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Evaluating the Reliability of Out-of-Class Assessments Amid Widespread Use of AI

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Abstract

Assessing student knowledge in engineering courses has become increasingly challenging due to widespread access to external resources. Homework assignments and take-home assessments, which are often used to evaluate higher-level problem-solving skills, have long been vulnerable to solution manuals and online tutoring services. In upper-level undergraduate and graduate engineering courses, the complexity of problems frequently necessitates assessment formats that extend beyond standard in-class exam periods, further increasing reliance on take-home exams and projects.

More recently, the availability of artificial intelligence (AI)–based tools have introduced additional concerns regarding the reliability of take-home assessments. AI tools can generate complete and well-structured solutions to complex engineering problems, making it difficult to determine the extent to which submitted work reflects individual student understanding. This paper examines the impact of AI use on the assessment of student learning in undergraduate and graduate mechanical engineering courses.

Examples of assigned problems and corresponding AI-generated solutions are presented to illustrate cases in which AI produces correct, partially correct, or incorrect results. In addition, results from an anonymous student survey are analyzed to examine how students are using AI tools. Survey findings indicate that students increasingly view AI as a tutoring resource to support learning, while also acknowledging its use as a shortcut to obtaining problem solutions, which may limit learning. These results provide insight into both the opportunities and challenges AI presents for engineering assessment.

Introduction

Engineering instructors commonly employ homework assignments, quizzes, projects, and examinations to evaluate student learning and mastery of course material. However, the reliability of out-of-class assessment methods has been questioned for many years due to student access to solution manuals, online resources, and external assistance [1]. As a result, instructors have increasingly recognized limitations in using homework and take-home assignments as direct measures of individual student knowledge and have adjusted assessment strategies accordingly [2].

The challenge of reliable assessment is particularly evident in upper-level undergraduate and graduate engineering courses, where problems often require extended time and multiple steps to solve. In such courses, time-limited in-class exams may be insufficient to assess higher-order critical thinking skills, leading instructors to rely on take-home exams, projects, and extended assignments [3]. While these formats allow for more complex and realistic problems, they also increase opportunities for unauthorized external assistance [5].

The growth of online tutoring platforms has further complicated the use of take-home assessments. Prior studies have documented how students use mobile devices to transmit problems to online tutors during, or outside scheduled assessments, receiving complete worked solutions in a brief period [5]. These practices make it difficult for instructors to distinguish between student-generated work and externally produced solutions, even when original problems are assigned.

More recently, the emergence of generative Artificial Intelligence (AI) tools has introduced additional challenges. AI systems such as ChatGPT can produce original text, structured explanations, and step-by-step solutions to engineering problems [6, 7]. Because AI-generated responses are typically original in wording and format, they may not be identified by traditional plagiarism-detection methods, raising concerns related to academic integrity and assessment validity [9].

Recent engineering education studies indicate that students are actively using AI tools as part of their academic workflow. Survey results from undergraduate mechanical engineering courses show that students commonly use AI for writing assistance, concept clarification, and exam preparation, while expressing caution regarding the accuracy of AI-generated numerical solutions [3, 4]. These findings suggest that AI tools are already influencing how students approach take-home assignments and assessments.

Faculty perspectives on the role of AI in assessment continue to evolve. Some faculty express concerns regarding academic integrity, while others recognize potential instructional benefits if AI use is explicitly addressed and guided [10, 11]. However, there is limited published work directly comparing AI-generated solutions with student-generated solutions for complex engineering problems typically given as take-home assignments.

The purpose of this paper is to evaluate the reliability of assessing students' knowledge through take-home exams, quizzes, and assignments in the context of widespread access to AI software. Examples from undergraduate and graduate mechanical engineering courses are presented, along with corresponding AI-generated solutions, to illustrate cases in which AI provides correct, partially correct, or incorrect results. In addition, results from an anonymous student survey are used to provide insight into student perceptions and usage of AI tools.

Examples of AI Generated Solution

In upper-level undergraduate and graduate engineering courses, solving complex or multi-step problems often requires extended time. In such courses, time-limited, in-class exams are often insufficient for assessing students' ability to solve higher-order problems. Prior to the widespread availability of digital solution manuals for textbook problems, instructors placed greater weight on homework assignments. In more recent years, many instructors have relied on take-home exams, projects, and extended assignments to assess students' ability to solve more complex problems [3]. Consequently, instructors have reduced the weight of traditional textbook homework assignments while increasing the emphasis on take-home assessments. However, with the increased availability of online tutoring platforms such as Chegg [3], and more recently AI-based software, it has become increasingly challenging to accurately assess students' knowledge through take-home assignments, exams, and quizzes.

Since 2025, we have evaluated the ability of AI software to correctly solve some of the more complex problems before assigning them to students. A few representative examples are presented in this paper. In the summer of 2025, we assigned the following two problems for the PhD Qualifying Examination in the areas of Thermodynamics and Heat Transfer.

Problem 1.
The Gibbs Free Energy of a system is given by:

$$G = cNRT - TNS_0 - NRT\left[\ln\left(\left(\frac{T}{T_0}\right)^c \left(\frac{P_0}{P}\right)\left(\frac{N_0}{N}\right)\right)\right] + NRT$$

where c, R, S_0, T_0, P_0, N_0 are constants or reference state variables.

a) Find an equation of state in the Gibbs representation (i.e., find $V(P, T, N)$)
b) Find internal energy U.

Although the exam was conducted in person, we examined whether ChatGPT could solve this problem correctly. We found that ChatGPT provided a nicely formatted and detailed solution. A copy of the solution is included in the Appendix.

The following heat transfer problem was also included in the same qualifying PhD examination.

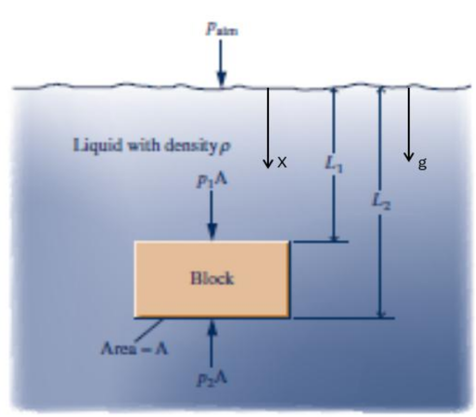
Problem 2
The local Nu numbers for laminar and turbulent flow over a flat plate are given by equations $Nu_x = 0.332\ Re_x^{1/3}\ Pr^{½}$ and $Nu_x = 0.032\ Re_x^{0.8}\ Pr^{0.43}$, respectively. If transition from laminar flow to turbulent flow occurs at $Re_{trans} = 50{,}000$, derive a relationship for an average $\overline{Nu_L}$ for a flow over a flat plate of a length L, where the flow is turbulent at x = L.

Again, the ChatGPT tool provided a very nicely formatted detailed solution to this problem. A copy of ChatGPT solution is included in the Appendix.

Early in the fall semester of 2025 the following take-home quiz problem was assigned to the students in ME 3293, the first course in Thermodynamics.

Problem 3
Consider a rectangular metal block shown in the diagram, having a mass of 600 kg is anchored to the bottom of a pool by a solid rod (not shown on the diagram), holing the metal block in place. The water in the pool has a density ρ = 1000 kg/m^3. The following information is given for the parameters shown on the figure: P_{atm} = 1.01 bar, L_1 = 1m, L_2 = 1.5 m, A = 1.0 m^2, and g = 9.81 m/s^2.

a) Evaluate the pressures at the top ($x = L_1$) and at the bottom ($x = L_2$) of the block, in kPa.
b) Determine the buoyancy force.



c) Draw a free body diagram at the bottom surface of the metal block showing all the forces acting Draw a free body diagram at the bottom surface of the metal block showing all the forces acting in the x direction (downward) and those in the opposite direction (upward), ignoring the cross-sectional area of the holding rod.
d) Calculate the force exerted by the holing rod, in Newton (N).
e) If the holing rod is removed, will the metal block move downward (in the x direction) or upward (opposite to x direction)? explain.

