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Heating Water, Igniting Minds: A Challenge-Based Approach to Entrepreneurial-Minded Learning in Chemical Engineering Thermodynamics

Dr. Daniela Mainardi, Louisiana Tech University

Daniela Mainardi is the Associate Dean for Graduate Studies in the College of Engineering and Science (COES), and the Thomas C. & Nelda Jeffery Professor of Chemical Engineering at Louisiana Tech University (LATech). Mainardi joined LATech in 2003 and has specialized in multi-scale modeling of kinetics and thermodynamics processes at the nano-scale. She has experience in multi-scale simulation tools and has conducted research on different nanotechnology-related topics with applications to catalysis and electro-catalysis. Mainardi has received funding from federal agencies resulting in over US$ 50 million total. She was awarded the prestigious NSF-CAREER award in 2005, and she is currently a Co-Principal Investigator of the largest (up to US$160 million for 10 years) NSF-funded "FUEL: Future Use of Energy in Louisiana" Cooperative Agreement ever awarded to the state of Louisiana. Mainardi is heavily involved in accreditation as well as student preparation and learning. She is the Assessment Coordinator for the COES, an American Institute of Chemical Engineers (AIChE) Education and Accreditation Committee member, an Executive Committee (ExCom) member-at-large for the Applied and Natural Sciences Accreditation Commission (ANSAC) of the Accreditation Board for Engineering and Technology (ABET) representing AIChE, and the Chair of the ABET Accreditation Council Committee for Visits Outside the US. Mainardi has been involved with ABET since 2015, when she first became a Program Evaluator for this organization. Mainardi has been committed to educate and train her Chemical Engineering students focusing on a problem-solving and critical thinking approach. Since Louisiana Tech University became a KEEN (Kern Entrepreneurial Engineering Network) partner in 2024, Mainardi has expanded her teaching style to incorporate an entrepreneurial mindset approach, so students can create personal, economic, and societal value through a combination of technical skills and human-centered thinking that consider the 3 C's (Curiosity, Connections, and Creating value). Funded by the Kern Family Foundation, KEEN is a partnership of engineering faculty and institutions committed to instilling an entrepreneurial mindset in engineering students, while supporting curriculum development and institutional change to help engineers become more innovative, adaptable, and impact-driven. She participated in KEEN workshops such as Integrating Curriculum with Entrepreneurial Mindset (ICE) 1.0 in 2024 and Learning from Failure (LFF) in 2025. Mainardi was recognized in 2025 as an Engineering Unleashed Fellow for her published Engineering Unleashed Card #4453: Think, Act, and Feel Thermodynamics, which is based on the integration of curiosity, connections, and value creation into engineering education.

Heating Water, Igniting Minds: A Challenge-Based Approach to Entrepreneurial-Minded Learning in Chemical Engineering Thermodynamics

Thermodynamics courses frequently emphasize mathematical formulation and solution techniques, with less emphasis on applying these tools to complex, real-world engineering systems. This paper presents an instructional intervention designed to re-center thermodynamics learning around engineering judgment, safety, and decision making under uncertainty. An open-ended, challenge-based activity grounded in entrepreneurial-minded learning was introduced in a junior-level chemical engineering thermodynamics course, immersing students in a realistic scenario with limited resources and operational constraints. Working in teams, students proposed and justified solution strategies, communicated their reasoning through oral presentations, and evaluated one another using a common rubric alongside faculty. Structured opportunities for feedback and revision enabled students to confront misconceptions, reassess assumptions, and refine their analyses. Multiple sources of evidence, including peer and faculty evaluations, reflective revision memos, and a longitudinal follow-up survey conducted one year after the experience, were used to examine both immediate and sustained learning outcomes. Findings indicate strong agreement between peer and faculty assessments, meaningful conceptual growth driven by learning from failure, and long-term transfer of skills related to safety awareness, creative problem solving, and value creation in professional contexts. The results suggest that embedding authentic, ill-structured challenges within core thermodynamics courses can promote deeper understanding and durable learning while preserving disciplinary rigor.

Introduction

Thermodynamics is a foundational component of chemical engineering curricula, yet decades of engineering education research have shown that students often experience persistent conceptual difficulties even after completing traditional instruction. Studies across multiple institutions have documented recurring misconceptions related to heat, temperature, energy conservation, phase behavior, and the interpretation of thermodynamic properties, indicating that procedural success does not necessarily translate to conceptual understanding [1–3]. Concept inventory research further demonstrates that these misconceptions can persist longitudinally unless instructional approaches explicitly target conceptual reasoning and sensemaking [3]. These findings motivate the use of learning environments that move beyond equation-driven problem solving toward activities that require students to articulate assumptions, interpret physical meaning, and reconcile models with real-world constraints [2–4].

Active, inquiry-based, and open-ended instructional approaches have been shown to support deeper learning in the thermal sciences by engaging students in conceptual repair and model-based reasoning [2,4]. In particular, ill-structured problems that lack a single correct solution can promote higher-order thinking by requiring students to frame the problem, select appropriate models, and justify decisions under uncertainty, which are key elements of professional engineering practice [5]. Within this context, challenge-based learning (CBL) has emerged as a well-studied pedagogical framework that situates learning within authentic, real-world scenarios while emphasizing iteration, collaboration, and communication [5–7]. Recent systematic reviews in engineering education report that CBL implementations consistently enhance student engagement and professional skill development, while also identifying ambiguity management, scaffolding, and assessment as critical design considerations [5–7].

Prior ASEE studies specifically examining challenge- or project-based formats in thermodynamics and related courses indicate that such approaches can improve student confidence, motivation, and ability to connect theory to practice [8–10]. Embedding thermodynamics problems within realistic constraints related to feasibility, safety, and environmental impact encourages students to treat core principles as reasoning tools that guide decisions, instead of viewing them as isolated equations to be applied mechanically. Such approaches reflect ongoing calls in engineering education to more closely connect disciplinary rigor with professional skills such as collaboration, communication, and ethical judgment [6,9].

Entrepreneurial-minded learning (EML) provides an additional evidence-based framework for structuring such experiences by explicitly emphasizing curiosity, connections, and value creation. Peer-reviewed studies examining EML integration in engineering courses report positive effects on students' ability to recognize opportunities, evaluate tradeoffs, and articulate the broader impact of technical decisions [11–13]. Rubric-based assessments of EML-aligned activities further suggest that transparent evaluation of creativity, feasibility, and communication can support both student learning and assessment reliability [11,12]. These findings support the instructional premise of embedding an entrepreneurial mindset within a core thermodynamics course: that students' conceptual understanding and professional judgment can be strengthened simultaneously through authentic, open-ended challenges.

At Louisiana Tech University (LA Tech), CMEN 3323 - Chemical Engineering Thermodynamics II is a required core course for chemical engineering majors. The "*Think, Act, and Feel Thermodynamics*" challenge published as the Engineering Unleashed Card #4453 [14] emerged from this need; a scenario in which students must apply thermodynamic theory under realistic constraints via an open-ended challenge that demands integration of theory and practice. Thus, this paper builds upon the previously published Card [14] by expanding its scope to present the theoretical foundation, instructional design, implementation, and assessment of the activity in alignment with ASEE standards for scholarly dissemination. The activity intentionally weaves together the KEEN pillars of curiosity, connections, and creating value, engaging students through creativity, communication, and structured reflection. The sections that follow provide a comprehensive account of the activity's design, classroom implementation, assessment strategy, and observed short- and long-term impacts within the Chemical Engineering program at Louisiana Tech University.

