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Proceedings of the International Conference on Teaching and Education
Vol. 1, Issue. 1, 2025, pp. 1-15
DOI: https://doi.org/10.33422/teconf.v1i1.976

ISSN: 3030-0835 online

Structured Rational Thought as a Resource to Design a Binding Case of Physics with Engineering

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Abstract

Designing Engineering Cases contributes to learning Physics principles. This involves a method derived from Structured Rational Thinking. The research objectives were: analyze the design process of the Case by students evaluation, with the dimensions of: clarity, coherence, relevance, sufficiency. It was described the relationship of rational thinking with evaluation. The first stage consisted of theoretically basing pedagogy related with rational thought of ancient Greece; Secondly, was developed the test design through an interaction matrix for order and interpret data that reflect level of conceptualization, according to types of structured thought: logical, methodical, narrative; For each type, dimensions of content, purpose and structure are evaluated, through anecdotal logs of the designed Case ; with a sample of a control and experimental group of 45 students. To measure the impact of understanding, three levels considered: little, moderate and a lot; each level related to a type of rational thinking with its dimensions, coded with an ordinal scale from 1 to 3. A summary table was constructed for identifying type of thought in student's interpretation when wrote logs about the Case readed. The results of evaluation showed optimal levels of relevance and sufficiency; with acceptable assessments that the Case is not totally coherent with a linear reality but complex. Conclusion, Rational Thought is effective to design and study Cases due to its systematic processes, which may improve understanding.

Keywords: Case method, engineering, Hooke's law, inductive thinking, active learning

1. Introduction

According to Malavé (2016), there are difficulties that engineering students face in learning physics, such as conceptual understanding and physics principles. Also, according to Brenzini and Martínez (2012), the effects of the lack of understanding of these principles in students, causes a deficiency in the acquisition of interpretive skills and conceptual-theoretical analysis, and therefore deficiencies in the effective application of knowledge during the circumstantial resolution of practical problems. An "ad hoc" example according to the College of Civil Engineers of Mexico (CICM) (2021), is the collapse of the section of line 12 of the Mexico City metropolitan; in its Tezonco-Olivos station, AGN (2022/1969). Furthermore, the lack of

understanding of "nuclear physical concepts"[1] is one of the factors that generates poor execution of engineering structures projects; For DNV (2021), this is one of the causes that generate design, construction and planning failures in various civil and architectural works. However, for Luna (2015) and Manpower (2019), this problem also brings with it the lack of reliability of graduates from higher schools, which endorse the acquisition of generic and specific skills. Therefore, it is proposed to explore and implement the "Structured Rational Thought" to generate a connection between Physics and engineering, but also investigate the effectiveness of the "Rational Thought" to design engineering cases and try to improve conceptual understanding of physics principles in students. Because if what is studied is not ordered, it is not understood, and if it is not understood, it cannot be explained. Therefore, studying a case methodically designed in a systematic way, could improve the conceptual understanding of the reality studied in a Case. Even the systematic design of a Case promotes the methodical way of study.

From the above, the relevance of the research in inquiring and generating knowledge in relation to the phenomenon: understanding and application of principles of physics to engineering, and with this it is intended to mitigate the consequences that arise from the lack of understanding in the learning of structural mechanics topics; such as lack of employability of university graduates; which according to Manpower (2019) and QS (2022), not only affects the economy of societies, it can also prevent loss of material resources and human lives, due to structural collapses. In addition, the Rational Thought could increase conceptual construction attached to reality; and it could reduce conceptual distortion due to imaginary preconceptions.

2. Research objectives

The general objective is to test the feasibility of implementing the “Rational Thought” as a philosophical and didactic methodological resource to learn engineering principles in structural courses, in the area of physics of professional studies, this through a Case study; As an example, the Higher School of Engineering and Architecture of the National Polytechnic Institute in Mexico. The specific objectives are: (a) first stage of the research: case design, considering the collapse of the “Golden Line of the Mexico City Metropolitan”; (b) second stage: development of didactic design and understanding assessment instrument. From the above, a relationship is established between the phenomenon under study and the research question is posed: How does the Rational Thinking modify the understanding of the concepts of Physics in engineering students?, and this with a methodical way of Case design.

