Fostering Critical Thinking through Real-World Case-Based Learning in Construction Engineering Education

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Abstract

Critical thinking is recognized as a key competency in engineering education and is commonly included among learning outcomes defined by accreditation agencies and higher education quality assurance frameworks. However, its operationalization and assessment remain challenging, particularly in highly applied technical courses. This study examines the development of critical thinking in an undergraduate construction engineering course through the implementation of three real-world case-based activities drawn from professional practice. An exploratory and descriptive research design was adopted, with no experimental manipulation. Critical thinking was analyzed using a rubric based on the Paul and Elder Intellectual Standards, employed as an analytical framework to examine patterns in students' reasoning across activities. The analysis focused on a subgroup of 14 students who completed all three activities. Descriptive results reveal differentiated developmental patterns across the nine critical thinking standards proposed by Paul and Elder, indicating that the criteria do not evolve uniformly across successive case-based activities. Standards associated with foundational and analytical processes exhibit relatively stable performance, while those linked to more complex reasoning show more pronounced changes across activities. Academic performance and student perception indicators were examined as complementary contextual information. Descriptive differences in final course grades and pass rates are observed according to levels of participation in the activities, without implying causal relationships. Perception data, drawn from an institutional instrument, are used to contextualize the findings and show relatively stable trends across academic terms. Overall, the findings highlight the value of real-world case-based activities, analyzed through an explicit critical thinking framework, for revealing differentiated patterns of reasoning development in highly applied engineering courses.

Keywords: Critical Thinking, Case-Based Learning, Construction Engineering Education, Rubric-Based Assessment

Introduction

Critical thinking constitutes a core competency in engineering education, especially in applied domains where technical problem-solving, information evaluation, and evidence-based decision-making are essential to professional practice. In construction engineering, these requirements arise early in technical courses that require students to analyze open-ended situations, evaluate alternatives, and justify decisions under normative, technical, and contextual constraints characteristic of professional environments [1], [2].

Despite its recognized importance, multiple studies indicate that the development of critical thinking during undergraduate education is not consistently addressed explicitly within disciplinary courses, even when curricula identify it as a transversal competency and accreditation agencies include it among their evaluation criteria [2]. Frequently, instructional emphasis remains on mastering technical content and standardized procedures, which limits opportunities for systematic analysis, argumentation, and informed decision-making in real-world contexts [1].

To address this gap, the engineering education literature proposes various pedagogical strategies that situate learning in contexts closely aligned with professional practice. Among these, real-world case-based activities are noted for their potential to support knowledge integration, technical reasoning, and the evaluation of alternatives in applied settings. However, prior research cautions that implementing active learning methodologies alone does not necessarily result in significant changes in students' perceptions of learning, as these indicators often remain stable and are influenced by cohort-specific characteristics [3].

Within this context, the present study investigates the development of critical thinking in construction engineering students through the implementation of real-world case-based activities in a highly applied technical course. The analysis integrates evidence from academic performance, student participation, and student perceptions to contribute situated evidence regarding the use of case-based methodologies in engineering education.

Despite increasing interest in these approaches, gaps remain in the literature concerning how critical thinking manifests and evolves in highly applied technical courses, particularly when students participate in successive real-world case-based activities within a single course. Specifically, there is limited empirical evidence that examines, in an integrated manner, critical thinking performance, student participation in case-based activities, and their relationship with academic outcomes in disciplinary contexts such as construction engineering.

To address this gap, the study is guided by the following research questions:
How does students' critical thinking performance evolve across successive real-world case-based activities in a construction engineering course, as assessed using a rubric based on Paul and Elder's criteria? What *descriptive relationships are observed among students' participation in case-based activities, their critical thinking performance, and their academic outcomes in the course?*

Literature review

The literature characterizes critical thinking as a complex competency that integrates higher-order cognitive skills, metacognitive processes, and dispositions associated with judgment and decision making. However, there is limited consensus regarding its operational definition and the most appropriate mechanisms for teaching and assessing it in higher education contexts, particularly in technically oriented programs [1], [2].

Synthesis studies and meta-analyses document a wide range of approaches and instruments used to promote and assess critical thinking in higher education, as well as persistent challenges related to conceptual consistency and the measurement of this competency within specific disciplinary contexts [2]. This methodological diversity complicates cross-study comparisons and underscores the need for explicit analytical frameworks aligned with the nature of engineering problem-solving [1].

In engineering education, these challenges are intensified by the traditional emphasis on technical content mastery and the correct execution of standardized procedures, which can overshadow deeper analysis of the reasoning underlying technical decision-making [3]. Several studies note that assessing critical thinking in engineering courses remains difficult, particularly when the objective is to capture reasoning processes situated in authentic and highly applied contexts [4].