For the following parts, consider that the metal block mass is equal to 200 kg.

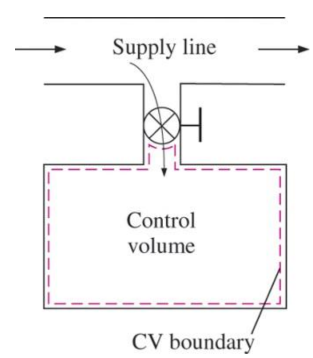
f) Recalculate the force exerted by the holing rod, in Newton (N).
g) Now, if the holing rod is removed, will the metal block move downward (in the x direction) or upward (opposite to x direction)? Explain.
h) If the metal block moves upward, draw a free-body diagram showing all the forces acting on the partially submerged metal block in water.

Before assigning this problem, it was checked if ChatGPT can solve this problem correctly. We found out that ChatGPT provided a very nicely formatted detailed solution to this problem. A copy of solution is included in the Appendix section.

Near the end of Fall 2025, the following problem was assigned as part of a survey questionnaire, in ME 3293. Students were asked to select AI software of their choice to solve the problem and to submit a copy of the solution generated by AI software.

Problem 4

A rigid**,** insulated tank of volume 5 m^3 is connected through a valve to a steam line through which superheated water vapor flows at 4 MPa and 500 °C. The tank initially contains water at 1 bar and a quality of x = 0.5. The valve is opened allowing steam to flow into the tank until the pressure inside the tank reaches 4 MPa.



a) Write down the most general form of **rate equations** for the conservation of mass, energy (first law), and second law for a control volume and simplify them for the control volume shown in the figure, ignoring the kinetic and potential energy effects.
b) Convert the rate equations written in part (a) into equations for a process taking place between the initial and the final states.
c) Evaluate the initial and the final mass of water inside the tank, in kg.
d) Determine the amount of mass entering the tank, in kg, the final temperature, and the entropy generation, in kJ/K for this process.

As part of the survey questionnaire, students were asked to identify the AI tool they used and to report the final temperature of the water in the tank. Fifteen (15) students reported using ChatGPT, seven (7) indicated Google Gemini, one student used Qwen-AI, one student used Copilot, one student used solutions generated by both ChatGPT and Google Gemini, and one student stated that they did not have access to an AI tool. The final temperatures reported by students ranged from 400 °C to 808.08 °C. We also used the free version of ChatGPT to obtain a solution to this problem. The ChatGPT solution provided correct numerical values for the initial and final masses in the tank; however, it indicated that obtaining a complete numerical solution could be quite involved without the use of computer software integrated with thermodynamic property data. Nevertheless, the solution offered an excellent step-by-step procedure for solving the problem. A copy of the ChatGPT solution is included in the Appendix.

A trial-and-error process was required to obtain accurate results for this problem. Using computer software integrated with thermodynamic property data, we obtained a final water temperature of 568.89 °C in the tank. Eight (8) out of 25 students reported final temperatures that closely approximate this value. Students were also asked whether they trusted the AI-generated solution. Four students indicated that they trusted the solution, while 22 students stated that they did not.

Near the end of Fall 2025 semester, the following problem was assigned as part of a survey questionnaire, in two sections of ME 4293, the second course in Thermodynamics. Students were asked to try using AI to solve the following problem and indicate the AI tool employed.

Problem 5

Air enters a compressor operating at steady state at 50°C, 0.9 bar, 70% relative humidity with a volumetric flow rate of 2 m^3/s. The moist air exits the compressor at 175°C, 1.5 bar.
Assuming the compressor is well insulated, determine:
(a) the relative humidity at the exit, in percent.
(b) the magnitude of the power input, in kW.
(c) the rate of entropy production, in kW/K.

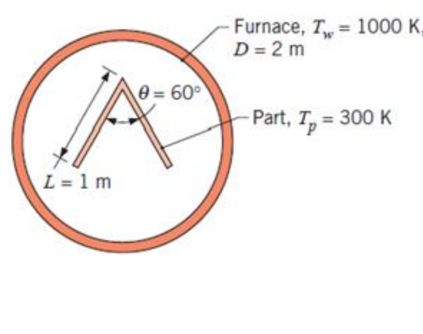
The problem was similar to a homework problem, and the correct answers are (a) 1.6%, (b) 249 kW, (c) 0.368 kW/K. A total of 76 students out of the total enrollment of 110 participated in the survey, but not all provided solutions to all three parts of the problem. For part (a) 68 students submitted numerical solutions in a range as low as 0.11% to as high as 38.0%, but most answers were around 1.6% to 1.7% so that 82% of the solutions were deemed correct. For part (b) 69 students submitted numerical solutions in a range as low as 54.7 kW to as high as 859.0 kW, with around 60% of the answers being sufficiently close to be deemed correct. For part (c) 69 students submitted numerical solutions in a range as low as 0.077 kW/K to as high as 243.0 kW/K, and about 65% were sufficiently close to the solution to be deemed correct.

Only 39 out of 76 survey participants identified the AI tools they used. Twenty-seven students used ChatGPT (about 70%), nine Gemini, one Grok, one Google lens and one Google AI.

Near the end of Fall 2025 semester, the following problem was assigned as part of a survey questionnaire, in ME 4313, Heat Transfer. Students were asked to try using AI to solve the following problem and identify the AI tool employed.

Problem 6

A long, V-shaped part is heat treated by suspending it in a tubular furnace with a diameter of 2 m and a wall temperature of 1000 K The “vee” is 1-m long on a side and has an angle of 60°. The wall of the furnace and the surfaces of the V part may be approximated as blackbodies and the part is at an initial temperature of 300 K. Calculate the net rate of radiation heat transfer per unit length to the part.



A total of 25 students out of a total enrollment of 51 students participated in the survey. One student stated the poor internet connection in the room prevented their use of AI. The solutions submitted ranged from 1.04 to 281 kW/m with many being around 110 kW/m. The correct answer is 169 kW/m. Fourteen students identified ChatGPT as the tool used (56%), five Gemini, one CoPilot, one Grok, one Google lens, and one Google AI. The survey questionnaire also asked the participants if they trusted the AI solution, with 3 students (12%) answering YES, 16 students (64%) answered NO, and 6 students (24%) indicated that they trusted the process and parts of the AI generated solution, but not necessarily the final result. None of the AI generated solutions submitted were within 10% of the correct answer for this problem.

As demonstrated by the examples presented in this paper, AI tools can be highly effective in helping students learn fundamental concepts and appropriate solution procedures for solving more complex engineering problems, provided they are used properly. Our experience indicates that many students too quickly give up when faced with more challenging problems. When we assign take-home work containing one or two relatively complex problems, we have observed that many students attempt only the easier problems and either ignore the more difficult ones or rely on AI-generated solutions. Since widespread availability and easy access to digital solution manuals, we have further observed that an increasing number of students spend more time searching for quick solutions to engineering problems rather than developing a deeper understanding of fundamental concepts and systematic problem-solving procedures.

Surveys

Parts of surveys conducted at the end of fall semester 2025 in ME 3293, ME 4293, and ME 4313 were devoted to students' use of AI tools in their engineering courses. Summaries of these survey results are presented in Tables 1 through 4. In these tables (SD), (D), (N), (A), and (SA) indicate that the respondents strongly disagree, disagree, is neutral, agree, and strongly agree with the statement, respectively.

Table 1 presents the survey results for ME 3293. Twenty-six students participated in this survey. When the total number in Table 1 is less than 26 in the table, it indicates that one or more students did not respond to the associated question.