3. Methodology

In the first stage of the research, the approach is qualitative, a descriptive process of case design was carried out: "Physics ignored as a design inadequacy of the collapse of the Metro's Golden Line"; this to answer the question: how to design a Case that involves Physics topics? see table 1; In the process of designing the Case, the following Cases were read: Decoding the DNA of the Toyota production system (1999), see link; Elephant Pums (2008), see link; California Products (2018), see link; review of expert reports and context of the accident, DNV (2021); writing of the first draft of the case, see link case (2022); discussion among peers through a blog on Wordpress, in which 16 discussion threads were registered in relation to the case, Wordpress (2022); adjustments and restructuring of the case, see table 2; and secondly student assessment, testing the dimensions of clarity, coherence, relevance and sufficienfy,

[1] Carcavilla (2019), define the term "nuclear physical concepts" as the set of principles that support the theories by which the notion of force as work is explained and scientifically justified, in relation to deformation of matter.

adapted from Escobar et al. (2022). For the students opinión pilotation, was used dichotomous questions and data triangulation. Then, was developed the test design through an interaction matrix for order and interpret data that reflect level of conprehension, according to types of structured thought: logical, methodical, narrative; For each type, dimensions of content, purpose and structure are evaluated, through anecdotal logs of the designed Case; with a sample of a control and experimental group of 45 students. To measure the impact of understanding, three levels considered: little, moderate and a lot; each level related to a type of rational thought with its dimensions, coded with an ordinal scale from 1 to 3. For example, when people try to explain a phenomenon, they do so in rational ranges: 1) Little attached to the procedure that involves ordering thoughts (pathetic-ethical level); 2) Moderately to the objective deductive scientific procedure level (logical level); 3) Very attached to the objective deductive scientific procedure (methodical level). To measure levels of understanding was used diagnostic survey of 13 questions on a 4-item Likert scale, as well as those obtained from the verification survey of 21 inferential questions of 4 items,

A summary table was constructed for identifying type of thought in student's interpretation when wrote logs about the Case readed. The above, with the following support structure according to HBS (2022), Harvard (2019) and DNV (2021): necessary cause, root cause, immediate cause, prevention, methodical application of systematic causal analysis technique based on barriers and evidence processing method, infra see table 1. In a second stage, of quantitative methodology; the hypothesis that arises as an affirmation will be verified, resulting from the theoretically supported research question: "with the Structural Rational Thought approach for teaching-learning physics principles in engineering, encreases the conceptual understanding capacity".

Table 1. Systematically case design that involves Physics topics. Source DNV (2021), Escobar (2022).

Case design stages and analogous methods used for the design of the Case				
Introduction Cause Zero	History Necessary cause	Background Root cause	Situation Immediate cause	Strategy matter Prevention effects
Systematic causal analysis technique barrier based			Systematic method of evidence processing	
Design		Review	Evaluation	

Table 2. Adjustments and restructuring of the case, as the review stage. Source own.

Phase 1	Phase 2	Phase 3
a) The case length was reduced from 8,591 to 6,064 words; from 58 to 24 pages.	a) Newspaper sources have been reduced, only for illustrative figures. Technical sources have been retained to support tables.	a) The average reading time was estimated at 200 to 300 words/min, with reading time in each case being 20 to 30 min.
b) In the sections, we tried to start with questions to address the reading.	b) Errors in unit designation were corrected.	b) The introduction section was summarized to make the content of the case more succinct.
c) Non-essential portions of text and tables were eliminated (e.g. the history of the subway and the section referring to the "immediate cause" within the case design).	c) In the "root cause" section of the case, the infographic was replaced with a conceptual chart that graphically summarized the content.	c) Technical references from the regulation, Title VI "Structural Safety" were incorporated.
d) All abbreviations of technical terms and associations are referenced in full text.	d) In the "root cause" section, the summary table was eliminated and the analysis of 23 causes that led to the accident were maintained.	

Note: Case review is summarized through a debugging process that includes not only removing and synthesizing case content, also included conceptual review. Sources AGN (2022), DNV (2021), Escobar (2022), FGJ (2021), Belfort (2021), Viadas (2018).

Table 3. Types and Characterization of Structured Thinking: (Ramírez J, 1998); (Engell,2020). According to its action or content. Source own.

Rational Logical Thought	**Narrative Thought**	**Rational Methodical Thought**
Establishes classifications of types and ideal prototypes.	Inductive, establishes relationships or groupings (syntagmatic).	Based on observation of facts. Support doubt with theory and affirm doubt.
Deductive start from Generalitie.	It starts from specificities Case studies.	Intuitive-inductive (divides reality into distinct parts). Doubt.
Based on ontological and teleological construction.	Descriptive dialogic based on social and historical construction.	Post-Judgments.
Homological-Argumentative (premises-a priori judgments).	Based on social interpretation of reality.	Search for meaning by reintegrating reality into its parts deduction.
Based on observation of facts.	Analogue (comparatives).	Establishes classifications of types and experimental prototypes.
Establishes correspondence from a model, canon, general archetype (paradigm).		Reality is constructed, woven from realities (complex nature).

