and evidence of learning has continued to be important. Integrity, in this context, becomes less about detecting misuse and more about designing sociotechnical learning environments where the responsible use of tools, transparent norms, and reflective participation are integral to what it means to learn. Specifically, we advocate for a shift away from AI detection and more towards design transparency, where we are explicit about what AI use is allowed in MEB and why. Doing so in MEB can be rather natural, where student learning is more directed to chemical engineering practices (e.g., how do chemical engineers approach problems) and the "correct answer" alone is less pedagogically important.

In many of the examples above, we have worked to make generative AI an explicit actor in the MEB classroom. However, to do this, we need to develop competency using these tools ourselves and create an environment where AI use becomes part of the classroom discussion rather than hidden from sight. Because an important part of classroom culture is participation norms, we have decided to encourage student discursive practices—including verbal discussions and reflection—so that we can reinforce ideas around the ways chemical engineering is about thinking and doing. Epistemologically, this can support students developing notions of expertise away from always being "correct" to how they think about things, and grapple with them when they are uncertain and confused. Because MEB is often the first chemical engineering course students take, we have generally prioritized showing students that they can solve problems in different ways and still be correct as a demonstration of "thinking like an engineer." We find that AI can help make this more true when used in intentional ways.

Conclusion & Future Work

When using AI for the MEB course, many of the general guidelines applied to new technologies in the classroom and to teaching in general should still apply. For example, students require clarity in expectations as described earlier. We found that we needed to be intentional and, often, granular when describing what is appropriate use for MEB, and also for us (as instructors) to know what role AI may potentially play in how students learn and solve problems in MEB. We have needed to be flexible when AI use is permitted, as the platforms use will evolve and occasionally devolve without warning, and the IT structures that support these services may suddenly degrade. Finally, as instructors, we should keep in mind the learning objectives for the course and each element of that course and avoid being distracted by the technological tool at the cost of limited time to be directly engaged with learning.

By sharing our collective experiences trying to intentionally integrate AI, and specifically a novice chatbot, into MEB, we hope to have inspired other instructors to consider how they may try similar approaches to enhance learning in their own courses with AI-enabled activities, and considerations. We plan to continue gathering data on these AI-enabled activities, along with our own reflections as instructors using AI in MEB, to share how learning and teaching in this important class is changing with generative AI.

AI Use Statement

AI was not used in the writing of this document, or analysis of data. Use of AI was limited to the testing and deployment of learning activities described in this paper.

IRB Statement

This paper was limited to the analysis of pedagogical materials and reflections created by the instructors of this project. As such, no IRB approval was needed for this paper.

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