Table 1. Students' response to survey questions related to the use of AI tools in ME 3293.

In your courses you have used Artificial Intelligence (AI) tools, like ChatGPT, Gemini, Copilot, Grok, etc.	SD	D	N	A	SA	Total
to write reports	12	4	8	2	0	26
to complete homework	6	4	6	9	0	25
to solve take-home-quiz or take-home exam problems	9	6	5	4	1	25
to understand concepts	1	0	0	11	13	25
to check spelling or grammar	4	3	4	9	6	26
Using an Artificial Intelligence (AI) tool is an effective way for students to solve more complex engineering problems.	2	6	6	5	7	26
A quick review of an AI generated solution to a complex engineering problem will enable you to solve a similar problem in an in-person-proctored exam situation	7	5	5	4	5	26

Based on the data in Table 1, more than 50% of students either strongly disagreed or disagreed with the statement that they had used an AI tool to write reports in their courses. More students agreed with the statement that they had used an AI tool to complete course homework assignments. Similarly, more than 50% of students either strongly disagreed or disagreed with the statement that they had used an AI tool to solve take-home quiz or take-home exam problems. In contrast, almost all students (24 out of 26 respondents) agreed that they have used an AI tool to better understand fundamental concepts in their courses. More than 50% of students also agreed that using AI tools is an effective way to solve more complex engineering problems. Surprisingly, 9 out of 26 students agreed with the statement that a quick review of an AI-generated solution to a complex engineering problem would enable them to solve a similar problem in an in-person, proctored exam setting.

Comparable questions were included in the surveys conducted in fall semester 2025 for ME 4293 and ME 4313 courses. Tables 2 and 3 provide summaries of these survey results. In ME 4293, 76 students participated in this survey and the results are presented in Table 2. When the total number in Table 2 is less than 76 in the table, it indicates that one or more students did not respond to the associated question.

Table 2. Students' response to survey questions related to the use of AI tools in ME 4293.

You have used Artificial Intelligence (AI) tools, like ChatGPT, Gemini, copilot, Grok, etc., to	SD	D	N	A	SA	Total
a) complete reports	14	12	20	20	10	76
b) complete homework	5	12	17	27	15	76
c) understand math/science concepts	2	1	3	21	49	76
d) understand engineering concepts	3	1	2	18	51	75
e) check grammar/spelling in reports	10	10	5	16	35	76
f) check homework solutions	5	6	8	37	20	76
g) check exam solutions	14	14	25	9	14	76

Table 2 results show that most students use AI to help understand math/science concepts and understand engineering concepts in engineering classes. This is encouraging to faculty who realize that students often do not fully comprehend the subtle details of challenging math/sci/engineering topics just from lecture. They need to engage with the material, often through reading the textbook and applying concepts to a variety of realistic situations (i.e., homework). When studying, students would seek help in study groups with peers, or supplemental textbooks or tutoring. With the advent of AI, students have another recourse to learn. Students comment that they ask AI questions which may seem "dumb," but AI is happy to rephrase and explain anew the concept that may be an obstacle for the individual student. Some students describe very interactive use of AI where they even ask AI to limit the length of response to not overwhelm the student who may be struggling to understand a particular assumption, approximation, or concept. Some comments that

AI can be like drinking from a fire hydrant, which pushes out gallons of information when only a sip is needed. Below are specific comments:

"I feel AI is a great tool to use and is improving a lot and really fast."
"I use AI to check my solutions for homework problems. It helps me catch mistakes."
"AI is like a study buddy who can explain each step. particularly good for learning."
"Great for late night tutoring"
"AI has been a huge help in learning this semester."

Twenty-five students participated in the ME 4313 survey and the results are presented in Table 3. When the total number in Table 3 is less than 25 in the table, it indicates that one or more students did not respond to the associated question.

The ME 4293 and ME 4313 surveys included additional questions related to the amount of time instructors should devote to teaching students how to use AI tools in their courses. The results of these surveys are presented in Tables 4 and 5. Again, 76 students participated in this part of the survey in ME 4293 during fall semester 2025 and the results are presented in Table 4. When the total number in Table 4 is less than 76 in the table, it indicates that one or more students did not respond to the associated question.

Table 3. Students' response to survey questions related to the use of AI tools in ME 4313.

You have used Artificial Intelligence (AI) tools, like ChatGPT, Gemini, copilot, Grok, etc., to	SD	D	N	A	SA	Total
a) complete reports	5	6	5	7	2	25
b) complete homework	5	3	4	9	4	25
c) understand math/science concepts	1	1	2	7	14	25
d) understand engineering concepts	1	1	2	7	14	25
e) check grammar/spelling in reports	2	2	6	7	8	25
f) check homework solutions	3	2	4	9	7	25
g) check exam solutions	7	7	9	1	1	25

Table 4. Students' response to survey questions related to lecture amount of lecture time to be used to teach how to use AI tools in ME 4293.

Amount of time engineering faculty should devote to teach how to use AI tools	SD	D	N	A	SA	Total
a) minimal lecture time	11	7	16	23	15	72
b) one lecture per semester	8	8	16	27	14	73
c) one week of lectures during the semester	20	24	17	8	3	72
d) more than one week of lectures per semester	32	17	14	2	5	70

Table 4 results can be interpreted that students believe some lecture time should be used to explain where AI is allowed and where prohibited. Student comments indicated they want to avoid being accused of academic dishonesty if they use AI. Many gave comments that AI is "worth mentioning but not excessively" discussing during lecture.

Twenty-five students participated in this part of the survey in ME 4313 during fall semester 2025 and the results are presented in Table 5.

When the total number in Table 4 is less than 25 in the table, it indicates that one or more students did not respond to the associated question.

Table 5. Students' response to survey questions related to lecture amount of lecture time to be used to teach how to use AI tools in ME 4313.

Amount of time engineering faculty should devote to teach how to use AI tools	a	b	c	d	Total
[a] less than one full lecture per semester; [b] one full lecture per semester; [c] one full week of lectures per semester [d] more than one full week of lectures per semester	11	7	16	23	72

The results from Table 5 from ME 4313 are consistent with results in Table 4 from ME 4293. Students seek clarity in the use as well as prohibited misuse of AI, so faculty should be clear at the beginning of the semester. In senior level courses, student comments appear more focused on using AI to "greatly improve efficiency and quality of learning" with many students acknowledging that AI can be used improperly to "stifle" learning.

Students' comments

Students were asked to briefly comment on the pros and cons of the use of AI in engineering education. Selected student comments are listed below.

A. Pros:

1. The main pro in this case will be it gives you equations and steps to the definitive answer.
2. Very good at helping me (with) the basic understanding of materials. Help me fix any issues I may have made when solving problems. Always available and I can ask any time. It does not have to be scheduled.
3. Makes understanding concepts easier; shows steps to get answers; may also show alternate way to get solution.
4. Able to build your own tutor for concepts, practice tests, and quizzes.
5. It is available 24/7 and allows for quick & customized concept clarification. It helps to organize thoughts, create study aids, and diagnose personal understanding. It removes the need to commute for personalized instruction. I recommend requiring the use of AI solution for at least one assignment. Require that one or two AI solutions (are) brought to class and demonstrate the difference between answers. It might immediately show the distrust in AI and demonstrate that you can easily recognize its work.
6. AI tool can help understand concepts and break down the lectures and book chapters into bite-size problems.
7. Explains in detail the concepts; generates problems to solve, creates study guides; tests you.
8. Can effectively summarize concepts if given proper sourcing. Can generate problems when given sources.
9. It can help students understand a concept. In a pinch students can check their HW answer.
10. Being able to get an understanding of how to walk through problems.
11. Using ChatGPT is nice to ask about certain parts of the process without the need to ask professor late at night. A nice way to double check your process.