From a professional practice perspective, critical thinking is closely linked to the ability to analyze technical alternatives, assess risks, and make decisions under uncertainty. Studies based on graduates' and professionals' perceptions indicate that these competencies are highly valued in the workplace, yet are not always explicitly developed during undergraduate education [5]. The literature consistently suggests that critical thinking does not emerge spontaneously from technical content mastery alone but requires intentional, structured instructional opportunities [2], [5].

Among pedagogical strategies for fostering critical thinking, problem-based and real-world case-based learning are particularly relevant in engineering education, as they situate learning in contexts closely aligned with professional practice and promote knowledge integration, technical argumentation, and the evaluation of alternatives [6]. Yu and Zin (2023) report that these methodologies may contribute to the development of higher-order cognitive skills; however, their effectiveness depends heavily on instructional design and the explicit articulation of the analytical criteria employed [6].

Studies by Sukackė et al. [7], Qamar et al. [8], and Shirazi and Chang [9] caution that incorporating active learning methodologies does not necessarily ensure significant changes in students' perceptions of learning. These studies report that perception-based indicators tend to remain relatively stable, as they are influenced by cohort-specific contextual factors and the characteristics of the assessment instruments used. This may result in discrepancies between observed improvements in performance and more modest changes in perceived learning.

Within this context, the use of real-world case-based activities evaluated through explicit analytical frameworks is proposed as a relevant strategy for making critical thinking visible in technical engineering courses [1]. Reported experiences across engineering disciplines suggest that engagement with authentic and complex problems, combined with performance-based assessment, enables a deeper examination of the reasoning processes students employ when addressing open-ended technical decisions [8], [9].

Based on the reviewed literature, gaps remain in the operationalization and assessment of critical thinking in highly applied courses, particularly in construction engineering. Specifically, there is a lack of studies that integrate successive real-world case-based activities with explicit analytical frameworks and jointly examine critical thinking performance, student participation, and their relationship with academic outcomes within a single course. This gap underscores the need to explore situated instructional experiences that enable analysis of how critical thinking manifests in contexts closely aligned with professional practice and how such practices can be incorporated to strengthen its development.

Methodology

This study employs an exploratory, descriptive research design with no experimental manipulation. Its purpose is to analyze patterns in the implementation of real-world case-based activities and their relationships with the evolution of critical thinking, academic performance, and student perceptions in a construction engineering course. The study does not seek to establish causal relationships; rather, it aims to describe and examine observable trends within the instructional context under consideration. This approach is consistent with the applied nature of the course and the research questions, which focus on changes in critical thinking performance over time and on the relationships among student participation, performance, and academic outcomes. The study was conducted within an undergraduate Construction Engineering program, specifically in the Concrete Technology course, offered during the fourth semester. The initial cohort consisted of $n = 31$ students (Spring semester 2025). However, it should be noted that the subgroup of students who completed the full implementation process consisted of 14 students. The criteria and procedures used to filter the final sample are described in a subsequent section.

Case-Based activities

Throughout the course, three real-world case-based activities were implemented. These activities were designed around authentic professional practice scenarios and aligned with core technical decisions in construction engineering, applicable regulatory frameworks, and the learning outcomes defined in the course syllabus. The critical-thinking activities were conducted during regular course sessions; therefore, only students who attended class could participate. Participation was voluntary and required informed consent. After review, participation was incentivized through extra credit applied to the unit's summative assessment. No penalties were imposed on students who chose not to participate or who were absent from class. Table 1 presents the topics and objectives of the real-world case-based activities implemented in this study. Due to space constraints, the full activity descriptions are not included in the main text; however, the specific questions associated with each activity are provided in the appendices.

Table 1. Overview of real-world case-based activities implemented in the course.

Activity: Title	Topic	Objective
1: Proportioning Workshop	Concrete mix design considering material properties and constraints associated with pumping operations. *(Aligned with the contents of Summative Assessment 1, S1).*	By the end of the activity, students will be able to reason as engineers-in-training when proportioning a concrete mix, linking technical calculations to evidence-based decision-making, and evaluating the coherence among material properties, construction conditions, and the expected performance of concrete.
2: Evaporation Rate Workshop	Evaluation of concrete evaporation rate under specific on-site environmental conditions. *(Aligned with the contents of Summative Assessment 2, S2).*	By the end of the activity, students will be able to reason as engineers in training by connecting the calculation of concrete evaporation rate with the interpretation of environmental conditions, the identification of critical factors, and evidence-based technical decision-making to prevent on-site defects.
3: Statistical Evaluation of Concrete Workshop	Statistical analysis of concrete strength test results to support acceptance or rejection decisions. *(Aligned with the contents of Summative Assessment 2, S2).*	By the end of the activity, students will be able to critically analyze concrete strength results using statistical quality control tools, compare alternative interpretations, and issue evidence-based technical judgments regarding material acceptance and construction planning.