Description of the Learning Challenge

The "*Think, Act, and Feel Thermodynamics*" challenge problem [14] is about an open-ended, scenario-based challenge in which two chemical engineering juniors, hiking in an Arizona National Park at an elevation of approximately 7,500 ft, become lost and encounter a remote wooden cabin. The cabin provides drinkable running water but has no electricity due to a fallen tree that disabled the power supply. Under conditions of significant diurnal temperature variation (hot daytime temperatures and cold nights), the students must devise a feasible strategy to heat water for a hot meal. With a fire ban in effect, students are restricted to a brand-new stainless-steel water hose, a thermos, and any additional materials they reasonably justify as being available within the cabin. Under these constraints, they are tasked with determining whether sufficient water can be heated in the hose for each individual to prepare a cup of ramen noodle soup and, if so, calculating the pressure developed inside the hose as the water reaches the required temperature. Within this context, students are asked to determine whether it is feasible to successfully heat the water to the "desired" temperature and, if so, to analyze the implications of their approach. To address thermodynamic questions regarding water temperature to make ramen noodle soup, and internal pressure in the hose, students must integrate theory with practice, apply technical concepts and tools such as Equations of State, steam tables, vapor pressure calculations, and make reasoned, data-supported decisions under realistic constraints. Importantly, no data sets, predefined solution pathways, or numerical values were provided to the students. This design choice required students to identify assumptions, determine what information was needed, justify modeling approaches, and make reasoned engineering judgments, mirroring an authentic engineering problem-solving processes. Thus, the activity encourages divergent thinking by allowing multiple solution pathways, while requiring critical assessment of feasibility, and safety and environmental considerations. The intentionally constrained and realistic nature of the scenario encouraged creative problem solving, engineering judgment, and the application of fundamental concepts to an authentic, ill-structured problem.

Implemented as a collaborative, team-based assignment, the exercise is designed to promote professional communication, teamwork, and critical engagement through oral group presentations and structured evaluation processes. Students assess one another's work through peer evaluation, while faculty assessment includes not only the course instructor but also invited faculty from Mechanical Engineering and Chemistry, providing interdisciplinary perspectives. All evaluations are guided by a common rubric that emphasizes clarity of communication, creativity, technical rigor, safety and environmental considerations and awareness. In addition, the activity incorporates a reflective "Perfect Problem" extension that encourages learning from failure by allowing teams to revisit their initial assumptions, respond to feedback, and refine their solutions after additional course content has been introduced. This iterative process reinforces metacognitive learning, supports continuous improvement, and helps students develop more mature engineering judgment over time.

Methodology for Implementation and Assessment

The challenge-based learning activity was first implemented in the junior-level Chemical Engineering Thermodynamics II course during the Winter Quarter of the 2024-2025 academic year, with a class size of 30 LA Tech chemical engineering students. Students were introduced to the open-ended challenge on the second day of class, intentionally early in the term, to encourage sustained engagement, iterative thinking, and integration of course concepts throughout the quarter. Upon introduction of the challenge, students were organized into small collaborative teams consisting of up to five members. From the outset, students were informed that the activity was intentionally structured to emphasize team interaction and group dynamics as a foundational component of the learning experience.

The challenge unfolded in multiple phases. The initial phase focused on team formation, collaboration, and collective problem framing, requiring students to communicate effectively, and develop a shared approach to addressing the open-ended problem. Approximately thirty days after the challenge was introduced and following completion of the course topics on Equations of State and vapor–liquid equilibrium for pure substances, each team delivered an oral group presentation describing their proposed solution, underlying assumptions, and technical reasoning. This milestone served as a formative checkpoint, allowing students to articulate their thinking, receive structured feedback, and reflect on both technical and teamwork-related aspects of their performance. The challenge then culminated near the end of the academic term with an optional, memo-style written submission. This final component provided students with an opportunity to respond to the feedback received during the oral presentation, revise their approach, and explicitly address identified weaknesses or misconceptions. Framed as a "re-vindication" opportunity, the memo encouraged students to engage in reflective practice, learn from failure, and demonstrate growth in both technical understanding and professional communication. Completion of the memo was optional and offered as a bonus-point opportunity, reinforcing intrinsic motivation while rewarding thoughtful revision, resilience, and continuous improvement.

Dedicated class time was intentionally allocated once per week until the day of the oral presentations to support group collaboration. During these sessions, student teams engaged in structured brainstorming, problem framing, and strategy development, while also having the opportunity to ask clarifying questions to the instructor.

Student performance was assessed using a structured evaluation rubric during the oral presentations. The rubric was designed to evaluate multiple dimensions of performance, including problem understanding, application of thermodynamic principles, quality of assumptions, logical reasoning, communication effectiveness, and the ability to justify decisions. Assessment occurred through multiple complementary perspectives to ensure a holistic evaluation of student performance. Peer evaluation was incorporated to allow students to assess the contributions, engagement, and effectiveness of each presenting group (excluding their own) using the evaluation rubric. This approach encouraged critical observation, reinforced understanding of performance expectations, and minimized self-evaluation bias. Faculty evaluation was conducted using the same rubric by the course instructor along with invited faculty evaluators from the Chemistry and Mechanical Engineering programs at Louisiana Tech University. The inclusion of interdisciplinary faculty evaluators provided broader perspectives on technical rigor, disciplinary integration, and the clarity and effectiveness of oral communication during the group presentations. This blended assessment model balanced expert judgment with student perspectives, promoting fairness, transparency, and alignment with professional evaluation practices while supporting the development of evaluative and reflective skills among students.

To promote individual accountability, students completed intra-group performance evaluations that included brief self- and peer-reflection on individual roles, contributions, and engagement within the team. This component encouraged personal responsibility and reflection on teamwork while providing insight into individual performance beyond the group-level assessments. In addition, students completed an End-of-Course Outcomes Assessment Survey at the conclusion of the term to reflect on their learning and overall course experience.

In addition to the immediate performance assessments, a follow-up survey was administered one year after the experience to examine the longer-term impacts of the challenge. This longitudinal instrument was designed to capture students' perceived retention of core thermodynamics concepts, sustained confidence in addressing open-ended and ill-structured engineering problems, and the influence of the experience on subsequent coursework, decision-making processes, and professional preparedness.

Thus, the integration of in-class observation, rubric-based faculty and peer evaluation, intra-group self- and peer-assessment, End-of-Course outcomes feedback, and the delayed follow-up survey constituted a multi-layered assessment framework. This comprehensive approach enabled the evaluation of both short-term learning outcomes and longer-term educational impacts, providing evidence of conceptual persistence, skill development, and reflective growth beyond the immediate instructional context.

Results and Discussion

Overview of Group Solution Approaches

Six teams, each composed of five students, delivered oral presentations proposing distinct solution strategies to address the challenge under the given environmental and resource constraints. Although all teams were tasked with the same problem, their approaches varied considerably, illustrating the open-ended nature of the challenge and the range of engineering judgment applied. The presentations demonstrated a broad range of solution pathways for heating up water, including passive solar heating, optical concentration, conductive heat transfer, and chemically driven energy release. Rather than converging on a single "correct" answer, the activity encouraged students to explore assumptions, justify modeling choices, confront uncertainty, and articulate engineering reasoning within an ill-structured, real-world scenario.

Several approaches relied on passive solar heating, with analyses considering ways to enhance heat absorption and reduce losses through insulation, surface exposure, or optical concentration. These solutions typically involved reasoning about radiative and conductive heat transfer, estimating temperature increases using energy balances, and applying thermodynamic property relationships to reason about pressure development within the hose. In some cases, limitations associated with environmental variability, such as solar intensity, reflection efficiency, and ambient conditions, were explicitly acknowledged and discussed. Other solar-based strategies incorporated combined heat-transfer mechanisms by assuming contact between the hose and sun-heated surfaces. These approaches emphasized energy balance reasoning and elevation-dependent effects on boiling behavior, using property data to examine how temperature and pressure might evolve during heating and how heated water could be transferred for food preparation. Some analyses also explored alternative conceptual pathways, such as modifying pressure conditions or supplementing heating methods, while explicitly addressing safety and environmental considerations associated with each idea.