12. People can ask questions to gain an understanding of what they need to solve for and for conceptual learning. I think it's good.

B. Cons:

1. The con is that when using tables, it throws random table values and messes up the final answer.
2. Letting students become dependent on a mindless thing. It doesn't know how to do everything correct(ly). So, it is wrong a large portion of time. It could go away at any given time, so we need to have our own working and solving skills.
3. Make students dependent. Allow students to shortcut through the course.
4. (One) Can become reliant and really lazy using them improperly.
5. It has far too few guiderails. It is too easy to be lazy in school and fail in the workforce.
6. AI can slow down a person's ability to understand and break down material, creating an unhealthy dependence.
7. Concepts can be wrong; many answers, way to(o) long to think.
8. Can easily make mistakes if problems are not properly stated. Possibly limits critical thinking by creating an over-reliance on a tool.
9. They can use to cheat on quiz/exams, as well as have AI to solve HW for them.
10. Often calculations can be incorrect and use incorrect/unreliable sources.
11. It is easy to say you completed the HW prob(lem) but didn't do anything. You are not learning if you let AI do it for you.
12. The people who take every answer at face value are not getting anything out of what is being asked to solve for. No self-repetition.

Summary

In the Fall 2025 semester, the authors taught two mechanical engineering thermodynamics courses with a total enrollment of approximately 150 students, in the same manner as they have been for more than 20 years, using a traditional assessment structure that included homework assignments, in-class quizzes, take-home assignments, midterm exams, a comprehensive final exam, and optional extra-credit opportunities.

The instructors have become increasingly aware that students routinely use artificial intelligence (AI) tools to complete out-of-class assignments. More recently, isolated incidents have revealed that some students have covertly brought mobile phones into exams and used AI tools to solve exam problems. Given the sophistication with which AI can now generate solutions to unique engineering problems, the authors believe that AI use is not limited to their courses but is also being widely used in prerequisite mathematics and science courses. As students increasingly rely on AI to generate solutions, they appear less capable of solving problems independently. Consequently, their mastery of foundational concepts in mathematics, science, and engineering is diminishing.

With the use of AI, submitted homework often appears to be of extremely high quality, featuring clear, step-by-step solutions, extensive commentary on intermediate processes, and well-articulated results. Comparisons between student submissions and AI-generated solutions reveal striking similarities. Because students do not have access to AI tools during exams, exam responses frequently expose fundamental weaknesses. Solutions are often incorrect or incomplete and frequently lack mature reflection on the physical meaning or significance of the calculated results. In thermodynamics, common errors include applying closed-system energy balances to open systems, using the ideal gas equation of state for two-phase liquid–vapor mixtures, and applying isentropic relations to processes with significant irreversibility.

It is now widely accepted that AI is a permanent presence in society and in engineering practice, and that engineering educators must acknowledge this reality. However, the path forward in engineering education remains unclear. The fundamental goals of engineering education—developing student knowledge, problem-solving ability, and communication skills—have not changed with the advent of AI. Students must still be able to think critically, analyze problems, and communicate effectively without reliance on AI. Assessing these capabilities has become significantly more challenging in an era of ubiquitous AI access. Any out-of-class work is inherently suspected, and even when the use of AI is explicitly prohibited, students recognize that proving AI-generated work is extremely difficult, so some students use it anyway.

In an ideal educational environment, students would use AI as a tutoring or learning aid to accelerate understanding and deepen conceptual mastery. However, this does not appear to be the reality for some students, who instead use AI as a shortcut that bypasses meaningful learning. Addressing this disconnect represents one of the most pressing challenges facing engineering educators today.

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Appendix
ChatGPT generated solutions

Problem 1.

The Gibbs Free Energy of a system is given by:

$$G = cNRT - TNS_0 - NRT\left[\ln\left(\left(\frac{T}{T_0}\right)^c\left(\frac{P_0}{P}\right)\left(\frac{N_0}{N}\right)\right)\right] + NRT$$

Where *c, R,* S_0, T_0, P_0, N_0 are constants or reference state variables.

c) Find an equation of state in the Gibbs representation (i.e., find *V (P, T, N)*)
d) Find internal energy *U*.

<u>ChatGPT Solution</u>

We are given the Gibbs free energy G as a function of T, P, N, with constants c, R, S_0, T_0, P_0, N_0:

$$G = cNRT - TNS_0 - NRT\left[\ln\left(\left(\frac{T}{T_0}\right)^c\left(\frac{P_0}{P}\right)\left(\frac{N_0}{N}\right)\right)\right] + NRT$$

Let's simplify this expression first.

Step 1: Simplify G

Use logarithmic identities:

$$\ln\left(\left(\frac{T}{T_0}\right)^c\left(\frac{P_0}{P}\right)\left(\frac{N_0}{N}\right)\right) = c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)$$

So:

$$G = cNRT - TNS_0 - NRT\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right] + NRT$$

Combine terms:

$$G = NRT(c+1) - TNS_0 - NRT\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Step 2: Find the Equation of State (Volume $V(P, T, N)$)

From thermodynamics:

$$V = \left(\frac{\partial G}{\partial P} \right)_{T,N}$$

Take the partial derivative of G with respect to P, keeping T and N constant:

Only the logarithmic term contains P, specifically:

$$-NRT \ln \left(\frac{P_0}{P} \right) = NRT \ln(P) + \text{const}$$

So:

$$\frac{\partial G}{\partial P} = \frac{d}{dP} \left(-NRT \ln \left(\frac{P_0}{P} \right) \right) = \frac{d}{dP}(NRT \ln P) = \frac{NRT}{P}$$

Therefore, the **equation of state** is:

$$\boxed{V = \frac{NRT}{P}}$$

Step 3: Find Internal Energy U

From thermodynamic identities:

$$U = G + TS - PV$$

We already have G, and from thermodynamics:

$$S = -\left(\frac{\partial G}{\partial T} \right)_{P,N}$$

Let's calculate S:

Go back to the expression for G:

$$G = NRT(c+1) - TNS_0 - NRT \left[c \ln \left(\frac{T}{T_0} \right) + \ln \left(\frac{P_0}{P} \right) + \ln \left(\frac{N_0}{N} \right) \right]$$

Now take the derivative of G with respect to T:

$$\frac{\partial G}{\partial T} = NR(c+1) - NS_0 - NR \left[c \ln \left(\frac{T}{T_0} \right) + \ln \left(\frac{P_0}{P} \right) + \ln \left(\frac{N_0}{N} \right) \right] - NRT \cdot \frac{c}{T}$$

Simplify:

$$\frac{\partial G}{\partial T} = NR(c+1) - NS_0 - NR\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right] - NRc$$

$$= NR(1) - NS_0 - NR\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Thus:

$$S = -\frac{\partial G}{\partial T} = NS_0 - NR - NR\left[-c\ln\left(\frac{T}{T_0}\right) - \ln\left(\frac{P_0}{P}\right) - \ln\left(\frac{N_0}{N}\right)\right]$$

$$S = NS_0 - NR + NR\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Now compute:

$$U = G + TS - PV$$

We already have:

- G (from above),
- S (just computed),
- $V = \frac{NRT}{P} \Rightarrow PV = NRT$

So:

$$U = G + TS - NRT$$

Now compute $G + TS$ using the simplified forms:

Recall:

$$G = NRT(c+1) - TNS_0 - NRT\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Multiply T by S:

$$TS = T\left[NS_0 - NR + NR\left(c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right)\right]$$

So:

$$TS = TNS_0 - NRT + NRT\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Now add $G + TS$:

$$U = G + TS - NRT = NRT(c+1) - NRT = \boxed{U = NRTc}$$

So:

$$U = G + TS - NRT$$

Now compute $G + TS$ using the simplified forms:

Recall:

$$G = NRT(c+1) - TNS_0 - NRT\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Multiply T by S:

$$TS = T\left[NS_0 - NR + NR\left(c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right)\right]$$

So:

$$TS = TNS_0 - NRT + NRT\left[c\ln\left(\frac{T}{T_0}\right) + \ln\left(\frac{P_0}{P}\right) + \ln\left(\frac{N_0}{N}\right)\right]$$

Now add $G + TS$:

$$U = G + TS - NRT = NRT(c+1) - NRT = \boxed{U = NRTc}$$

Final Answers

- **Equation of state** (Gibbs representation):

$$\boxed{V = \frac{NRT}{P}}$$

- **Internal energy**:

$$\boxed{U = NRTc}$$

Problem 2

The local Nu numbers for laminar and turbulent flow over a flat plate are given by equations $Nu_x = 0.332\ Re_x^{1/3}\ Pr^{½}$ and $Nu_x = 0.032\ Re_x^{0.8}\ Pr^{0.43}$, respectively. Assuming that transition from laminar flow to turbulent flow occurs at $Re_{trans} = 50{,}000$. Derive a relationship for an average $\overline{Nu_L}$ for a flow over a flat plate of a length L, where the flow is turbulent at x = L.

ChatGPT solution

We're given **local** Nusselt number correlations for flow over a flat plate:

- **Laminar:**

$$Nu_x = 0.332\, Re_x^{1/3} Pr^{1/4}$$

- **Turbulent:**

$$Nu_x = 0.032\, Re_x^{0.8} Pr^{0.43}$$

Transition occurs at

$$Re_{x,\text{trans}} = 5 \times 10^4$$

We want the **average Nusselt number over the plate length** L, $\overline{Nu}_L$, assuming the flow **is turbulent at** $x = L$.

Step 1: Definition of average Nusselt number

$$\overline{Nu}_L = \frac{1}{L} \int_0^L Nu_x \, dx$$

Because of transition, split the plate:

$$\overline{Nu}_L = \frac{1}{L} \left[\int_0^{x_{tr}} Nu_{x,\ell} \, dx + \int_{x_{tr}}^{L} Nu_{x,t} \, dx \right]$$

where

$$Re_x = \frac{U_\infty x}{\nu}, \qquad x_{tr} = \frac{Re_{tr}\, \nu}{U_\infty}$$

Step 2: Laminar contribution

✦ Get Plus ×

$$Nu_{x,\ell} = 0.332\, Pr^{1/4} \left(\frac{U_\infty x}{\nu}\right)^{1/3}$$

$$\int_0^{x_{tr}} Nu_{x,\ell} dx = 0.332\, Pr^{1/4} \left(\frac{U_\infty}{\nu}\right)^{1/3} \int_0^{x_{tr}} x^{1/3} dx$$

$$= 0.332\, Pr^{1/4} \left(\frac{U_\infty}{\nu}\right)^{1/3} \left(\frac{3}{4} x_{tr}^{4/3}\right)$$

Substitute x_{tr}:

$$= 0.249\, Pr^{1/4} Re_{tr}^{4/3}$$

Step 3: Turbulent contribution

$$Nu_{x,t} = 0.032\, Pr^{0.43} \left(\frac{U_\infty x}{\nu}\right)^{0.8}$$

$$\int_{x_{tr}}^{L} Nu_{x,t} dx = 0.032\, Pr^{0.43} \left(\frac{U_\infty}{\nu}\right)^{0.8} \int_{x_{tr}}^{L} x^{0.8} dx$$

$$= 0.032\, Pr^{0.43} \left(\frac{U_\infty}{\nu}\right)^{0.8} \left[\frac{L^{1.8} - x_{tr}^{1.8}}{1.8}\right]$$

$$= 0.0178\, Pr^{0.43} \left(Re_L^{0.8} - Re_{tr}^{0.8}\right) L$$

Step 4: Average Nusselt number

Divide by L:

$$\boxed{\overline{Nu}_L = 0.0178\, Re_L^{0.8} Pr^{0.43} - 0.0178\, Re_{tr}^{0.8} Pr^{0.43} + 0.249\, Re_{tr}^{4/3} Pr^{1/4}}$$

Step 5: Final form (compact)

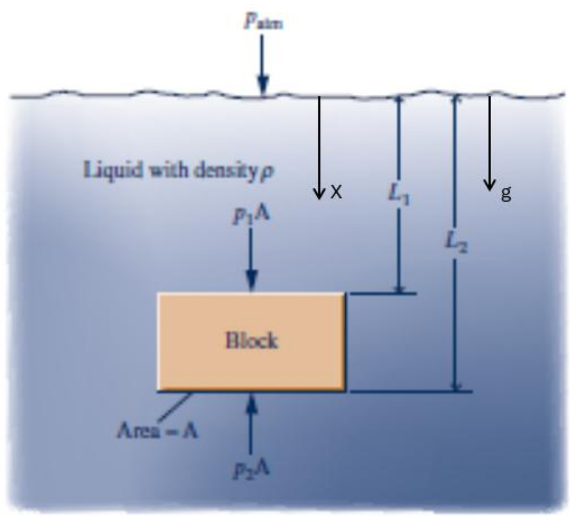
Using $Re_{tr} = 5 \times 10^4$:

$$\boxed{\overline{Nu}_L = 0.0178\, Re_L^{0.8} Pr^{0.43} + \left[0.249\, Re_{tr}^{4/3} Pr^{1/4} - 0.0178\, Re_{tr}^{0.8} Pr^{0.43}\right]}$$

This is the average Nusselt number for a flat plate w **laminar–turbulent transition**, valid when the flow is turbulent at $x = L$.

Problem 3

Consider a rectangular metal block shown in the diagram, having a mass of 600 kg is anchored to the bottom of a pool by a solid rod (not shown on the diagram), holing the metal block in place. The water in the pool has a density ρ = 1000 kg/m^3. The following information is given for the parameters shown on the figure: P_{atm} = 1.01 bar, L_1 = 1m, L_2 = 1.5 m, A = 1.0 m^2, and g = 9.81 m/s^2.



a) Evaluate the pressures at the top (x = L_1) and at the bottom (x = L_2) of the block, in kPa.
b) Determine the buoyancy force.
c) Draw a free body diagram at the bottom surface of the metal block showing all the forces acting Draw a free body diagram at the bottom surface of the metal block showing all the forces acting in the x direction (downward) and those in the opposite direction (upward), ignoring the cross-sectional area of the holding rod.
d) Calculate the force exerted by the holing rod, in Newton (N).
e) If the holing rod is removed, will the metal block move downward (in the x direction) or upward (opposite to x direction)? explain.

For the following parts, consider that the metal block mass is equal to 200 kg.

f) Recalculate the force exerted by the holing rod, in Newton (N).
g) Now, if the holing rod is removed, will the metal block move downward (in the x direction) or upward (opposite to x direction)? Explain.
h) If the metal block moves upward, draw a free-body diagram showing all the forces acting on the partially submerged metal block in water.