Three assessment instruments and data sources were used in this study to collect the data, as described below.

First, Critical thinking was assessed using a rubric based on the model proposed by Paul and Elder [1]. Table 2 presents this model, which consists of nine critical thinking standards. The questions associated with these standards serve as cognitive scaffolding that supports students in questioning, reviewing, and refining their reasoning. Rather than focusing solely on the final answer, these questions encourage explanation, justification, and evaluation of the decisions made, thereby promoting deeper and more transferable understanding. In this study, these questions were adapted for each real-world construction case-based activity (Table 1). The full set of questions associated with each activity is provided in the appendices.

Table 2. Critical thinking standards and associated cognitive scaffolding questions (adapted from Paul and Elder [1]).

Critical Thinking Standards[1]	Cognitive scaffolding questions
Clarity	Could you elaborate further? Could you give me an example? Could you illustrate what you mean?
Accuracy	How could we check on that? How could we find out if that is true? How could we verify or test that?
Precision	Could you be more specific? Could you give me more details? Could you be more exact?
Relevance	How does that relate to the problem? How does that bear on the question? How does that help us with the issue?
Depth	What factors make this a difficult problem? What are some of the complexities of this question? What are some of the difficulties we need to deal with?
Breadth	Do we need to look at this from another perspective? Do we need to consider another point of view? Do we need to look at this in other ways?
Logic	Does all this make sense together? Does your first paragraph fit in with your last? Does what you say follow from the evidence?
Significance	Is this the most important problem to consider? Is this the central idea to focus on? Which of these facts are most important?
Fairness	Do I have any vested interest in this issue? Am I sympathetically representing the viewpoints of others?

Second, we have the Rubric-Based assessment, for this, each standard was evaluated on a five-level scale, with 1 representing the lowest level of performance and 5 the highest. This resulted in a maximum possible score of 45 points per activity. The rubric was applied consistently across the three real-world case-based activities. The original version of the rubric and the associated questions are included in the appendices.

Third, academic performance was considered a complementary source of information. The indicators analyzed included students' final course grade and pass/fail status. The final grade was calculated as a weighted combination of the summative assessments (S1 and S2) and the laboratory workshop component, in accordance with the course's assessment scheme. Course approval was determined using the institutional grading scale, in which a final grade of 4.0 or higher indicates a passing grade.

Last, student perceptions were examined using the results from Question 6 of the institutional teaching evaluation survey, which assesses the extent to which practical or applied activities contribute to learning in the course. Data from Question 6 of the teaching evaluation survey were analyzed descriptively and used as contextual information. Results were reviewed across five academic terms in order to situate the findings within the broader course context. It should be noted that this instrument was not designed specifically for the present study and was not used as a direct measure of critical thinking.

Data analysis

The analysis was based on students' responses to the three real-world case-based activities described above, which were part of the regular course implementation. Responses were downloaded from Google Forms and organized in Microsoft Excel, where the data were systematized for analysis. The analytical procedure was structured in two complementary phases. In the first phase, the full cohort of students enrolled in the course (n = 31) was considered. Students' overall performance was analyzed as a function of their level of participation in the proposed activities, categorized according to the number of activities completed (zero, one, two, or three). Academic performance indicators and course pass rates were used to explore general patterns between participation and academic outcomes. In the second phase, the analysis focused on the subgroup of students who completed all three activities (n = 14), allowing for a more in-depth examination of the evolution of critical thinking over the semester. For this group, a rubric based on critical thinking standards was consistently applied across the three activities to identify progressions, recurrences, and changes in how students approached the proposed cases. This analysis was not intended to assign comparative scores, but rather to characterize the development of critical reasoning over time. In addition, descriptive comparisons were conducted among critical thinking performance, academic outcomes, and student perception data derived from the institutional survey, with the aim of exploring potential convergences and tensions across these dimensions. Given the exploratory nature of the study, the sample size, and the non-experimental design, no inferential statistical tests were applied.

From an ethical standpoint, the study was conducted in accordance with institutional guidelines for educational research. All data were derived from regular course activities and institutional evaluation processes, with no additional interventions introduced for research purposes. Data were anonymized prior to analysis, and results are reported in aggregate form to ensure participant confidentiality. Access to student perception data was limited exclusively to aggregated results.

Results

The results are presented in sequence. First, academic performance is reported according to the number of real-world case-based activities completed. Next, the evolution of critical thinking is examined in light of the standards described in the previous sections. This is followed by the results of critical thinking performance by standard. Finally, results from the institutional teaching evaluation survey are presented. Table 3 presents the academic performance of the 31 students enrolled in the course, grouped by the number of real-world case-based activities completed during the semester (0, 1, 2, or 3). For each group, the average final course grade, the number of students who passed the course, and the corresponding pass rate are reported.