In addition to solar-driven concepts, chemically driven heating strategies were also proposed. These approaches examined the use of exothermic chemical processes as potential heat sources, with students evaluating feasibility, sustainability, and controllability under the given constraints. Analyses typically involved estimating heat release from chemical reactions or dissolution processes, transferring that energy to water contained within the hose, and considering system boundaries and pressure conditions. Thermodynamic property data, steam tables, and Equations of State were used to reason about system behavior, while safety considerations related to reaction handling, pressure management, and environmental impact were explicitly discussed.

Collectively, the presentations demonstrated that students engaged with the challenge by exploring multiple viable conceptual pathways rather than converging on a single prescribed solution. The diversity of approaches highlighted how open-ended constraints encouraged students to articulate assumptions, select and justify modeling frameworks, and confront uncertainty, reinforcing the focus on engineering reasoning and judgment rather than solution convergence.

Peer and Faculty Assessment of Oral Presentations

Student peers and faculty evaluators independently assessed the oral presentations using a shared evaluation rubric encompassing *Understanding of the Problem and Constraints*, *Solution Design to Heat Water, Analysis of Heating up Water Inside the Hose, Pressure Calculation and Analysis, Safety and Environmental Considerations, Creativity and Resourcefulness, Clarity of Communication,* and *Bonus-Point Eligibility.* The *Bonus-Point Eligibility* component was contingent upon a presentation demonstrating a highly original and innovative approach, proposing effective methods while reflecting a deep understanding of the problem through clear reasoning and thoughtful consideration of relevant details, challenges, and potential obstacles.

A strong positive relationship was observed between student peer evaluations and faculty evaluations across all presenting groups, with a correlation coefficient of $r = 0.86$. The standard deviation of the correlation coefficient across groups was 0.03 in average, indicating small variability in the strength of agreement between peer and faculty assessments from group to group and suggesting that students were generally able to apply the shared evaluation rubric in a manner consistent with faculty judgment. Although correlation does not imply causation, the combination of a high mean correlation and a small dispersion supports the conclusion that peer evaluation functioned as a reliable and meaningful complement to faculty evaluation within the overall assessment framework. The comparative results of student peer evaluations and faculty evaluations across all rubric components are presented in Figure 1.

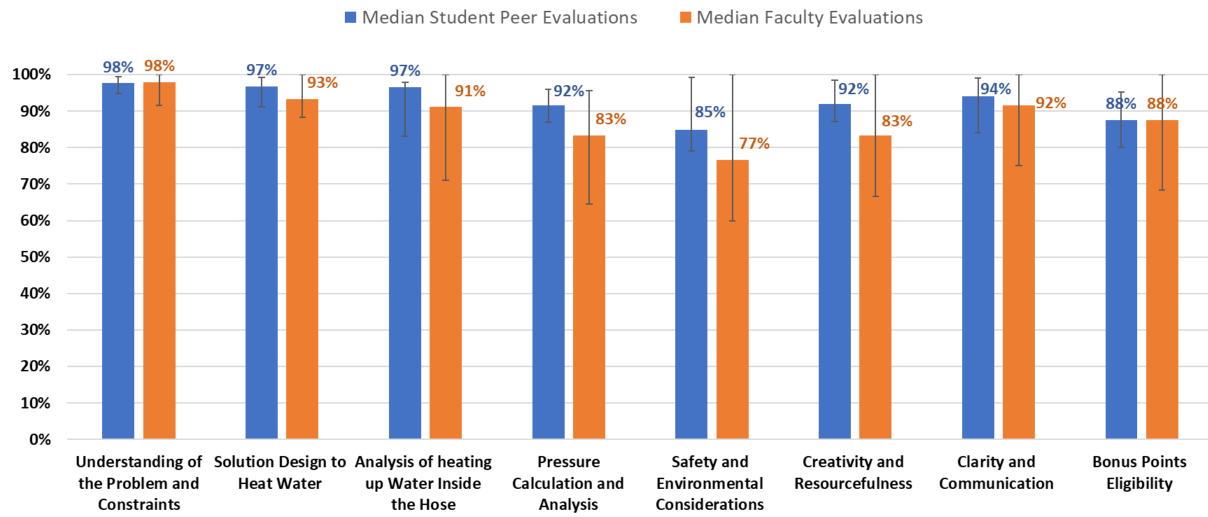

Figure 1. Median normalized rubric scores (expressed as percentages of the maximum possible points in each category) for group oral presentations collectively, comparing student peer evaluations and faculty evaluations across all rubric dimensions.

Figure 1 presents the median values of the average student peer evaluations and average faculty evaluations for group performance across each rubric category. The figure aggregates scores at the group level and reports the median across all groups, providing a robust comparison of how student peers and faculty collectively assessed performance within each evaluation dimension. Thus, the percentages shown in the figure represent normalized rubric scores, expressed as a fraction of the maximum possible points allocated to each rubric category. For each evaluation dimension (e.g., *Understanding of the Problem and Constraints*, *Solution Design to Heat Water*, *Pressure Calculation and Analysis*), raw scores assigned by student peers and faculty were first averaged at the group level based on the point limits defined in the evaluation rubric (e.g., 16 points maximum for *Understanding of the Problem and Constraints*, 20 points maximum for *Solution Design to Heat Water*, 15 points maximum for *Pressure Calculation and Analysis*, etc.), and then converted to percentages. As a result, a value such as 92% in a given category indicates that, for the median group, evaluators awarded approximately 92% of the maximum points available for that rubric dimension. This normalization allows direct comparison across categories with different point weights and provides a consistent interpretation of performance relative to the expectations articulated in the rubric. The bars shown in the figure further contextualize these percentages by indicating the range of group performance within each category. Specifically, they span from the minimum to the maximum of the averaged group scores (converted to percentages) assigned by student peers or faculty, respectively. Together, the median values and bars illustrate not only typical performance relative to rubric expectations, but also the degree of variability across groups in each evaluation dimension.

For *Understanding of the Problem and Constraints*, both student peers and faculty reported median scores of 98%, reflecting a nearly complete understanding of the problem statement, objectives, and constraints, with only minor gaps such as limited attention to secondary considerations. *Solution Design to Heat Water* was also rated highly, with student peers assigning a median of 97%, indicating well-conceived and effective designs closely aligned with constraints, while faculty assigned a slightly lower median of 93%, suggesting that some solutions, though feasible, may have lacked the full technical depth, robustness, or justification expected at the highest level. In the *Analysis of Heating Water Inside the Hose*, student peers (97%) and faculty (91%) both recognized generally correct application of thermodynamic concepts and energy transfer reasoning, though faculty noted occasional oversimplified assumptions or incomplete analyses. Greater divergence emerged in *Pressure Calculation and Analysis*, where student peers assigned a median of 92%, reflecting largely correct calculations and discussion of safety implications with some missed nuances, while faculty assigned a lower median of 83%, indicating partial correctness accompanied by shortcomings such as inappropriate model selection, incomplete phase-behavior treatment, or insufficient safety justification. Similar patterns were observed for *Safety and Environmental Considerations*, with student peers (85%) recognizing that risks were addressed but often at a surface level, and faculty (77%) applying more stringent expectations regarding completeness, justification, and integration of safety into technical reasoning. For *Creativity and Resourcefulness*, student peers (92%) viewed solutions as highly original and inventive, whereas faculty (83%) acknowledged creativity but noted that it was not always supported by equally strong technical grounding or feasibility analysis. *Clarity and Communication* received consistently high ratings from both student peers (94%) and faculty (92%), indicating clear, well-organized, and professionally delivered presentations with only minor weaknesses. Finally, for *Bonus Points Eligibility*, both student peers and faculty reported median scores of 88%, suggesting that while many submissions demonstrated strong originality and innovation, they did not fully satisfy all criteria for the highest bonus designation, often due to uneven technical depth, incomplete treatment of challenges, or limited justification of novelty.