ChatGPT solution

Great — let's solve it step by step. I'll use the given data:

- $m = 600$ kg (parts a–e)
- $\rho_{\text{water}} = 1000\ \text{kg/m}^3$
- $P_{\text{atm}} = 1.01\ \text{bar} = 1.01 \times 10^5\ \text{Pa}$
- $L_1 = 1.0\ \text{m}$ (depth to top of block)
- $L_2 = 1.5\ \text{m}$ (depth to bottom of block)
- $A = 1.0\ \text{m}^2$ (horizontal area)
- $g = 9.81\ \text{m/s}^2$

Block height $H = L_2 - L_1 = 0.5\ \text{m}$. Block volume $V = A \cdot H = 1.0 \cdot 0.5 = 0.5\ \text{m}^3$.

a) Pressures at top ($x = L_1$) and bottom ($x = L_2$) of the block (kPa)

Hydrostatic pressure at depth h:

$$p = P_{\text{atm}} + \rho g h.$$

- Top ($h = L_1 = 1.0$ m):

$$p_{\text{top}} = 1.01 \times 10^5 + 1000(9.81)(1.0) = 101000 + 9810 = 110810 \text{ Pa} = 110.81 \text{ kPa}.$$

- Bottom ($h = L_2 = 1.5$ m):

$$p_{\text{bot}} = 101000 + 1000(9.81)(1.5) = 101000 + 14715 = 115715 \text{ Pa} = 115.72 \text{ kPa}.$$

(You can round to e.g. 111.0 kPa and 115.7 kPa if desired.)

b) Buoyant force F_B

Buoyant force = weight of displaced fluid $= \rho g V$:

$$F_B = 1000 \cdot 9.81 \cdot 0.5 = 4905 \text{ N} \ (\approx 4.905 \text{ kN}).$$

(Also note $F_B = A(p_{\text{bot}} - p_{\text{top}}) = 1.0(115715 - 110810) = 4905 \text{ N}$.)

---

c) Free-body forces (vertical/downward = +x direction as stated)

Consider all vertical forces on the block (ignore the rod cross-sectional area effect on pressures):

- Downward forces:
  - Weight $W = mg = 600 \cdot 9.81 = 5886 \text{ N}$ (downward)
  - Hydrostatic pressure on the top surface: $p_{\text{top}} A = 110810 \text{ Pa} \cdot 1.0 \text{ m}^2 = 110810 \text{ N}$ (downward)
  - If the holding rod acts, it exerts a downward force F_{rod} on the block (unknown sign/magnitude until equilibrium used).
- Upward forces:
  - Hydrostatic pressure on the bottom surface: $p_{\text{bot}} A = 115715 \text{ N}$ (upward).

(Vertical side pressure components cancel pairwise, so only top and bottom pressures contribute.)

Equilibrium equation (up positive):

$$p_{\text{bot}} A - \left(p_{\text{top}} A + W + F_{\text{rod}}\right) = 0.$$

Or rearranged for the rod:

$$F_{\text{rod}} = p_{\text{bot}} A - p_{\text{top}} A - W = F_B - W.$$

b) Buoyant force F_B

Buoyant force = weight of displaced fluid $= \rho g V$:

$$F_B = 1000 \cdot 9.81 \cdot 0.5 = 4905 \text{ N} \ (\approx 4.905 \text{ kN}).$$

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  - Hydrostatic pressure on the top surface: $p_{\text{top}} A = 110810 \text{ Pa} \cdot 1.0 \text{ m}^2 = 110810 \text{ N}$ (downward)
  - If the holding rod acts, it exerts a downward force F_{rod} on the block (unknown sign/magnitude until equilibrium used).
- Upward forces:
  - Hydrostatic pressure on the bottom surface: $p_{\text{bot}} A = 115715 \text{ N}$ (upward).

(Vertical side pressure components cancel pairwise, so only top and bottom pressures contribute.)

Equilibrium equation (up positive):

$$p_{\text{bot}} A - \left(p_{\text{top}} A + W + F_{\text{rod}}\right) = 0.$$

Or rearranged for the rod:

$$F_{\text{rod}} = p_{\text{bot}} A - p_{\text{top}} A - W = F_B - W.$$

d) Force exerted by the holding rod (N) — for $m = 600$ kg

We have $W = 5886 \text{ N}$, $F_B = 4905 \text{ N}$. Thus

$$F_{\text{rod}} = F_B - W = 4905 - 5886 = -981 \text{ N}.$$

The negative sign indicates the rod must apply a **downward** force of magnitude **981 N** on the block to hold it in place. (Equivalently: the rod must pull the block down with 981 N.)

---

e) If the holding rod is removed, will the block move downward or upward?

Since $W = 5886 \text{ N} > F_B = 4905 \text{ N}$, the net force is downward. Therefore **the block will move downward** (sink) if the rod is removed.

Now the second part: block mass = **200 kg** (all else same).

f) Recalculate the force exerted by the holding rod (N) — for $m = 200$ kg

- Weight $W = 200 \cdot 9.81 = 1962 \text{ N}$.
- Buoyancy unchanged: $F_B = 4905 \text{ N}$.

Rod force:

$$F_{\text{rod}} = F_B - W = 4905 - 1962 = 2943 \text{ N}.$$

Positive here means the rod must apply an **upward** net force to satisfy the sign convention used earlier? (Careful with sign convention:) From earlier derivation $F_{\text{rod}} = p_{\text{bot}}A - p_{\text{top}}A - W = F_B - W$. If $F_B > W$, this expression is positive, so in that equation it would be a positive upward contribution balancing downward forces — but physically the rod must **pull down** on the block to keep it submerged. To avoid confusion: the magnitude of the force the rod must a[illegible]y **downward** on the block is 2943 N (i.e., the rod must hold the block down with 2943 N).

(Equivalent statement: the net upward unbalanced buoyancy is 2943 N, so the rod must supply 2943 N downward to hold equilibrium.)

---

g) If the rod is removed (for $m = 200$ kg), will the block move downward or upward?

Because $F_B = 4905 \text{ N} > W = 1962 \text{ N}$, net upward force → **the block will move upward** (float up).

---

h) If the metal block moves upward and floats, what height of the block remains in the water? (for $m = 200$ kg)

At floating equilibrium, buoyancy = weight:

$$\rho g V_{\text{sub}} = W \quad \Rightarrow \quad V_{\text{sub}} = \frac{W}{\rho g} = \frac{m}{\rho}.$$

So

$$V_{\text{sub}} = \frac{200}{1000} = 0.2 \text{ m}^3.$$

With cross-sectional area $A = 1.0 \text{ m}^2$, submerged depth

$$h_{\text{sub}} = \frac{V_{\text{sub}}}{A} = 0.2 \text{ m}.$$

So **0.20 m of the block's height remains submerged** (out of the 0.5 m block height).

(Equivalent statement: the net upward unbalanced buoyancy is 2943 N, so the rod must supply 2943 N downward to hold equilibrium.)

---

g) If the rod is removed (for $m = 200$ kg), will the block move downward or upward?

Because $F_B = 4905 \text{ N} > W = 1962 \text{ N}$, net upward force → **the block will move upward** (float up).

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h) If the metal block moves upward and floats, what height of the block remains in the water? (for $m = 200$ kg)

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So

$$V_{\text{sub}} = \frac{200}{1000} = 0.2 \text{ m}^3.$$

With cross-sectional area $A = 1.0 \text{ m}^2$, submerged depth

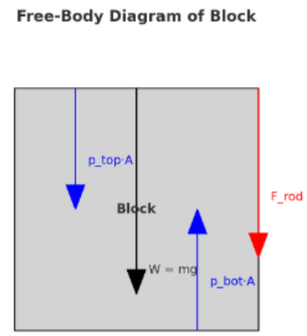
$$h_{\text{sub}} = \frac{V_{\text{sub}}}{A} = 0.2 \text{ m}.$$

So **0.20 m of the block's height remains submerged** (out of the 0.5 m block height).

Summary (numeric)

- $p_{\text{top}} = 110.81 \text{ kPa}.$
- $p_{\text{bot}} = 115.72 \text{ kPa}.$
- Buoyancy $F_B = 4905 \text{ N}.$
- For $m = 600 \text{ kg}$: weight $= 5886 \text{ N}$, rod must hold **981 N downward**, block sinks if rod removed.
- For $m = 200 \text{ kg}$: weight $= 1962 \text{ N}$, rod must hold **2943 N downward**, block rises if rod removed; submerged depth at float = **0.20 m.**

If you want, I can draw a tidy labeled free-body diagram (PNG/SVG) showing pressures, forces and signs.