Note: the table shows different theoretical positions in relationship with rational thought, which is the basis of several ancient and contemporary methods, such as the Aristotelian logic, Socratic maieutics and Case method

Figure 1. Types and Characterization of Logical Rational Structured Thinking : According to its purpose or classic form (Engell,2020). Source own.

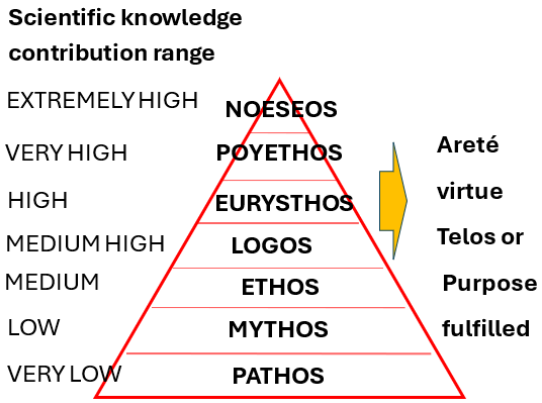


Figure 2. Types and Characterization of Rational Methodical Structured Thinking: According to its purpose or modern form (Engell,2020). Source own.

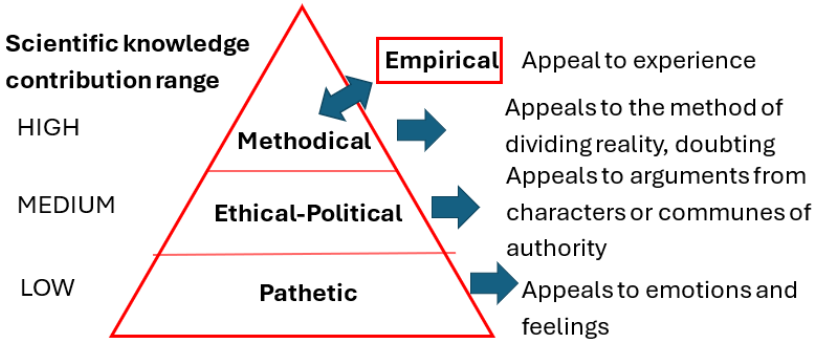
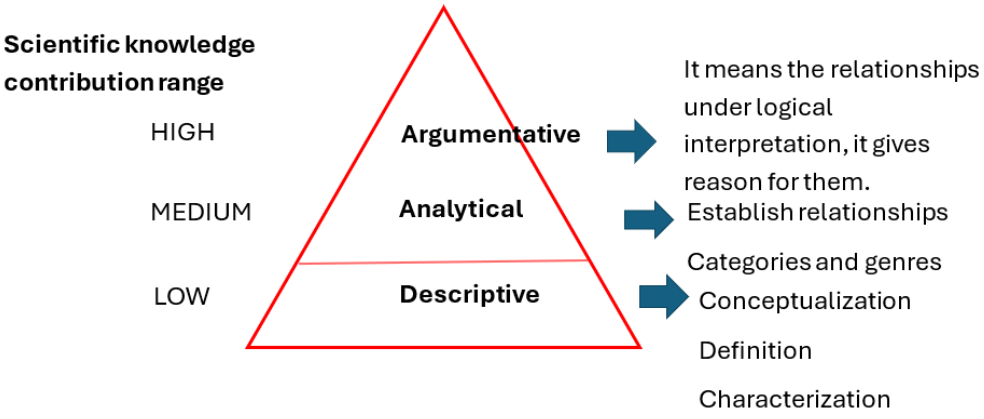


Figure 3. Types and Characterization of Logical Rational Structured Thinking: According to its classical Structure, source own. Source own.



Note: The content of the figures is representative of classical and modern philosophical theoretical compendium, for the measurement of conceptual aspects.

Figure 4. Types and Characterization of Rational Methodical Structured Thinking: According to its modern Structure. Source own.

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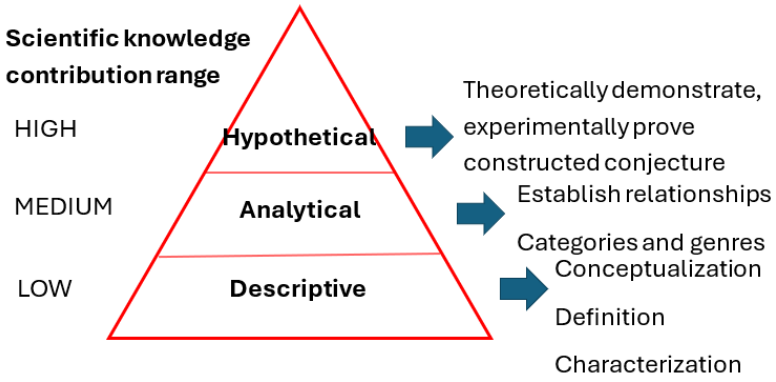


4. Theoretical framework

The reality we perceive is given to us from general schemes; through a structure of deductive thought, Descartes (1628). Our brain analyzes reality by dividing it into as many simple parts as possible = Intuition. Then, a more objective interpretation of the "being" of this is made, through observation. (Descartes, 1628). Giving an account of reality implies knowing the aspects of its being (ontological) and its purpose (entelechy = possibility of being).