Overall, the median results indicate strong alignment between peer and faculty assessments across categories, reinforcing the consistency of the shared rubric when applied by different evaluators. In several areas, such as *Understanding of the Problem and Constraints* and *Bonus Points Eligibility*, the median scores assigned by students and faculty are identical or nearly identical, suggesting close agreement on core aspects of performance. In other categories, student medians are consistently modestly higher than faculty medians, with the most pronounced differences observed in *Pressure Calculation and Analysis*, *Safety and Environmental Considerations*, and *Creativity and Resourcefulness*. These differences may suggest that faculty evaluators applied more conservative standards related to technical rigor, analytical completeness, and safety awareness. In several cases, and as expected, faculty evaluators identified incorrect assumptions, modeling errors, or safety-related oversights that were not readily recognized by student evaluators. These differences reflect variations in experience and disciplinary perspective, particularly when evaluating complex, open-ended work, and highlight the complementary roles of peer and faculty assessment in identifying both strengths and areas for improvement.

Learning from Failure Through Reflection and Revision

During the question-and-answer sessions following each oral presentation, it became evident that some groups may have held misconceptions, made incorrect assumptions, or had not fully considered safety and other practical constraints. Immediate feedback was provided to address these issues, followed by the opportunity for each group to meet individually with the instructor outside of class to discuss areas for improvement without receiving prescriptive guidance. These follow-up meetings, held in the weeks that followed, allowed students time to reflect on the feedback, reexamine their assumptions, and, if they elected to do so, begin revising their approach in preparation for the optional memo submission.

Four of the six groups elected to submit the optional revision memo, using it as an opportunity to revisit their assumptions, respond to feedback, and refine their proposed solutions. Analysis of these memos, in comparison with the groups' original challenge-problem approaches, revealed clear evidence of learning from failure, iterative improvement, and growth in engineering judgment over the course of the quarter. In one case, the memo reflected a meaningful refinement in modeling approach, as an initially selected Equation of State was reconsidered and replaced with a formulation better suited for describing liquid and near-boiling water behavior, leading to a markedly different interpretation of pressure development within the system. This correction prompted a deeper consideration of physical realism and resulted in a more thorough treatment of safety and environmental factors, including pressure limitations and protective measures. The revised work reflected a progression from procedural calculation toward more informed model selection and safety-aware reasoning. In another instance, learning emerged through reassessment of assumptions related to phase behavior and operational risk. An initial analysis extended the system to full boiling conditions, implicitly introducing elevated pressure concerns. Subsequent reflection led to recognition that this assumption was unnecessary for achieving the intended objective and introduced avoidable risk. The revised approach maintained the system in the liquid phase, allowing pressure to remain low and manageable. This shift reflected developing engineering judgment and a closer alignment between thermodynamic theory and practical safety considerations, along with a clearer appreciation of when vapor–liquid equilibrium models are appropriate versus when simpler liquid-phase descriptions may be sufficient. Additional evidence of conceptual growth was observed in revisions that addressed oversimplified assumptions about phase behavior and pressure evolution. Initial analyses that treated the system as entirely vapor-phase were reconsidered, leading to adoption of a more realistic equilibrium-based description. Alongside improvements in thermodynamic modeling, these revisions incorporated enhanced attention to heat-transfer mechanisms and safety considerations, including insulation strategies, system configuration, and pressure mitigation. Finally, revisions included in other memos demonstrated learning through correction of both thermodynamic and chemical reaction modeling assumptions. Early analyses included unnecessary equilibrium and quality calculations that were later identified as inconsistent with the system's design objectives. Through reflection, these analyses were simplified and corrected by selecting appropriate property data and refining reaction modeling assumptions using literature-supported values. These revisions indicated improved understanding of thermodynamic property usage, Equation of State applicability, and chemical reaction modeling, as well as greater alignment between analytical methods and physical reality.

Across all four revision memos, students moved beyond attempting to "get the right answer" and instead engaged in deeper reflection on assumptions, model selection, safety, and physical realism. These outcomes illustrate how structured feedback and opportunities for revision supported learning from failure and fostered more mature technical reasoning and professional judgment by the end of the quarter.

End-of-Course Outcomes Survey

Implemented at the end of the term on a voluntary and anonymous basis, the End-of-Course Outcomes Survey is a reflective assessment instrument designed to capture students' perceptions of their learning, skill development, and overall course experience. The survey combines structured Likert-scale items with open-ended questions to evaluate how specific instructional components supported conceptual understanding, problem-solving ability, and professional skill development. Open-ended prompts allow students to articulate which elements of the course were most effective, and what aspects could be improved, providing qualitative insight that complements quantitative course evaluation data.

Students' written feedback collected with this instrument reflected a broad range of perspectives, underscoring both the instructional value of the challenge and opportunities for refinement in how it is framed and supported. Students consistently identified the challenge problem as one of the most influential and memorable elements of the course, distinguishing it from more traditional instructional components. Many students emphasized that the open-ended structure required them to actively grapple with uncertainty, make assumptions, and justify decisions, which they found both challenging and intellectually rewarding. Several students specifically noted that encountering the challenge twice, initially and again through the revision process, was particularly valuable, as it allowed them to recognize gaps in their early reasoning and directly connect course content learned later in the quarter to improvements in their original approach. This iterative structure helped students move beyond surface-level problem solving toward a deeper conceptual understanding of thermodynamics and its practical application. In addition, students frequently highlighted the collaborative nature of the challenge, describing how group discussion, shared responsibility, and peer learning improved their understanding and fostered stronger connections within the class. The challenge was also described as "fun" and more engaging than conventional assignments, in part because it required creativity and encouraged thinking beyond standard solution pathways. A small subset of students, however, noted initial uncertainty regarding expectations, assumptions, and overall solution direction. For those students, the timing of the activity early in the term, combined with its overlap with the winter break, contributed to feelings of discomfort or challenge in navigating the problem space.

Overall, student reflections indicate that the challenge successfully integrated technical reasoning with creativity, collaboration, and real-world context, supporting both conceptual learning and the development of professional engineering skills. Many students characterized the activity as intellectually demanding and ultimately rewarding, emphasizing that its open-ended structure encouraged deeper thinking and application beyond routine problem solving. At the same time, several students initially interpreted the ill-defined nature of the problem as a lack of clarity and offered constructive suggestions such as clearer upfront framing, explicit articulation of expectations, or guidance on modeling boundaries. Others recommended adjusting the timing or scope of the activity. Notably, many comments also reflected an evolving appreciation for the challenge after the revision phase, once additional course content had been introduced. Taken together, the feedback suggests that while the challenge was demanding and at times uncomfortable, it was also a meaningful and influential component of the course, highlighting the importance of carefully balancing open-ended exploration with scaffolding that supports student confidence and readiness.

One-Year Follow-up Survey: Long-Term Impact and Transfer of Learning

A one-year follow-up survey was administered on a voluntary and anonymous basis to assess longer-term impacts of the challenge, with 12 of the 30 students completing the instrument. Responses were primarily collected using Likert-scale items, supplemented by open-ended reflection prompts to provide qualitative insight into student thinking and learning.

Results from this survey indicated that students demonstrated strong recall of the scenario and its purpose, with most respondents indicating that they remembered the challenge at least somewhat clearly and one-third of the respondents recalling it perfectly, suggesting that the experience may have stood out relative to more traditional coursework. This persistence is further contextualized by students' subsequent academic and professional experiences, as nearly all respondents reported participation in senior design or capstone projects (91.7%), with many also engaging in internships/co-ops (58.3%), undergraduate research (41.7%), and additional coursework (58.3%), providing multiple opportunities for applying and reinforcing what they learned. When asked what stood out most from the challenge, students most frequently identified teamwork and creativity, followed by technical problem solving, safety and real-world constraints, and the sense of fun or unexpectedness associated with the activity (Figure 2). These responses align with earlier performance data and highlight that the students viewed creativity and collaboration as integral to effective engineering practice. This mindset appears to have translated into action, as students reported frequently identifying needs or opportunities to improve projects or organizations after completing the challenge, with nearly all respondents indicating they did so sometimes (50%) or very often (41.7%) and only one student said rarely.