Differences are observed in both average final grades and pass rates across the groups. Students who completed all three activities achieved an average final grade of 4.51 and a 100% pass rate, whereas groups that completed one or no activities showed lower averages and lower pass rates. Students who completed two activities exhibit intermediate results in terms of both average final grade and pass rate.

The final course grade serves as a comprehensive indicator of academic performance, integrating multiple assessment components, including written examinations and practical activities outlined in the course syllabus. The results are reported descriptively, given that participation in the activities was voluntary and that the study does not control for prior academic performance or other academic and contextual factors.

Table 3. Academic performance by number of activities completed (grading scale: 1.0–7.0; passing threshold ≥ 4.0; maximum grade: 7.0).

Completed activities	**n**	**Average final grade**	**Students passing (≥ 4.0)**	**Pass rate (%)**
0	3	2.63	1	33.3 %
1	4	1.83	0	0.0 %
2	10	3.32	5	50.0 %
3	14	4.51	14	100.0 %

Regarding the evolution of student performance across activities, Figure 1 illustrates the average critical thinking performance of the 14 students who completed the three case-based activities, assessed using a rubric aligned with the nine Universal Intellectual Standards proposed by Paul and Elder [1]. Criterion-level analysis shows increases in precision, depth, breadth, and significance, with average values in the third activity exceeding those in the first. Notably, depth exhibits a sustained increase across the three activities, suggesting progressive improvement in students' ability to engage with complex aspects of the cases. In contrast, the criteria of clarity, accuracy, relevance, and logic exhibit less variation, remaining within similar ranges throughout the period analyzed. The fairness criterion shows a decrease in the third activity compared to the second. Overall, the radar chart reveals a more homogeneous performance profile in the third activity, characterized by more balanced average values across criteria and fewer extreme scores than in the first activity.

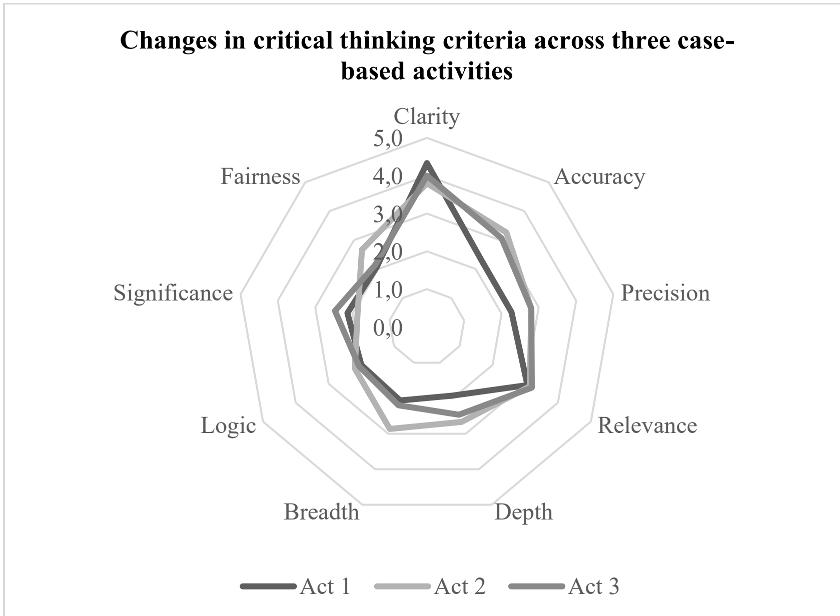

Figure 1. Development of critical thinking across three case-based activities.

The radar chart represents the average scores of the 14 students who completed all activities, assessed through a rubric aligned with the nine Universal Intellectual Standards of Paul and Elder [1]. Higher values indicate stronger performance in each criterion. By disaggregating performance by critical thinking standard, the results shown in Figure 2 are obtained, which present the outcomes for each activity.

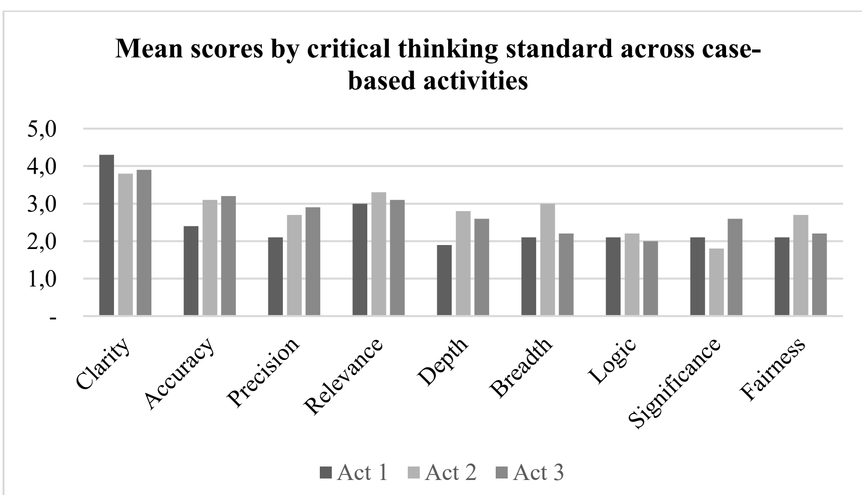

Figure 2. Descriptive comparison of mean scores by critical thinking standard across the three case-based activities.