What makes that something that we perceive of reality what it is? = ontological or being aspects of that portion of reality perceived as a generality (Aristotle, 353 BC). It is important to characterize the reality that is perceived as a general portion. Identify the invariant features that make that reality what it is. Example: The human body is revealed to us as a total and complete entity, and to understand it we must divide each of its parts or organs, in order to understand the whole from the interaction of its parts.

Methodical thinking consist in abstracting from reality the universal principles that support it, even is an objective observation of the nature of the being of reality, as a perceived fact (Descartes R, 1628); and this is very related with the term of Hypostasis, concept that defines the real being or aspects that support the being (its action and its end) (Aristotle, 353 BC). In the case of this research, the hypostasis are the principles that support the being of any portion of reality studied. It is necessary to generate knowledge rather than truths and beliefs; based on a reliable structure of thought, which goes beyond the structure of thought derived from classical logic. (Leibniz G, 1714). Below in the figure number 5 we see the types of structured reasoning, derived from the theoretical compendium.

Table 4. Types of structured rational thinking. Source own.

Classical (ancient) philosophy	Modern philosophy	Science	Narratives Discourse
Structure of thought based on an "a priori" judgment or premise, from which knowledge develops.	Methodical thinking (starting point problematize the phenomenon) plus rational (logical) thinking.	Modern Philosophy plus Empiricism (causal logical nature)	Social construct and mediated. (Condition of story, discursive nature, narrative) (Baudrillard,1969).

Note: Structural thinking types are abstract and noumenal in nature, yet very useful for learning and measuring
learning levels.

Therefore, Methodical thinking before emotions, instinct or tendencies; even before purely logical thinking. Balancing the ambivalent "rational-emotional", "interpretive-subjective" nature equal to ataraxia (Adorno, 1952).

5. Comprehension assessment instruments and Didactic design

Table 5. Interaction matrix for order and interpret data through anecdotical logs of the Case, differences in structure with high levels in purpose and content. Source own.

Very high-level comprehension	**High level of conprehension**	**Low conprehension level**
Logical content	Logical content	Logical content
Logical purpose	Logical purpose	Logical purpose
Argumentative structure	Analytical structure	Descriptive structure
Tendency to establish meaningful reflections	Tendency to establish relationships but with an absence of the students own reflections	Content and logical purpose are incompatible with descriptive structure.

Note:The data reflect level of comprehension and contribution level to the Scientific Knowledge of the Case readed: Structure of Thought according to its Content, Purpose and Structure. Own source.

Table 6. Interaction matrix for order data through anecdotical logs, with intermediate level in purpose and differencies in structure with high levels in content. Source own.

High level comprehension	**Intermediate level**	**Low conprehension level**
Logical content	Logical content	Logical content
Ethical purpose	Ethical purpose	Ethical purpose
Argumentative structure	Analytical structure	Descriptive structure
Establishes reflections meant by 3rd parties	Establishes relationships generated by 3rd parties, absence of reflections derived from them.	The descriptive structure reveals the absence of logical content.

Table 7. Interaction matrix for order data through anecdotical logs,with low levels in purpose and differences in structure with high levels in content. Source own.

Medium Low level	**Low level**	**Very Low conprehension level**
Logical content	Logical content	Logical content
Pathetic purpose	Pathetic purpose	Pathetic purpose
Argumentative structure	Analytical structure	Descriptive structure
Tendency to establish meaningful reflections	Tendency to establish relationships but with an absence of the students own reflections	Content and logical purpose are incompatible with descriptive structure.

Table 8. Interaction matrix for order data through anecdotical logs,with high levels in purpose, medium level in content and differences in structure. Source own.

Intermediate level	**Intermediate level**	**Low conprehension level**
Narrative content	Narrative content	Narrative content
Logical purpose	Logical purpose	Logical purpose
Argumentative structure	Analytical structure	Descriptive structure
Narrative content shows the absence of argumentative structure but reaffirms a descriptive structure. It may have a relative logical purpose if it is based on a general reading code	There may be evidence of logical relationships even if there is a lack of content of logical and objective origin	Incompatibility between the logical and the descriptive narrative

Table 9. Interaction matrix for order data through anecdotical logs,with medium level in purpose, medium level in content and differences in structure. Source own.