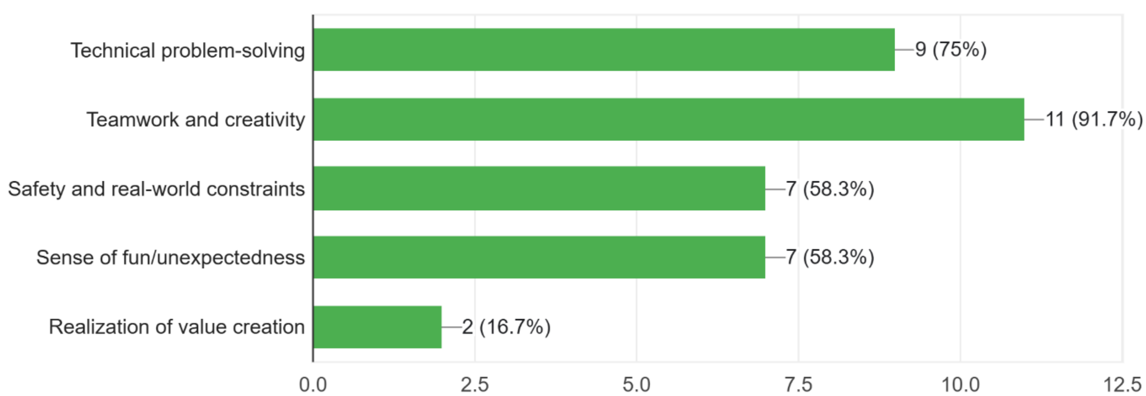

Figure 2. Distribution of student responses (n = 12) identifying the most memorable aspects of the challenge one year after completion.

The influence of feasibility, safety, and impact on students' engineering approach is also evident in the survey results. Most respondents reported that this mindset strongly influenced their thinking, while the remainder indicated at least occasional influence, and none reported no influence (Figure 3). This finding reinforces earlier observations that safety considerations became more salient, as students reflected on their initial assumptions and analyses.

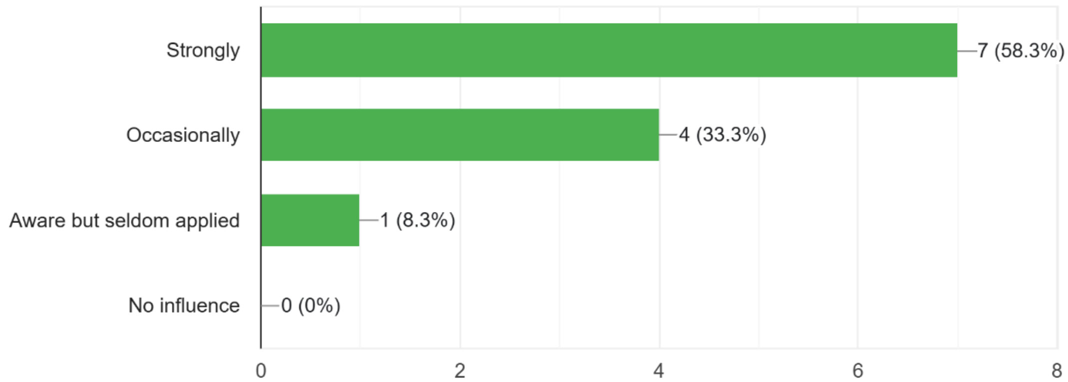

Figure 3. Distribution of student responses (n = 12) regarding the influence of feasibility, safety, and impact on their engineering mindset one year after the challenge.

At the same time, students reported strong gains in their ability to connect thermodynamics concepts to real-world outcomes, with all respondents rating the experience as at least somewhat effective and the majority rating it as good or excellent (Figure 4), indicating that the challenge successfully bridged theory and practice.

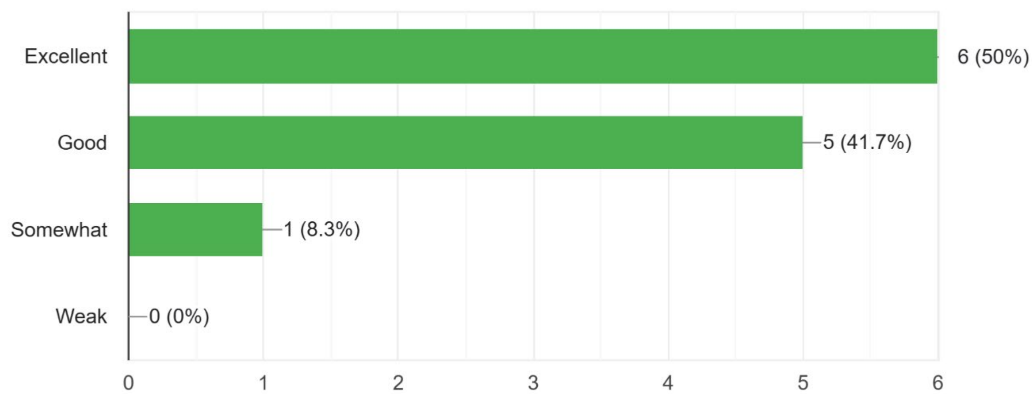

Figure 4. Distribution of student ratings (n = 12) of the challenge's effectiveness in linking thermodynamics theory to real-world outcomes.

Confidence-related outcomes further support the long-term impact of the experience. One year later, most students reported being very confident (66.7%) in their ability to turn ideas into useful or valuable results, with the remaining respondents indicating moderate confidence (33.3%) and none expressing neutrality or lack of confidence. Students also perceived entrepreneurial-minded learning frameworks such as Curiosity, Connections, and Creating Value as relevant to engineering education, with most rating them as very relevant (58.3%) or somewhat relevant (33.3%) and only one student expressing uncertainty. Importantly, students reported applying the "*Think–Act–Feel*" mindset across a wide range of contexts, including internships, capstone projects, other courses, research, and everyday life (Figure 5), demonstrating broad transfer beyond the original classroom setting.

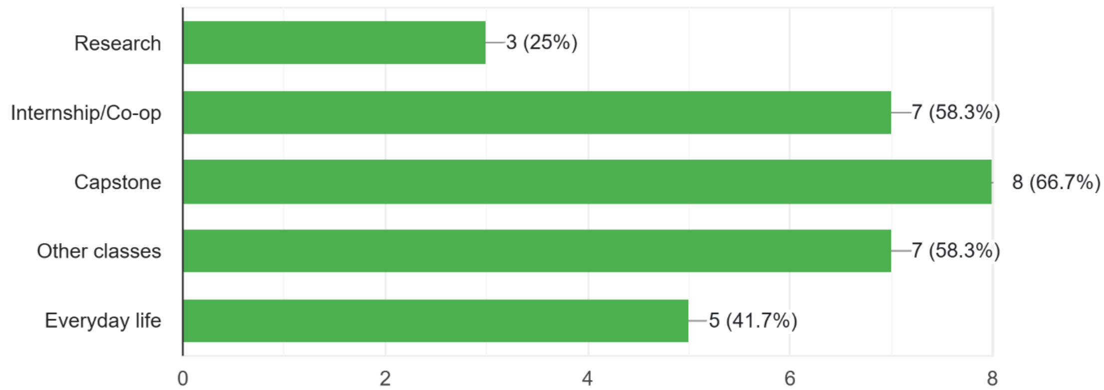

Figure 5. Distribution of student-reported contexts (n = 12) in which the "*Think–Act–Feel*" mindset was applied after the challenge.

When asked to summarize the experience in a single word or phrase, students overwhelmingly used descriptors such as "fun", "creative", "open-ended", "innovative", and "rewarding". These descriptors are synthesized visually in Figure 6, reinforcing the qualitative survey findings. Collectively, the results indicate that the challenge successfully combined technical rigor with creativity, engagement, and real-world relevance, supporting both cognitive and affective dimensions of student learning.