To facilitate interpretation, Table 4 provides a structured summary of the development patterns observed across the critical thinking standards.

Table 4. Mean performance and observed trends across critical thinking standards.

Standard	1	2	3	Trend	Interpretive notes
Clarity	4.3	3.8	3.9	*Stable/slight decrease*	High mean scores were observed from the first activity, followed by a slight decrease, suggesting early consolidation rather than incremental development.
Accuracy	2.4	3.1	3.2	*Increasing*	Mean scores show a progressive increase across activities, indicating improved verification and correctness of responses.
Precision	2.1	2.7	2.9	*Increasing*	A gradual and consistent increase suggests greater specificity and detail in students' reasoning over time.
Relevance	3.0	3.3	3.1	*Stable*	Scores remain relatively constant across activities, indicating consistent alignment of responses with the problem context.
Depth	1.9	2.8	2.6	*Increasing (sustained)*	A clear and continuous increase across activities, representing one of the most pronounced developments among the standards.
Breadth	2.1	3.0	2.2	*Increasing*	Improvement is observed mainly between the first and second activities, followed by stabilization in the third.
Logic	2.1	2.2	2.0	*Stable*	Mean scores remain relatively low and stable, with no clear pattern of improvement across activities.
Significance	2.1	1.8	2.6	*Increasing*	A moderate upward trend, particularly evident in the third activity, suggesting growing attention to the importance of key issues.
Fairness	2.1	2.7	2.2	*Increasing (sustained)*	A slight increase is observed between the beginning and the end of the course; however, a substantial improvement is evident in the intermediate activity.

Note. Scores range from 1 to 5. Values correspond to mean rubric scores for students who completed all three activities.

Overall, the descriptive analysis reveals differentiated development patterns across the critical thinking standards. While dimensions such as depth, precision, accuracy, breadth, and significance exhibit a clear increasing trend across activities, other standards, such as clarity, relevance, and logic, remain relatively stable over time, suggesting that these skills may have already developed at earlier stages of the course or are less sensitive to short-term instructional interventions. In contrast, fairness displays a non-linear pattern, with higher scores in the second activity, followed by a decrease in the third, indicating that this dimension may be particularly influenced by task design and collaborative dynamics rather than by cumulative progression.

To examine student perceptions, question 6 of the institutional teaching evaluation survey was used (Tab. 5). This item asks whether the instructor implemented applied activities that contributed to achieving learning outcomes (e.g., problem solving, analysis of real-world situations, or practical activities).

Table 5. Percentage of students who responded “agree” or “strongly agree” to Question 6 of the institutional teaching evaluation survey across five consecutive academic terms.

Term	**202320**	**202410**	**202420**	**202510**	**202520**
% Agree or Strongly Agree	81.2%	86.2%	89.7%	47.8%	85.0%
Average Grade	3.47	4.27	3.92	3.68	3.67
Pass Rate (%)	46.8	78.9	64.3	52.6	66.7

Across the five academic terms analyzed, student perceptions of practical learning experiences show a relatively stable pattern. However, a noticeable decline is observed in the term immediately preceding the intervention (202510), which corresponds to a course offering that was implemented without real-world case-based activities, similar to the earlier terms.

In this context, indicators of student perception, final course grade, and pass rate are used as contextual references, without implying causal relationships among them or with the implementation of specific activities. Nevertheless, the observed evolution of academic indicators over time suggests the relevance of further exploring, in future course offerings, the potential contribution of active learning methodologies and workshops explicitly oriented toward the development and assessment of critical thinking in relation to academic performance.

Discussion

The results of this study provide an opportunity to examine the development of critical thinking in a highly applied construction engineering course from a situated perspective, integrating evidence from performance in case-based activities, student participation, and contextual indicators of perception and academic performance. Given the exploratory and descriptive nature of the study, the discussion focuses on interpreting observed patterns across critical thinking evaluation criteria rather than establishing causal relationships, consistent with prior research adopting similar analytical approaches in engineering education [4], [7].

Overall, the findings indicate that critical thinking standards do not develop uniformly throughout the course, but rather exhibit differentiated trajectories aligned with their cognitive complexity and contextual demands. This interpretation is consistent with the Critical Thinking Standards framework proposed by Paul and Elder [1], which conceptualizes critical thinking as a system of interrelated dimensions that do not necessarily evolve linearly or simultaneously (Figure 3).