Intermediate level	**Intermediate level**	**Low conprehension level**
Narrative content	Narrative content	Narrative content
Ethical purpose	Ethical purpose	Ethical purpose
Argumentative structure	Analytical structure	Descriptive structure
It may have a relative logical purpose if it is based on a general reading code agreed upon and constructed socially or historically; to give meaning to the phenomenon in question interpreted	There may be evidence of logical relationships even if there is a lack of content of logical and objective origin	Incompatibility between the ethical and the narrative

Table 10. Interaction matrix for order data through anecdotical logs,with low level in purpose, medium level in content and differences in structure. Source own.

Low comprehension level	**Low level**	**Very Low conprehension level**
Narrative content	Narrative content	Narrative content
Pathetic purpose	Pathetic purpose	Pathetic purpose
Argumentative structure	Analytical structure	Descriptive structure
Incompatibility with argumentative structure.	Incompatibility with the analytical structure, lack of this one	Total absence of methodical and rational thought structure.

Note: It is considered that the implications of narratives to generate structured rational thought in a dialogic manner through socialization, with the enrichment of different points of view characteristic of narratives; however, the objectification of this knowledge could also be considered low-level, since reconciling intersubjectivities is a complex task in itself.
From the perspective of the scientific method and methodical structured rational thought, the researcher's philosophical reflections to pose the research question also in itself demands serious reflection to ensure that the ideas generated, although subjective and specific to the researcher, are not mere superficial intuitions, but rather the product of serious philosophical reflection through the rational use of thought.

Table 11. Anecdotal Log and Student Focal Team Performance Evaluation Rubric in the Implementation of Rational Thinking for Learning. Referenced from Tabra (2019).

Dimension students work interpretation logbooks	**Measurement scale**			
1. Logical content, Logical purpose, Argumentative structure 2. Logical content, Logical purpose, Analytical structure 3. Logical content, Logical purpose, Descriptive structure	High evidence	Medium evidence	Low evidence	Null evidence
4. Logical content, Ethical purpose, Argumentative structure 5. Logical content, Ethical purpose, Analytical structure 6. Logical content, Ethical purpose, Descriptive structure	High evidence	Medium evidence	Low evidence	Null evidence
7. Logical content, Pathetic purpose, Argumentative structure 8. Logical content, Pathetic purpose, Analytical structure 9. Logical content, Pathetic purpose, Descriptive structure	High evidence	Medium evidence	Low evidence	Null evidence
10. Narrative content, Logical purpose, Argumentative structure 11. Narrative content, Logical purpose, Analytical structure 12. Narrative content, Logical purpose, Descriptive structure	High evidence	Medium evidence	Low evidence	Null evidence
13. Narrative content, Ethical purpose, Argumentative structure 14. Narrative content, Ethical purpose, Analytical structure 15. Narrative content, Ethical purpose, Descriptive structure	High evidence	Medium evidence	Low evidence	Null evidence
16. Narrative content, Pathetic purpose, Argumentative structure 17. Narrative content, Pathetic purpose, Analytical structure 18. Narrative content, Pathetic purpose, Descriptive structure	High evidence	Medium evidence	Low evidence	Null evidence

Note: Codified measurement scale. A 4-item rating scale will be used for each of the 18 dimensions of interpretive student work assessment:high evidence, medium, low, and null evidence of understanding; coded with ordinal values from 3 to 0, respectively. 0 for null evidence; 1 for low, 2 for medium and 3 for high evidence of comprehension.

Table 12. Didactic design for the implementation of structured rational thinking to learn disciplinary principles. Source own.

Didactic design	
Conceptual comprehension	**Tools**
1. Case study, general and reflective reading (2 sessions)	Case text designed
2. Reading of the case in classroom plenary (1 session)	Socratic dialogue
3. Anecdotal Logs description, interpretacion Case (2 sessions)	Rubric anecdotal logs (18 dimensions on a Likert scale, 4 coded items, range 0-3

4. Control and experimental group survey for comprehension levels (2 sessions)	Diagnostic survey 13 questions coded by Likert scale 4 items and Constation survey 21 inferential questions, with 4 items

Table 13. Anecdotal log format. Source Muñoz (2010) & UDLA (2015).