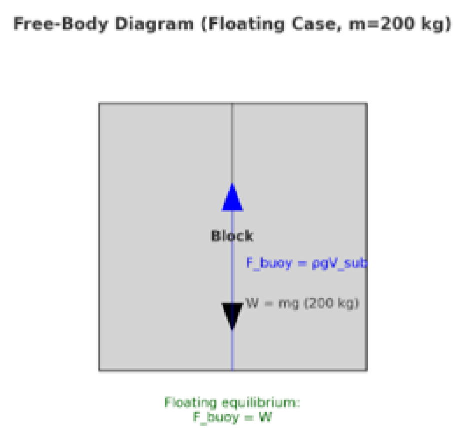


Here's the **free-body diagram** of the block in water:

- **Downward forces:**
  - $W = mg$ (black) — the block's weight
  - $p_{\text{top}}A$ (blue) — hydrostatic pressure on the top surface
  - F_{rod} (red) — force applied by the holding rod (downward when needed)
- **Upward force:**
  - $p_{\text{bot}}A$ (blue) — hydrostatic pressure on the bottom surface

This balance of forces yields the buoyancy relation and shows when the rod must pull down to hold the block.

Do you want me to also make a second diagram for the **floating case** (when $m = 200$ kg and the rod is removed)?



Here's the **free-body diagram for the floating case** ($m = 200$ kg):

- **Downward force:**
  - Weight $W = mg = 200g$
- **Upward force:**
  - Buoyant force $F_{\text{buoy}} = \rho g V_{\text{sub}}$

At equilibrium while floating:

$$F_{\text{buoy}} = W$$

This balance determines the **submerged volume** and explains why only 0.20 m of the block's height remains underwater.

Would you like me to also sketch the block **partially submerged in water** (showing the 0.20 m submerged depth out of 0.50 m total)?

It seems like I can't do more advanced data analysis right now. Please try again later.

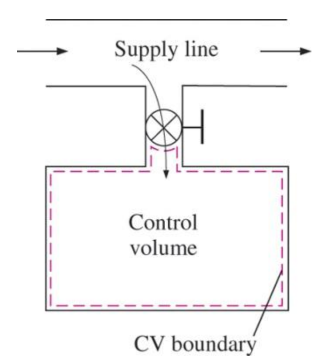
But I can describe exactly how the diagram would look so you can easily sketch it yourself:

- Draw a **rectangular block** of height **0.50 m**.
- Mark a **horizontal waterline** cutting the block at **0.20 m** from the bottom (so 0.30 m is above water).
- Shade the submerged portion (the lower 0.20 m) lightly in blue to indicate it's underwater.
- Label:
  - "0.20 m submerged" (lower section)
  - "0.30 m above water" (upper section)
- Add force arrows:
  - **Downward arrow from the block's center** labeled $W = 200g$.
  - **Upward arrow from the submerged portion's centroid** labeled $F_{\text{buoy}} = \rho g V_{\text{sub}}$.
- Note that the two forces are equal in magnitude (floating equilibrium).

Would you like me to make a **clean hand-drawn-style sketch** (using simple shapes/lines) instead of a plotted diagram?

Problem 4

A rigid**,** insulated tank of volume 5 m^3 is connected through a valve to a steam line through which superheated water vapor flows at 4 MPa and 500 ºC. The tank initially contains water at 1 bar and a quality of x = 0.5. The valve is opened allowing steam to flow into the tank until the pressure inside the tank reaches 4 MPa.



a) Write down the most general form of **rate equations** for the conservation of mass, energy (first law), and second law for a control volume and simplify them for the control volume shown in the figure, ignoring the kinetic and potential energy effects.
b) Convert the rate equations written in part (a) into equations for a process taking place between the initial and the final states.
c) Evaluate the initial and the final mass of water inside the tank, in kg.
d) Determine the amount of mass entering the tank, in kg, the final temperature, and the entropy generation, in kJ/K for this process.

ChatGPT solution

Good problem. I'll walk you through how to solve it (with reasonable assumptions) — a)–d) — step by step. You'll need to use steam tables for water/steam; I show the main steps, the equations, and numerical estimates. (Because the final state requires iteration, the numerical answer is approximate.)

---

a) General and simplified governing equations for the control volume

Let's define a control volume (CV) = the rigid, insulated tank + the fluid inside, plus mass inflow from the steam line.

Mass balance

General (rate) form:

$$\frac{dm_{CV}}{dt} = \dot{m}_{in} - \dot{m}_{out} .$$

Simplified: no outflow, so

$$\frac{dm}{dt} = \dot{m}_{in}.$$

Energy (First law)

General form (neglecting kinetic and potential energies):

$$\frac{dE_{CV}}{dt} = \dot{m}_{in}h_{in} - \dot{Q} - \dot{W}_{shaft} + \dot{m}_{in}\left(\frac{V_{in}^2}{2}\right) + \dots$$

But here: rigid, insulated → no heat transfer ($\dot{Q} = 0$); no shaft work; and we ignore kinetic/potential changes. So:

$$\frac{dU}{dt} = \dot{m}_{in} h_{in},$$

where U is internal energy of the fluid in the tank, and h_{in} is the specific enthalpy of the incoming steam.

Second law (entropy balance)

General form:

$$\frac{dS_{CV}}{dt} = \dot{m}_{in}s_{in} + \dot{S}_{gen},$$

since no heat transfer across the boundary and no mass leaving.

So simplified:

$$\frac{dS}{dt} = \dot{m}_{in}s_{in} + \dot{S}_{gen}, \quad \dot{S}_{gen} \geq 0.$$

b) Integral (process) equations from initial to final state

Integrate from initial state (subscript 1) to final state (subscript 2):

- Mass:

$$m_2 = m_1 + m_{in}.$$

- Energy:

$$U_2 = U_1 + m_{in} h_{in}.$$

- Entropy:

$$S_2 = S_1 + m_{in} s_{in} + S_{gen} \quad \Longrightarrow \quad S_{gen} = S_2 - S_1 - m_{in} s_{in}.$$

Also, because the tank is rigid:

$$v_2 = \frac{V}{m_2} \quad \text{(specific volume in final state)}.$$

Then you use thermodynamic property relations (tables) at final pressure p_2 = 4 MPa to find the corresponding internal energy u_2, specific entropy s_2, and temperature T_2 consistent with that v_2.

c) Initial mass in the tank

- Volume $V = 5 \text{ m}^3$.
- Initial state: pressure 1 bar, quality $x = 0.5$.

From saturated-water tables at 1 bar:

- $v_f \approx 0.001043 \text{ m}^3/\text{kg}$,
- $v_g \approx 1.694 \text{ m}^3/\text{kg}$.

So the specific volume of the mixture:

$$v_1 = v_f + x(v_g - v_f) \approx 0.001043 + 0.5(1.694 - 0.001043) \approx 0.8475 \text{ m}^3/\text{kg}.$$

Thus the mass initially present:

$$m_1 = \frac{V}{v_1} = \frac{5}{0.8475} \approx 5.90 \text{ kg}.$$

So **initial mass ≈ 5.9 kg**.

(This is small because the mixture is mostly vapor and vapor has large specific volume.)

d) Mass entering, final temperature, and entropy generation — approximate numerical evaluation

We next proceed to compute how much mass enters, final state, etc.