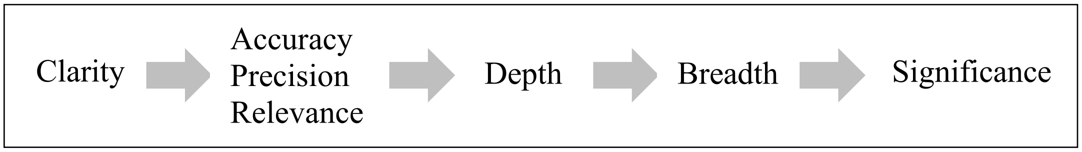

Figure 3. Conceptual progression of critical thinking standards based on the Paul–Elder framework.

Within this framework, foundational standards such as clarity and relevance exhibit relatively high and stable values from the first activity onward (Figure 2). This pattern suggests that students entered the course with an established capacity to communicate ideas clearly and remain aligned with the problem context. As argued by Zapalska et al. [11], the early consolidation of lower-complexity cognitive skills can function as a necessary foundation for the development of more advanced forms of reasoning. From this perspective, the observed stability does not imply stagnation but rather reflects a level of mastery that allows cognitive resources to be directed toward more complex analytical dimensions.

In contrast, standards associated with analytical refinement and progressive reasoning (such as accuracy and precision) show gradual increases across activities. These trends may be associated with repeated engagement in structured analytical tasks and systematic feedback throughout the course. Such patterns are consistent with prior studies indicating that iterative exposure to case-based reasoning supports incremental improvements in the verification, correction, and specificity of technical responses in applied engineering contexts [9], [10].

Standards related to higher-order reasoning processes, including depth, breadth, and fairness, exhibit more variable, non-linear patterns across activities. Depth, in particular, shows a sustained increase, suggesting progressive improvement in students' ability to analyze assumptions, address complexity, and engage with underlying conditions of the cases examined. Breadth improves primarily between the first and second activities before stabilizing, indicating that the consideration of multiple perspectives may be activated relatively early but consolidated through continued exposure to contextualized problems. Fairness exhibits a non-linear pattern, reinforcing the notion that this standard is highly sensitive to task design, contextual ambiguity, and the degree of interpretive openness required by each activity [1].

These patterns align with research indicating that critical thinking in engineering extends beyond clarity of communication and involves higher-order cognitive processes, such as deep analysis, integration of multiple sources of information, and evaluation of alternatives prior to decision-making [12]. From this perspective, the observed differentiation among standards reflects a transition from foundational cognitive processes to more complex, context-dependent forms of reasoning, particularly when students engage with authentic, open-ended professional scenarios [5], [6], [8].

Regarding academic performance, descriptive differences in average final grades and pass rates were observed across levels of participation in case-based activities. Although these results do not support causal inference, they highlight student participation as a relevant contextual variable in the instructional process. This finding aligns with previous studies suggesting that academic performance, critical thinking development, and student perceptions do not necessarily evolve in parallel, particularly in courses incorporating active learning methodologies [4], [7].

Similarly, student perceptions captured through Question 6 of the institutional instrument remain largely stable across the analyzed terms, except for the period immediately preceding the intervention. Consistent with prior research, perception-based indicators appear to be influenced by cohort-specific contextual factors and therefore offer limited sensitivity as direct measures of complex cognitive development [5]. Accordingly, these data are interpreted as complementary indicators of the learning experience rather than explanatory variables for observed performance or critical thinking outcomes.

Taken together, the results support the use of real-world case-based activities analyzed through explicit critical thinking frameworks to identify differentiated developmental patterns in highly applied technical courses. Rather than exhibiting uniform progression, the findings highlight standard-specific trajectories that are sensitive to instructional design, task complexity, and contextual demands. This interpretation reinforces prior work emphasizing the value of authentic problem contexts and theoretically grounded analytical frameworks for examining critical thinking in engineering education [1], [5], [6], [8].

Conclusion

This study suggests that the development of critical thinking in technical and highly applied contexts does not follow a uniform trajectory; rather, it responds in differentiated ways to the characteristics of learning activities and the type of reasoning required. Through real-world, case-based activities and analysis grounded in the Paul and Elder framework, the study identifies specific patterns in the evolution of critical thinking standards, providing situated empirical evidence of how these dimensions manifest and develop within a construction engineering course.

The findings show that the critical thinking criteria do not evolve uniformly over the course, confirming that their development follows differentiated trajectories depending on the nature of the reasoning involved. In particular, criteria associated with foundational and analytical skills show relatively high performance from the initial activities, suggesting prior mastery that serves as a baseline for reasoning. In contrast, criteria linked to higher-order cognitive processes, such as depth and the consideration of multiple perspectives, display the greatest relative growth across the case-based activities, highlighting the potential of this instructional design to foster more reflective, integrative, and contextually grounded forms of thinking.