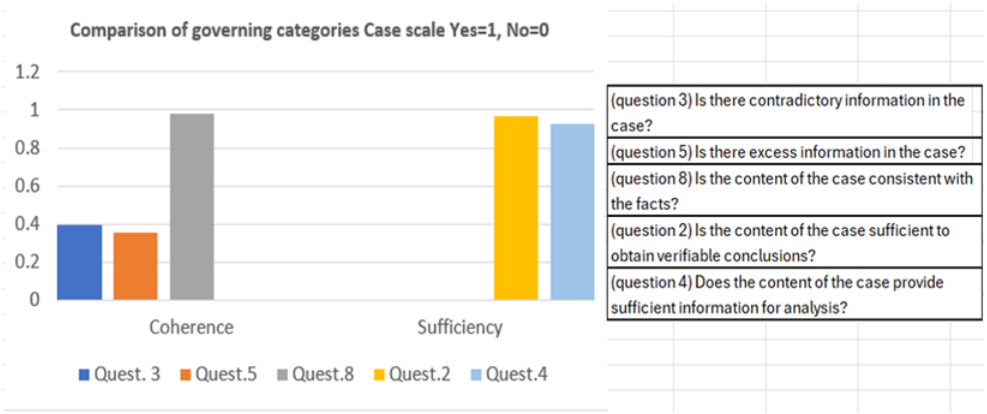
Narrative	
DESCRIPTION OF THE SITUATION (Descriptive language)	ANALYSIS AND INTERPRETATION (Evaluative language)
Keywords when developing the description: it was discussed, in order, at the time of dialogue.	Keywords in evaluative development: we identify, through dialogue, for the solution.
Conclusions	
Keywords in the conclusive development: the aspects to be prevented, the actors involved, such facts taught us, the causes suggest a future, the problems teach us, the solutions implemented are.	

Note: In Table 13 the purpose of the log is to record the experiential aspects related to the case study: exchange of approaches and opinions regarding the individual reading of the case and the discussion in focus groups of students. Relevant aspects to record:What was said?;What was seen?;What was questioned?;What was thought about what was heard, seen, and questioned?;What were the reflections on expectations, obstacles, references to what should be, interpretations, personal explanations, and interactions?

6. Case validation

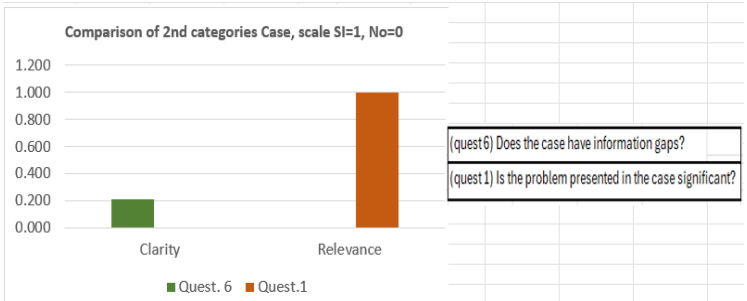
As part of the case designing process, user evaluation was required; the instrument to make this measurement is based on the characteristics that a case should have according to Ellet (2007). 4 sections were evaluated, by surveying a sample of 45 engineering students, aged between 18 and 25 years; using a 6-dimensional "google forms" form, with 12 questions, with the option of dichotomous responses, Escobar (2022). A dichotomous scale was used, for precise comparisons of the students' criteria when evaluating; the yes and no values were coded with ordinal values of 1 and 0, quantitative work was built.

Chart 1. Triangulation of data dimensions of coherence and sufficiency



Source own, reference Cisterna (2005)

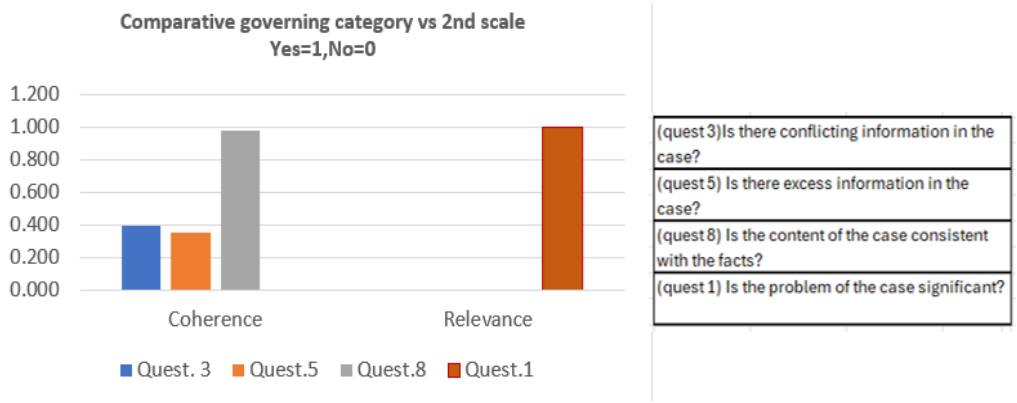
Chart 2. Triangulation of data dimensions clarity and relevance



Source own, reference Cisterna (2005)

In chart 1, questions 3 and 5, 40% indicate coherence, there is disparity with questions 2 and 4 which indicate 100% relevance, there is no triangulation; it is inferred that 40% perceive the case superficial, 60% say that it is not coherent with complex reality. Question 8 has a high level of triangulation with questions 2 and 4, the case adheres to reality with sufficient data for analysis. In Chart 2 there is a low level of triangulation, since 20% indicate that the case has information gaps and 100% indicate relevance, it is inferred that 20% read superficially.