Figure 6. Word cloud of key descriptors used by students to characterize the challenge experience one year after completion.

In addition to the presented survey results, open-ended responses to the prompt asking students to describe their personal takeaways one year after the experience provided rich qualitative evidence of lasting impact. Many students explicitly recalled making mistakes ("the part that we got wrong") or recognizing limitations in their initial solutions, describing these moments as valuable reminders of the importance of checking assumptions, avoiding complacency, and revisiting calculations, particularly with respect to pressure and safety considerations. Students repeatedly emphasized the lack of prescriptive guidance as a defining feature of the challenge, noting that having to "think outside the box", independently identify variables, and resist over-specifying the problem fundamentally changed how they approached engineering tasks.

Brainstorming and collaboration were frequently cited as both challenging and impactful, with several students reflecting on discomfort early in the process that evolved into stronger communication, teamwork, and time-management skills. Creativity emerged as a central theme, with students describing the experience as fun, rewarding, and memorable because it allowed them to connect creativity directly to thermodynamics coursework. Importantly, safety awareness surfaced repeatedly in these reflections, as students acknowledged that real-world solutions introduced more safety concerns than initially anticipated, reinforcing the need for professional judgment. These qualitative insights closely align with the quantitative trends observed in Figures 2-5 and the dominant descriptors summarized in the word cloud (Figure 6), collectively demonstrating that students retained not only technical concepts but also deeper lessons related to engineering judgment, collaboration, creativity, and learning from failure.

Responses to the prompt asking students to describe a situation after completing the challenge in which they recognized a need, acted on it, and created value for others provided strong evidence of sustained transfer beyond the classroom. Most examples occurred in internships, capstone projects, or subsequent coursework, where students described proactively identifying gaps in understanding, safety risks, inefficiencies, or communication breakdowns. Several students reported taking initiative to learn unfamiliar processes by engaging mentors, observing operations, and asking targeted questions, thereby improving safety awareness and cross-departmental understanding. Others described recognizing and mitigating hazards, such as identifying equipment leaks or addressing chemical releases, actions that directly improved safety for others. Value creation also manifested through organizational improvements, including streamlining data management, optimizing chemical feed rates to reduce operating costs, and developing decision matrices to help teams evaluate economic and environmental trade-offs. Beyond technical settings, students described applying the same mindset to collaborative and everyday situations, such as redistributing workload among stressed coworkers or assisting others in challenging conditions. All together, these responses demonstrated that students internalized the challenge's emphasis on recognizing needs, acting under uncertainty, and creating value, which are core behaviors of entrepreneurial-minded engineers, and continued to apply them in professional, academic, and personal contexts long after the course concluded.

When asked which aspects of the challenge had the most lasting influence, students most frequently identified moments of struggle, ambiguity, and error as the most impactful learning experiences. Many specifically cited "the part we got wrong", incorrect model selection, and underestimation of safety considerations as pivotal in shaping their understanding of thermodynamics and engineering judgment. Students emphasized that working on a problem with minimal structure and limited guidance was initially uncomfortable and even nerve-racking, but ultimately transformative, helping them learn to balance creativity with fundamental principles and avoid overcomplicating solutions. Creative brainstorming, exposure to multiple solution pathways through peer presentations and collaborative teamwork were also repeatedly highlighted as influential, with several students noting that the experience changed how they approached open-ended problems in internships and later coursework.

All these reflections indicate that the challenge was most impactful when it pushed students beyond comfort, required them to confront mistakes, and exposed them to multiple valid engineering approaches, while also offering clear opportunities for iterative refinement in future implementations.

Conclusion

This study demonstrates that an open-ended, challenge-based learning experience grounded in entrepreneurial-minded learning can effectively connect thermodynamics theory to real-world engineering practice. The "*Think, Act, and Feel Thermodynamics*" challenge engaged students in applying core concepts under realistic constraints, requiring them to define assumptions, select appropriate models, evaluate safety and feasibility, and communicate solutions professionally. Introducing the challenge early in the course and allowing students to iterate through uncertainty encouraged creativity, teamwork, and engineering judgment.

Assessment results have shown strong alignment between student peer and faculty evaluations, supporting the use of peer assessment as a meaningful complementary tool, while also highlighting the importance of faculty guidance in areas such as safety and modeling rigor. Longitudinal survey data collected one year after the experience indicate durable learning outcomes, including sustained recall of the challenge, improved confidence in addressing open-ended problems, and continued application of the "*Think–Act–Feel*" mindset in internships, capstone projects, and professional contexts. Collectively, these findings suggest that integrating entrepreneurial-minded, challenge-based activities into core engineering science courses can enhance technical understanding, professional skill development, and students' ability to create value in complex, real-world situations.

Extensions, Limitations, and Future Work

Although the learning activity was implemented within a junior-level chemical engineering thermodynamics course, its underlying structure and instructional approach are readily adaptable to other courses and disciplines. The challenge is built around an authentic, ill-structured scenario that requires students to frame problems, make and justify assumptions, select appropriate models, and balance technical analysis with safety, feasibility, and environmental considerations, which are skills that are fundamental across engineering and STEM fields. Instructors in disciplines such as mechanical, civil, environmental, industrial, or materials engineering could adopt a similar challenge-based framework by situating core disciplinary content within realistic constraints relevant to their contexts. The emphasis on open-ended problem solving, iterative refinement, peer and faculty assessment, and reflection supports transferable competencies including engineering judgment, teamwork, communication, and learning from failure.

Several factors help contextualize the findings of this study and point toward opportunities for continued refinement of the challenge. In particular, the results from the one-year follow-up survey are based on voluntary participation and therefore represent the perspectives of a subset of students who completed the experience ($n = 12$). While these responses offer valuable insight into long-term learning and perceived transfer, the sample size and self-selection limit generalizability and preclude statistical inference. Future implementations will aggregate longitudinal data across multiple cohorts and course offerings to increase sample size and enable more robust analyses of persistence and transfer over time.

While the follow-up data indicate that students perceived transfer of learning across internships, undergraduate research, capstone design, and subsequent coursework, the present study was not designed to support statistical correlation between specific post-course experiences or comparisons with students who did not complete the open-ended challenge. The limited follow-up sample size and self-selection of respondents preclude disaggregation by experience type and causal inference. Future work will address this limitation through longitudinal data collection across multiple cohorts and the inclusion of appropriate comparison groups, such as prior offerings or parallel sections without the challenge-based intervention. Planned analyses include examining whether engagement in experiential learning opportunities such as co-ops, undergraduate research, or design-based courses is associated with differential retention, confidence, or application of safety- and feasibility-oriented reasoning. These efforts will enable a more rigorous examination of how challenge-based learning in foundational engineering science courses interacts with subsequent academic and professional experiences.

Building on insights gained from the Winter 2024-2025 implementation, the challenge is being refined in the current Winter 2025-2026 offering through the introduction of a pre-assessment survey administered at the outset of the activity. This instrument is designed to capture students' initial impressions, confidence levels, prior experiences, and baseline approaches to open-ended problem solving before sustained group interaction occurs. Administering the pre-assessment immediately upon introduction of the challenge is intended to strengthen the assessment framework by enabling comparisons between students' initial perceptions and subsequent reflections collected through post-assessment and longitudinal follow-up instruments. This ongoing refinement reflects a continuous-improvement approach, allowing instructional decisions to be informed by emerging evidence and supporting a more robust evaluation of changes in student mindset, engagement, and learning over time. An additional motivation for the timing of the pre-assessment was to preserve the authenticity of students' initial thinking. In an educational environment where generative AI tools are increasingly accessible, capturing baseline responses early helps document students' instinctive reasoning and sensemaking before reliance on external tools. While AI-based technologies can serve as valuable supports for learning, reflection, and iteration, their premature or uncritical use may displace key cognitive processes such as assumption development, conceptual reasoning, and productive struggle; processes that are central to the learning objectives of this challenge. The pre-assessment therefore serves both evaluative and pedagogical purposes by encouraging students to engage cognitively with the problem before additional scaffolding is introduced.