The analysis of academic performance further reveals descriptive differences in final course grades and pass rates according to students' levels of participation in practical activities. Although these results do not support causal inferences, they reinforce the importance of considering student participation as a key component of the instructional process in technical courses, particularly when activities require analysis, argumentation, and evidence-based decision-making.

Student perception indicators, derived from a specific item of the institutional evaluation instrument focused on practical activities and their contribution to learning, are used in this study as contextual references. These indicators help situate the findings within the historical trajectory of the course, but do not constitute direct measures of critical thinking development, nor do they independently explain the observed academic outcomes.

Taken together, the results support the use of real-world, case-based activities, analyzed through explicit critical-thinking frameworks, to make visible differentiated patterns of development in highly applied technical courses. This work contributes to the engineering education literature by demonstrating that critical thinking manifests in a situated and complex manner and that its analysis benefits from approaches aligned with authentic professional decision-making rather than from generic instruments or measures based solely on perception.

Finally, the findings of this study open several avenues for future research to deepen the understanding of the development of critical thinking in technical engineering courses. There is a need to further refine assessment instruments to reduce potential sources of bias, improve sensitivity to different dimensions of critical thinking, and strengthen alignment with specific case-based interventions, strengthen the design of case-based practical activities, and promote sustained student participation, while accounting for variables such as class attendance. Additionally, the intentional and explicit integration of these strategies within course methodologies warrants further exploration, as does the examination of longitudinal designs across the curriculum, including critical thinking assessments in subsequent or capstone-level courses. Given that the Construction Engineering program spans 10 semesters, future studies could examine this competency at different curricular milestones to analyze its progressive development and its articulation with increasingly complex, authentic case-based academic experiences.

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Appendix

Appendix 1. Critical Thinking rubric based on the Paul and Elder framework

Critical Thinking Element	Guiding Questions (Paul & Elder)	5 – Excellent	4 – Good	3 – Acceptable	2 – Insufficient	1 – Deficient
Clarity	Could you elaborate further? Could you illustrate what you mean? Could you provide an example?	The idea is expressed with complete clarity; it is easy to understand without ambiguity. Includes examples. explanations. and sufficient development.	The idea is generally clear but could be further elaborated or supported with additional examples.	The idea is understandable but contains unclear or underdeveloped parts; greater precision or examples are needed.	The idea is poorly expressed. with ambiguities or insufficient explanation; it is difficult to understand.	The idea is confusing. incoherent. or impossible to understand; it is neither explained nor illustrated.

Accuracy	How could we verify this? How could we test whether this is true?	All information is correct. verifiable. and based on reliable sources; no errors are present.	Most information is correct. with minor details requiring verification.	Contains some inaccuracies or unverified data; further review is required.	Contains several errors or questionable claims; verification is insufficient.	Information is incorrect. unverifiable. or incompatible with available evidence.
Precision	Could you be more specific? Could you provide more details?	Provides concrete details (who. how. when); includes data. examples. and specificity.	Generally specific and detailed. though further clarification may be needed in some areas.	Provides general information but lacks specific details or concrete examples.	Vague. general. or incomplete; essential details are missing.	No details are provided; the response is entirely general or imprecise.
Relevance	How does this relate to the problem or question?	All information is pertinent and directly connected to the topic or problem.	Mostly relevant. with some secondary but acceptable elements.	Mixes relevant ideas with tangential ones; improved focus is needed.	Several ideas are irrelevant or disconnected from the central issue.	Information is unrelated to the problem or question.
Depth	What makes this a difficult problem? What complexities are involved?	Addresses the complexity of the issue. analyzing causes. implications. and challenges rigorously.	Recognizes complex aspects but could further develop the analysis.	Mentions superficial difficulties without in-depth analysis.	Describes the problem in an overly simple way. without acknowledging its complexity.	Does not identify any complexity; analysis is entirely superficial.
Breadth	Do we need to consider another perspective or point of view?	Considers multiple perspectives. recognizes alternative viewpoints. and critically compares them.	Includes some additional perspectives. though analysis is limited.	Acknowledges at least one alternative perspective without deeper analysis.	Superficially mentions other viewpoints without integrating them.	Considers only one perspective; the view is highly limited.