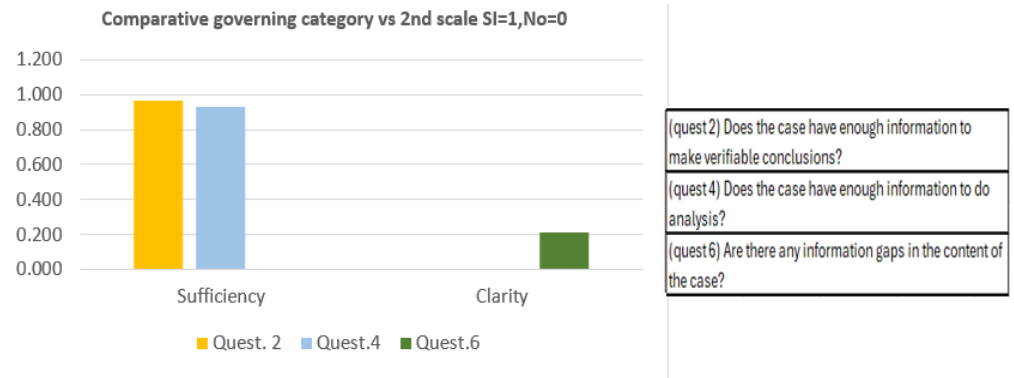
Chart 3. Triangulation of data dimensions coherence and relevance



Source own, Cisterna reference (2005)

In Chart 3 there is low triangulation between questions 3 and 5, and question 1; since 40% perceive the case as contradictory and coherent with the multi-focus reality and apparently disordered. 60% make a superficial reading and say that the case is not coherent with this reality and is coherent with a linear, ordered and idealized reality. It is inferred that 100% perceive the case as relevant, even though they did not get deeply involved.

Chart 4. Triangulation of data dimensions of sufficiency and clarity



Source own, reference Cisterna (2005)

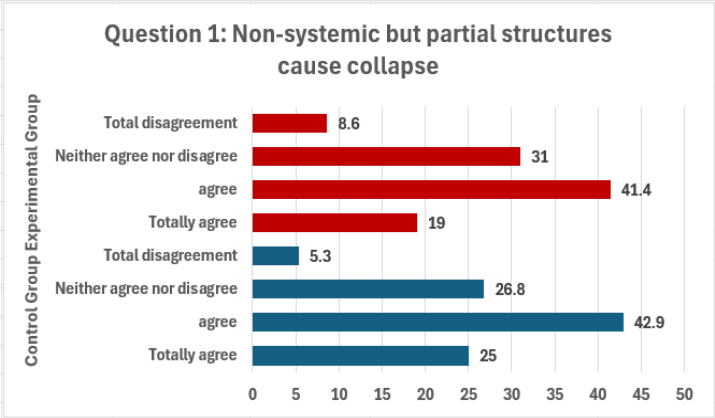
In chart 4 level of triangulation between sufficiency and clarity is low, 20% perceive info. gaps vs. 80% do not.

7. Levels of understanding with Structural Thouhgt

In the process of implementing structured rational thinking to learn physics principles, performance was found to be better in the experimental group compared to the control group. The sample of 45 students who underwent methodical, logical, and narrative learning achieved

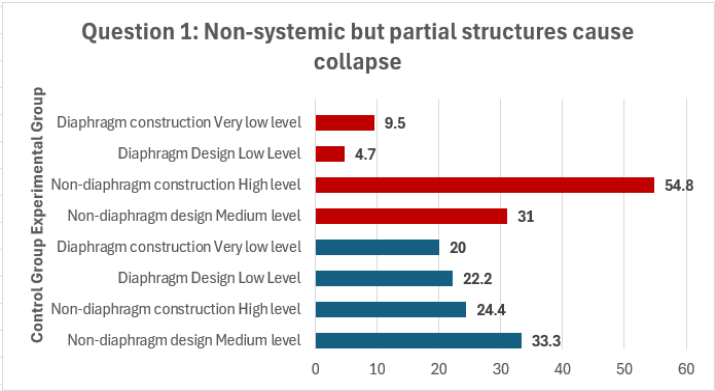
higher levels of comprehension than those students who continued their learning through traditional pedagogical frameworks. Structured rational thinking fosters learning through active knowledge construction, as opposed to conditioning-based learning with frameworks grounded in didactic behaviorism. Therefore, the data obtained from the diagnostic survey of 13 questions on a 4-item Likert scale, as well as those obtained from the verification survey of 21 inferential questions of 4 items, are as follows:

Chart 5**.** Triangulation of diagnostic survey data, control group and experimental group, question 1. O.s



In chart 5, it is inferred for question 1 that the levels of preconceptions are very similar, with maximum percentages of 41.4% and 42.9% and minimum percentages of 8.6% and 5.3% for both groups.