Future work will explore more explicit integration of AI literacy within the challenge, including guided discussions on appropriate and responsible use of AI tools to support, rather than replace engineering reasoning. Planned refinements include clearer expectations regarding independent ideation, structured checkpoints emphasizing human judgment and safety reasoning, and optional reflective prompts that ask students to critically evaluate AI-generated suggestions when such tools are used later in the process. Additional directions may include expanding experimental or demonstration-based components, strengthening safety framing earlier in the challenge, and extending the assessment framework across multiple institutions and course contexts. Although formal standards such as ASTM and consultation with licensed Professional Engineers were not explicitly incorporated into this iteration of the challenge, future implementations may include structured prompts that ask students to identify when consultation with domain experts or reference to applicable standards would be appropriate in real-world practice, thereby strengthening connections between conceptual analysis, safety, and professional responsibility. Overall, these efforts aim to preserve the cognitive benefits of open-ended problem solving while adapting the challenge to an evolving technological and educational landscape.

Recommendations for Early and Cross-Curricular Implementation

Findings from this study suggest that open-ended, challenge-based problems such as the "*Think, Act, and Feel Thermodynamics*" activity can be productively implemented earlier and more broadly across the chemical engineering curriculum, including first-fundamentals courses such as material and energy balances. In early courses, similar challenges can be scaled by simplifying the physical system while preserving the essential features that drive learning: authentic context, limited information, realistic constraints, and the requirement that students articulate assumptions, justify model selection, and reason about feasibility and safety. Introducing such experiences early can help normalize ambiguity and shift students' perceptions of engineering problem solving away from equation selection toward sensemaking and judgment, which may reduce the shock often encountered later in junior-level courses.

Evidence from this work further suggests that the approach is broadly transferable across undergraduate engineering courses, as the core learning mechanisms, iterative reasoning, learning from failure, peer comparison of multiple solution pathways, and reflection are discipline-agnostic. Concerns about diminished impact from reusing similar problems can be mitigated through intentional design choices observed in this implementation: emphasizing justification over numerical answers, varying constraints or stakeholder perspectives, incorporating peer evaluation and oral defense, and requiring reflective revision. Because the educational value of the challenge emerged largely from students confronting incorrect assumptions, revising models, and learning from critique rather than converging on a single solution, merely "copying" prior work would not substitute for the cognitive engagement required. Thus, recycling or adapting challenges across cohorts is unlikely to lessen their impact when assessment prioritizes reasoning, decision-making, and reflection over final results.

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Appendix

This attachment includes the Oral Evaluation Rubric and the one-year follow-up survey for reference. The "Points" column shown in the Oral Evaluation Rubric is not visible to students or faculty using the rubric.

Oral Evaluation Rubric

1. Understanding of the Problem and Constraints (16 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The students demonstrate a comprehensive understanding of all aspects of the problem (constraints, environment, and resources). They accurately identify and explain all key challenges: fire hazard, limited resources, and environmental factors such as the 7500 ft elevation among others.	16
	The students understand most aspects of the problem but may miss one or two minor details or fail to address all constraints.	14
	The students show basic understanding but fail to recognize some major challenges or misunderstand key aspects of the scenario.	11
	The students have limited understanding of the problem or misinterpret the constraints, affecting the quality of their solution.	7
	The students show a poor or incomplete understanding of the problem and its constraints.	2

2. Solution Design to Heat Water (20 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The students propose a clear, effective, and creative plan for heating the water using available resources (metal hose, nozzle, thermos, and cabin resources). They make full use of the materials at hand and consider practical constraints like safety, heat transfer, and resource efficiency.	20
	The students present a reasonable plan but may overlook some factors or fail to fully optimize available resources.	18
	The students offer a basic solution that addresses the general goal but may overlook important resources or provide an incomplete solution.	15
	The plan is incomplete or impractical, failing to effectively utilize available resources or consider safety.	11
	The students do not provide a viable or practical plan to heat the water.	6

3. Analysis of Heating up Water Inside the Hose (15 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The students provide a scientifically accurate and detailed analysis of whether water will heat up inside the hose. They clearly explain the relationship between pressure, temperature, and the hose material. They also propose practical methods to facilitate the heating up the water, such as external heat sources.	15
	The students provide a mostly accurate explanation but may miss some minor details or overlook the effect of certain variables.	13
	The explanation is basic, lacking clarity or depth. The students may not consider key variables, such as pressure or hose material.	10
	The analysis is incomplete or incorrect, with significant misunderstandings about the process of heating up water inside the hose.	6
	The students fail to provide an explanation or provide fundamentally flawed reasoning regarding heating up water.	1

4. Pressure Calculation and Analysis (15 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The students accurately calculate or estimate the pressure inside the hose based on the heating process, considering the relevant thermodynamic principles. They offer a detailed explanation and discuss safety factors.	15
	The students provide a mostly correct estimation or explanation, but some minor errors or omissions affect the technical accuracy.	13
	The students provide a rough estimate or incomplete explanation, missing some key details or misapplying basic principles.	10
	The students offer little to no explanation or an incorrect calculation regarding the pressure inside the hose.	6
	The students fail to address the pressure issue or provide a fundamentally incorrect analysis.	1

5. Safety and Environmental Considerations (5 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The students demonstrate a strong understanding of the safety risks involved, including fire hazards, pressure buildup, and potential injuries. They provide clear and practical solutions to mitigate these risks.	5
	The students identify most major safety risks but may overlook some minor issues or provide less effective mitigation strategies.	4
	The students recognize some safety risks but fail to offer clear or comprehensive solutions.	3
	The students fail to address key safety risks or offer inadequate or unsafe solutions.	2
	The students fail to address safety risks or provide no mitigation strategies.	1

6. Creativity and Resourcefulness (5 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The students show exceptional creativity and resourcefulness in utilizing the available materials (hose, nozzle, thermos) to solve the problem. They explore multiple innovative ways to overcome the scenario's challenges.	5
	The students show creativity but may miss some opportunities for resource optimization or innovation.	4
	The students present a basic solution with little creativity, relying mostly on conventional approaches.	3
	The students fail to show creativity and do not explore alternative solutions beyond basic ideas.	2
	The students do not demonstrate creativity or resourcefulness.	1

7. Clarity and Communication (4 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The presentation is clear, well-organized, and logically structured. The students communicate their solution in an easy-to-follow and engaging manner.	4
	The presentation is mostly clear, but some parts may be slightly disorganized or unclear.	3
	The presentation is understandable but lacks clarity or organization in certain areas.	2
	The presentation is difficult to follow or poorly structured.	1
	The presentation is unclear or disorganized, making it hard to understand the solution.	0

8. Bonus Points Eligibility (20 points maximum)

Choose ONLY 1 OPTION by placing an "x" right next to the selected answer from the choices below:

		Points
	The solution is highly original and innovative, proposing new, effective methods while demonstrating a profound understanding of the problem, addressing all relevant details, challenges, and obstacles with clear reasoning and deep technical insight.	20
	The solution is creative and introduces new ideas while still relying on some conventional approaches, covering most key details with a strong understanding and solid reasoning, though a few aspects could be further explored or explained in more depth.	18
	The solution is somewhat creative, relying on standard methods with limited originality, addressing the main aspects but missing key details, and demonstrating a basic understanding of the problem with a somewhat superficial explanation and incomplete justification of key concepts.	15
	The solution lacks creativity, relying on basic methods with few original ideas, overlooks important details that affect its feasibility, and demonstrates limited understanding with significant gaps in reasoning and a lack of clear technical justification.	11
	The solution is uncreative, relying on simplistic approaches without new ideas, lacks attention to detail with critical aspects overlooked, and demonstrates minimal understanding with little to no technical reasoning.	6

One-year Follow-up Survey

Section 1 of 6

Think, Act, and Feel Thermodynamics — one-year follow up Survey

Please help me make the learning of *Chemical Engineering Thermodynamics II* topics more enjoyable by providing your input!