Step 1: Properties of incoming steam

The steam line supplies superheated steam at 4 MPa and 500 °C. From steam-tables for superheated steam at that condition (pressure 4 MPa, 500 °C):

- $h_{in} \approx 3446.0 \text{ kJ/kg}$ (specific enthalpy) Ohio Personal W...
- $u_{in} \approx 3100.3 \text{ kJ/kg}$ (specific internal energy) Ohio Personal W...
- $s_{in} \approx 7.092 \text{ kJ/(kg}\cdot\text{K)}$ Ohio Personal W...

We will use h_{in} in the energy balance, and s_{in} in the entropy balance.

Step 2: Energy balance → relation for m_{in} and u_2

Let m_{in} = mass of steam entering. Then

$$U_2 = U_1 + m_{in}h_{in} \quad \Longrightarrow \quad (m_1 + m_{in})\, u_2 = m_1\, u_1 + m_{in}\, h_{in}\,.$$

We estimated before: $m_1 \approx 5.90 \text{ kg}$; $u_1 \approx 1463 \text{ kJ/kg}$ (from rough saturated-mixture estimate). Thus $U_1 \approx 5.90 * 1463 \approx 8\,627 \text{ kJ}$.

So

$$(5.90 + m_{in})\, u_2 = 8\,627 + 3446\, m_{in}. \qquad (1)$$

But we don't yet know u_2 — it depends on the final specific volume $v_2 = \dfrac{5}{5.90 + m_{in}}$ and pressure 4 MPa via compressed-liquid or two-phase properties.

Step 3: Approximate final state and solve

Because the tank is rigid and the final mass might be large, we expect v_2 to be relatively small → the contents will probably be compressed (subcooled) water (liquid), or possibly saturated liquid/vapor mixture — but likely mostly liquid, since water is being condensed as steam enters, giving up latent heat to cool down.

A common simplifying approach in such problems: assume the final state is **compressed liquid** at 4 MPa, and approximate its internal energy u_2 ≈ the internal energy of saturated liquid at 4 MPa (or just slightly above).

From saturated-water tables (or compressed-liquid tables) for 4 MPa, saturated liquid internal energy u_f is roughly on the order of ~1000–1200 kJ/kg. (Exact u_f depends on saturation temperature ~250 °C.) For instance, at 250 °C (saturation at ~4 MPa), some sources give $u_f \approx 1085 \text{ kJ/kg}$ Gauth +1 .

So let's **approximate** $u_2 \approx 1085 \text{ kJ/kg}$.

Then from (1):

$$(5.90 + m_{in}) \cdot 1085 = 8627 + 3446\, m_{in} \;\Rightarrow\; 1085\cdot 5.90 + 1085\, m_{in} = 8627 + 3446\, m_{in}$$

Compute left side constant: 1085 × 5.90 ≈ 6,402. So

$$6,402 + 1085\, m_{in} = 8,627 + 3446\, m_{in} \;\Rightarrow\; 6,402 - 8,627 = (3446 - 1085)m_{in} \;\Rightarrow\; -2,225 = 2361\, m_{in} \;\Rightarrow\; m_{in} \approx -0.94 \text{ kg}.$$

We get a **negative** m_{in}! That is impossible. The negative result means that our assumption $u_2 = 1085 \text{ kJ/kg}$ (saturated-liquid internal energy) is inconsistent with the energy balance — in reality, the tank cannot end up as cold saturated liquid at that internal energy, because adding high-enthalpy steam would deposit more energy than that, so the final internal energy must be much higher than saturated-liquid values.

Hence the final state must have **much higher** internal energy — likely a mixture (liquid + vapor) or even a compressed mixture, or a **saturated mixture** at 4 MPa, with internal energy somewhere between u_f and u_g. So the correct approach is to iterate:

- pick a trial m_{in},
- compute m_2, then v_2, then from tables at 4 MPa find the corresponding u_2,
- check if (1) is satisfied; adjust m_{in} until convergence.

Step 4: Example of iterative (approximate) solution

Because a full accurate iteration requires detailed compressed-liquid / saturated-mixture tables at 4 MPa, I'll outline how you would do it in principle — plus give a rough estimate based on typical textbook behavior.

1. Guess a final mass m_2, compute $v_2 = 5/m_2$.
2. At $p_2 = 4 \text{ MPa}$, check steam tables for what phase corresponds to that v_2: saturated mixture, compressed liquid, etc. Determine the corresponding internal energy u_2.
3. Plug into energy balance to see if the mass guessed is consistent.
4. Adjust m_2 (or m_{in}) until energy balance holds.

In many standard problems of this kind, the final result is often that **almost all the liquid in the tank remains liquid** (since steam condenses), so the final state is compressed (subcooled) or saturated liquid + a tiny amount of vapor, and the final mass ends up quite la (hundreds or thousands of kg). That matches that v_2 becomes close to the liquid specific volume (~0.001 m³/kg), so $m_2 \approx 5/0.001 = 5,000 \text{ kg}$.

Let's test roughly: if $m_2 \approx 5,000 \text{ kg}$, then $m_{in} \approx 4994 \text{ kg}$. Energy required to condense that much steam: $m_{in} h_{in} \approx 4994 \times 3446 \approx 1.72 \times 10^7 \text{ kJ}$. The resulting internal energy $U_2 \approx 1.72e7 + initial \approx 1.72e7\ kJ$, so average $u_2 \approx U_2/m_2 \approx 3430 \text{ kJ/kg}$. But that is extremely high — comparable to superheated internal energies. That would imply final temperature very high or a mostly vapor state, which contradicts our assumption that final is liquid. So that guess is inconsistent.

In short — **without a computer or detailed table lookup for compressed-liquid and mixture states at 4 MPa**, giving a precise numerical answer is quite involved. That is why many textbook problems pick data so that the answer is a saturated mixture at 4 MPa, or else they supply extra information (e.g. final quality or temperature) to close the problem.

Hence I cannot reliably produce a *quantitatively* accurate final mass, final temperature, and entropy generation with only coarse tables — the problem is under-determined unless you iterate with full property data.

Nevertheless, the **correct method** is as described; if you want, I can **set up a small spreadsheet (with approximate steam-table data)** and iterate to give a *reasonable numerical answer* — accuracy perhaps to 5–10%.

Why this problem is tricky / what you must watch out for

- Because the tank is rigid and insulated, the final state is determined by mass and energy balances — but there is no guarantee whether the final fluid is liquid, mixture, or vapor; you must check with property tables.
- Assuming compressed liquid (or saturated-liquid) may lead to contradiction (as we saw) if the actual energy in the tank is too high.
- Realistically, much of the incoming steam will condense and release latent heat; but that heat must go somewhere — here it remains in the tank, so fluid ends up at a high internal energy, possibly saturated mixture or supercritical fluid (though 4 MPa < critical pressure).
- Hence an iterative calculation (or use of software / detailed steam tables) is essential for a proper answer.

Conclusion — what you should deliver formally (in exam style)

- **(a)** Mass, energy, entropy rate equations for CV; simplified to $\frac{dm}{dt} = \dot{m}_{in}$, $\frac{dU}{dt} = \dot{m}_{in}h_{in}$, $\frac{dS}{dt} = \dot{m}_{in}s_{in} + \dot{S}_{gen}$.
- **(b)** Integrated (process) form: $m_2 = m_1 + m_{in}$; $U_2 = U_1 + m_{in}h_{in}$; $S_2 = S_1 + m_{in}s_{in} + S_{gen}$. And the rigid-volume relation $v_2 = V/m_2$.
- **(c)** Initial mass ≈ 5.90 kg.
- **(d)** Outline of final-state calculation, with data for incoming steam; and explanation that precise final mass/temperature/entropy generation requires iteration with full steam-tables.

If you like — I can **perform that iteration numerically** (in a spreadsheet-style manner) using publicly available water/steam tables, and give you **a candidate final solution** (with mass entering, final temperature entropy generation) — that way you'll have a "complete answer."
Do you want me to do that now?