Chart 6**.** Triangulation constation survey data verification, control and experimental group question 1, O.s.



In chart 6, a value of 54.8% is observed associated with a high level of conceptual understanding for experimental group, a very marked difference with the control group whose values do not show a high level of understanding. Therefore, The results for the remaining questions of the diagnostic and verification surveys reveal results very similar to those shown in graphs 5 and 6, finding a pattern of responses in this regard.

Chart 7**.** Evaluation by judges students interpretation work of the case by anecdotal logs, of the section 4 of the rubric related with thought with logical evidence in content, ethic in purpose and argumentative in structure. O.s.

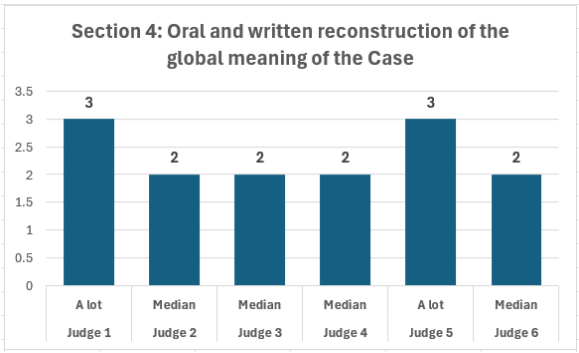
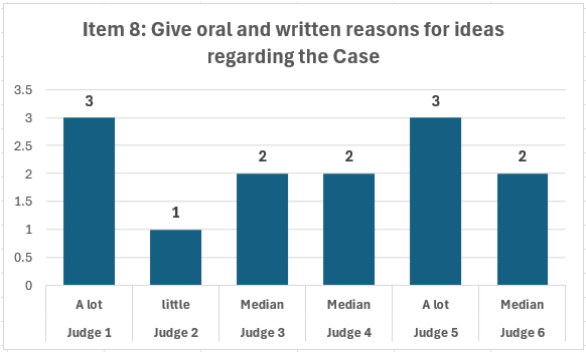


Chart 8**.** Evaluation by judges students interpretation work of the case by anecdotal logs, of the section 8 of the rubric related with thought with logical evidence in content, pathetic in its purpose and analysis in structure O.s.



In chart 7 and 8, levels of 3 and 2 can be seen, which correspond to high and medium evidence of rational thinking with a logical, ethical, argumentative tendency and a logical, pathetic, analytical tendency in categories of rational thinking according to their content, purpose and structure respectively. From the above, we infer a moderate presence, with a tendency to high, of structured rational thinking for learning. The levels documented by the surveys therefore indicate that students' level of reflection is good, as they not only engage in methodical logical categories but also provide arguments for their ideas. The susceptibility to the development of inferences is recurrent.

8. Conclusions

In the light of the results from the data, the case is evaluated well, with Good levels, because of his systematically proceedure, that generate aceptable levels of relevance and sufficiency, however coherence and clarity with médium levels, because reality has a complex nature, and a none logical causal nature. Relating to the implementation of Rational Thought, One thing is “the method or procedure to properly guide thoughts” and another is “rational thinking” that generates the method, which in turn generates scientific knowledge to be shared or taught.

In the teaching of thematic principles, a method for guiding reason in the conception of “simple” and autonomous or disconnected realities (ancient classical method) may be used insufficiently; Represented by “Rational Logic” Method to confront a simple reality, in the face of paradoxes and dilemmas. Method to confront reality, conceived or interpreted as a set of “complex and interconnected realities”; Represented by “Rational Methodical Thought”, not of a simple nature, its nature is composite, not causal but counterfactual; also called “vortex” nature (interwoven or braided reality, dynamic and not static).

Even in the field of learning it is concluded that studying a case methodically designed in a systematic way, improve the conceptual understanding of the reality studied in a Case. And

this is due to the systematic design process of a Case, that consequently promotes the methodical way of study and learning.

9. Acknowledgment

Thank you very much to Professor Hector Alejandro Cervantes Nila, for his inspiration.

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