Purpose of this Survey: To assess how the "mountain cabin challenge – heating water to make soup" (*Think, Act, and Feel Thermodynamics*) experience influenced your ability to create value through engineering thinking, one year after completing the activity.

Did you complete the *Think, Act, and Feel Thermodynamics* challenge in Thermodynamics II? *

- ○ Yes
- ○ No

How clearly do you remember the scenario and purpose of the challenge? *

- ☐ Not at all
- ☐ Slightly
- ☐ Somewhat clearly
- ☐ Perfectly clearly

Since then, which of the following experiences have you had? *(Select all that apply)* *

- ☐ Internship/Co-op
- ☐ Undergraduate Research
- ☐ Senior Design/Capstone
- ☐ Other coursework
- ☐ None

Section 2 of 6

Reflection on the Experience

Description (optional)

When you recall the challenge, what stands out the most? *

- [ ] Technical problem-solving
- [ ] Teamwork and creativity
- [ ] Safety and real-world constraints
- [ ] Sense of fun/unexpectedness
- [ ] Realization of value creation
- [ ] Other:

In one or two sentences, what personal takeaway do you still remember from that experience? *

Short answer text

After section 2 Continue to next section

Section 3 of 6

Creating Value Mindset

Description (optional)

Since the challenge, how often have you spotted needs or opportunities to improve something in a project or organization? *

- [ ] Very often
- [ ] Sometimes
- [ ] Rarely
- [ ] Never

The challenge emphasized feasibility, safety, and impact. How much has that mindset influenced your engineering approach? *

- [ ] Strongly
- [ ] Occasionally
- [ ] Aware but seldom applied
- [ ] No influence

Rate how well the challenge helped you connect Thermodynamics concepts with real-world outcomes. *

- [ ] Excellent
- [ ] Good
- [ ] Somewhat
- [ ] Weak

One year later, how confident are you in turning ideas into useful or valuable results? *

- [ ] Very confident
- [ ] Somewhat
- [ ] Neutral
- [ ] Not confident

How relevant do you find entrepreneurial-minded learning (EML) frameworks such as Curiosity – Connections – Creating Value to engineering education? *

- [ ] Very relevant
- [ ] Somewhat
- [ ] Unsure
- [ ] Not relevant

Section 4 of 6

Application Beyond the Course

Description (optional)

Have you applied this "Think-Act-Feel" mindset in any of the following? *

- [ ] Research
- [ ] Internship/Co-op
- [ ] Capstone
- [ ] Other classes
- [ ] Everyday life

Describe one situation you experienced after completing the challenge, where you recognized a need, acted on it, and created value for others. *

Long answer text

To what extent did this experience prepare you to create value in complex or uncertain situations? *

- [ ] A great deal
- [ ] Somewhat
- [ ] Slightly
- [ ] Not at all

Section 5 of 6

Sustained Impact and Feedback

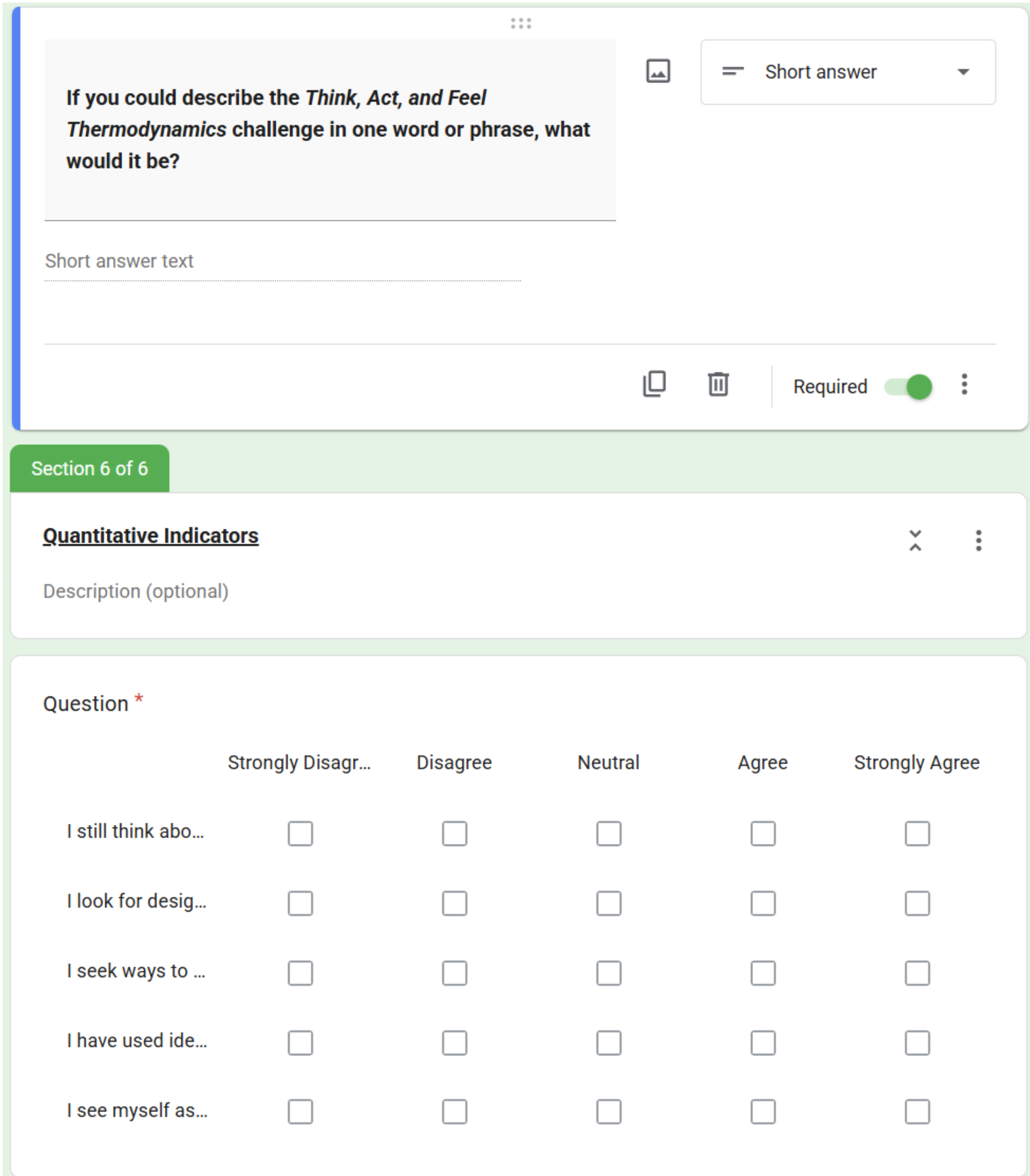
Description (optional)

What part of the challenge had the most lasting influence on you? *

Short answer text

What could have made the experience even more valuable or meaningful? *

Long answer text



If you could describe the *Think, Act, and Feel Thermodynamics* challenge in one word or phrase, what would it be?

Short answer

Short answer text

Required

Section 6 of 6

Quantitative Indicators

Description (optional)

Question *

	Strongly Disagr...	Disagree	Neutral	Agree	Strongly Agree
I still think abo...	☐	☐	☐	☐	☐
I look for desig...	☐	☐	☐	☐	☐
I seek ways to ...	☐	☐	☐	☐	☐
I have used ide...	☐	☐	☐	☐	☐
I see myself as...	☐	☐	☐	☐	☐

These full sentences are shown below:

I still think about thermodynamic principles when tackling real problems.
I look for design choices that improve safety, cost, or sustainability.
I seek ways to make engineering outcomes more useful to others.
I have used ideas from the challenge in later work.
I see myself as someone who can create value through engineering.