Logic	Do the ideas make sense together? Do conclusions follow from the evidence?	Ideas flow coherently; there are no contradictions. and reasoning is well supported.	Generally coherent. with minor gaps or weak connections.	Shows minimal coherence; stronger transitions and explanations are needed.	Contains several contradictions or logical gaps; structure is confusing.	Lacks logic; ideas are disconnected or contradictory .
Significance	What is the most important issue or central idea?	Focuses on what is most important; clearly identifies and develops the central idea.	Appropriatel y prioritizes information but includes some secondary elements.	Mixes key ideas with secondary ones without clear prioritization.	Focuses on minor aspects. neglecting essential issues.	Fails to identify the central point; content is irrelevant or scattered.
Fairness	Am I representing other viewpoints empathetically? Am I aware of my own biases?	Presents balanced arguments. recognizes personal biases. and evaluates all perspectives fairly.	Generally fair. with minor biases that do not dominate the analysis.	Shows noticeable bias that partially affects the analysis.	Strongly biased; alternative perspectives are not considered.	Completely biased; dismisses or ignores any opposing viewpoints.

Appendix 2. Questions for activities 1, 2, and 3

Case-Based Activities and Guiding Questions Aligned with Critical Thinking Criteria

1. Proportioning Workshop

- Clarity: What do you understand by “Proportioning”? Explain it in your own words and provide a practical construction-site example.
- Accuracy: How can we verify that the water demand values used correspond to the actual aggregate conditions and target slump?
- Precision: What additional data would be required to make the calculation more specific (e.g. aggregate density, actual moisture content)?
- Relevance: How does the pumping condition (150 m height) directly influence Proportioning?
- Depth: What factors make it difficult to ensure that concrete can be pumped over that distance? What challenges must be considered in the design (e.g. pumping pressure, segregation, slump)?

- Breadth: From another perspective, how would the mix design change if, instead of architectural walls, we used other materials? Were the concrete placed in a slab exposed to a marine environment or extreme climate?
- Logic: Review your calculations and justifications. Does the relationship between water/ cement and admixtures make technical sense as a whole? Are your conclusions consistent with the data used?
- Significance: Among all the factors analyzed, which do you consider most critical for ensuring the quality of this specific concrete (e.g., strength, workability, esthetics, pumpability)? Why?
- Fairness: Did your group consider all proposed ideas, or were some dismissed prematurely? For example, assumptions regarding workability. admixture use, or other aspects. Explain the decisions made and the rationale behind them.

2. Workshop: Concrete Evaporation Rate

- Clarity: What do you understand by evaporation rate in the context of concrete placement? Explain it in your own words and describe why it is important to know this parameter before planning construction operations.
- Accuracy: How can you verify that the environmental data used (temperature, wind, humidity) accurately represent actual site conditions? What sources or instruments should be used?
- Precision: What additional data would be necessary to improve the reliability of the calculation (e.g. concrete temperature, transportation time, solar radiation)?
- Relevance: Why is it important to consider the evaporation rate when deciding the timing or method of concrete placement? What impact could ignoring this parameter have on final concrete quality?
- Depth: What technical factors make controlling water evaporation in concrete on-site complex? Consider variables such as air temperature, wind, setting time, and admixture use.
- Breadth: If the same placement were carried out in a different context (e.g., coastal area, high-altitude site, or extreme wind conditions). How would the procedure or mitigation strategy change?
- Logic: Are your results consistent with the criteria established in Chilean Standard NCh170-2016? Explain whether the relationship between the data used and your conclusions is technically sound.
- Significance: Among all the factors analyzed (temperature, wind, humidity, admixtures, setting time). Which do you consider to have the greatest impact on cracking risk in this case? Justify your choice.
- Fairness: Did you consider all ideas proposed within the group or were some dismissed? Explain what arguments or evidence led you to make specific decisions regarding evaporation control in concrete.

3. Workshop: Statistical Evaluation of Concrete Quality

- Clarity: What do you understand by statistical quality control of concrete? Explain in your own words what it involves and its purpose within the construction process.
- Accuracy: How can you verify that the strength results used are reliable and originate from a controlled procedure? What measures should be taken to ensure test validity?
- Precision: What factors could affect the precision of the measurements (e.g. specimen handling, curing temperature, human or instrumental errors)? How could these sources of error be minimized?
- Relevance: Why is it important to analyze strength results statistically rather than relying solely on the average? How does this analysis influence decisions regarding concrete acceptance?
- Depth: How complex is it to determine concrete conformity when test results show high variability? What technical or environmental factors could explain differences between specimens or batches?
- Breadth: If another control method were applied (e.g, standard deviation, percentile-based criteria, or batch control). How might the conclusions differ? Do you think the moving average method is sufficient on its own?
- Logic: Is there coherence between the results obtained and the conclusions proposed by your group? Explain whether the reasoning used to decide concrete acceptance or rejection is consistent with the data.
- Significance: Among all aspects analyzed (variability, moving average, acceptance limits, standard deviation), which do you consider most influential in the final technical decision? Justify your answer.
- Fairness: Were all possible interpretations within the group considered before reaching a decision? Explain the criteria used to reach technical consensus and how objective evaluation was ensured.