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The Case Method Articulating Physics with Engineering "Collapse of the Mexico City Metro Gold Line"

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ABSTRACT

Objectives are to describe the process of designing a case of physics for engineering, its use with the case method. For this, its genesis, scope, types of cases, and attached methods were addressed. The methods for the design were: three cases readed, expert reports reviewed, draft of the case written and the SRVE model implemented in 4 steps: structure, review, validation, evaluation. Background, situation, prospects as structure; validation addressed dimensions of clarity, coherence, relevance, sufficiency; Aiken statistical implemented to validate instruments. The evaluation involved data triangulation and a table of categories by estates. The results indicate that agents evaluated the case with optimal levels of relevance and sufficiency; agreed with acceptable assessments that the case is not 100% coherent with a linear but with a complex reality. As conclusions, the method application is limited in engineering, the existence of designed cases also, implement the model to improve learning is necessary.

Keywords: Case Method, Hooke's Law, Engineering, Physics, Case Design, Inductive Thinking, Socratic Dialogue, Active Learning

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1. Introduction

The objective of this research is to present the results of the design process of a Case, based on a real situation contextualized in the field of Civil Engineering; and addressed through the "Case method" as a didactic strategy for meaningful learning, and for the development of conceptual understanding skills. The research will seek to establish the bases for the implementation of the Case method in engineering; to do so, the research questions that will be answered: how to systematically design an engineering Case?, and what characteristics does the Case method have, to consider it an effective option in factual learning? Questions that will be answered in the sections: The Genesis of the use of cases in the educational system, use of the case method in learning, understanding of physical principles in engineering, types of cases for learning in engineering, design of a physics case for engineering, the case study characteristics, relevant physical concepts and their engineering relationship, methodology used in the design of the case, results and conclusions. The above according to the following problem: during the 20th century, teachers, pedagogues and psychologists observed a growing tendency to perpetuate both teaching and learning, by teachers and students of various fields of knowledge, at different levels; through educational models based on conditioning, in which mechanical repetition and memorization of concepts was recurrent by students, as well as the magisterial class in which the teacher pours knowledge (Luna, 2015). For the 21st century, educational approaches propose changing the teaching-learning processes, based on the incorporation of didactic strategies focused on the construction of student knowledge, including the "Case method" and "problem-based learning"; which promote Constructivism, as a pedagogical approach opposed to Behaviorism (Luna, 2015). This aims to improve learning by focusing the student on a sense-building scheme, with examples close to reality, instead of a behavior-shaping scheme.

The first one teaches to think, the second one appeals to a system of stimuli so that the student responds by memorization, to an external social system previously established but alien to him. That is, to propose a learning scheme that takes into account the cognitive processes of the student, rather than a scheme centered on his responses or behaviors (Ulate, 2014). Therefore, due to the pedagogical characteristics of the "Case study method", it has been considered by Ventura et al. (2014), as a didactic strategy that reports benefits according to the objectives for 21st century learning established by UNESCO, and by the "index of learning styles" proposed by Felder & Silverman (2002), implemented in universities worldwide; especially applied in engineering careers, to identify the most representative learning styles, including: active, sensorial, visual and sequential.

Furthermore, the Mexican educational reform of 2016 not only aims to implement teaching strategies consistent with a new educational model based on competencies and active learning styles. It also stops considering the teacher as a transmitter of “knowledge prescribed in a vertical curriculum, not very open to creativity and adaptation to different environments” by students; who are conceived from this approach, with heterogeneous learning characteristics, referred to the Ministry of Public Education (SEP, 2016) in De Luna and Díaz (2017, p.5). Even this training proposal is ratified in Mexico by the National Association of Universities and Higher Education Institutions (ANUIES); with a view to organizing learning to solve problems through case studies, and generating the cultural capital that allows students to project themselves to an effective professional praxis by developing four types of learning: learning to know, to do, to be and to collaborate (De Luna et al., 2017).

2. Physics Case Design for Engineering

The objective of this research is to present the process involved in designing a Case in a systematic way, which links physics with engineering; considering for this purpose, the collapse of the "Golden Line of the Mexico City Metropolitan"; and to answer the question: How to build, review and validate, an Engineering Case that involves Physics topics?; For the design process of the Case, the following structure was considered: background, situation and prospects; validation by expert judges of the dimensions: clarity, coherence, relevance and sufficiency, for each part of the case; and calculation of the Aiken statistic to corroborate the level of efficiency of the survey reagents of the validation criterion by judges, piloting for opinion and evaluation of students of the same dimensions, data triangulation and statistical correlation. The methodology used in this inquiry is qualitative and quantitative, and was carried out at the Higher School of Engineering and Architecture (Esia) of the National Polytechnic Institute (IPN, 2003) in Mexico. The above is justified by the importance of designing a Case to learn engineering, which lies in the fact that its methodical study has the potential to develop the ability of comprehension, which involves higher-order thinking to interpret information and be able to express it in our own words; in addition to involving reading, discussion and individual and collective reflection. However, to learn about topics in physics and engineering, the challenge is to have a Case study.

2.1. Understanding Physical Principles in Engineering

In Mexico, the “Case method” is currently considered in the engineering programs of the Tecnológico de Monterrey and the IPN (2003); both triggering references for the incorporation of the method in the teaching-learning process of Physics and Engineering (Garvin, 2014; Chaves, 2022). The relevance of this lies in the fact that conceptually understanding the physical principles that govern engineering phenomena is not a simple didactic task, nor is it easy to learn; therefore, it is necessary to “train in skills and competencies” which allow to effectively solve problems in the field (Escobar,F. et al., 2022, p. 5). Escobar,F. et al. (2022, p.6) tells us that the learning activities that have been carried out in the past and that are still perpetuated, “do not tend to develop higher-order cognitive skills; rather, it is customary to learn the contents by memorizing, but without understanding […], which eventually might not be fertile for discussion and proposals”. There is a tendency to form “learning machines”, without reflective and problem-solving abilities. Hence, the importance of generating criteria through “designing and analyzing contextualized physics problems, based on the professional practice of engineering; which is a way […] to stimulate in students, cognitive processes” elaborated, through the resolution of complex problems and addressing real cases. A skill that the “World Economic Forum” predicts will be the third most relevant in 2025. Therefore, for Escobar,F. et al. (2022, p.6,7) “designing learning activities that prepare engineering students to make decisions, investigate information, and know where to apply it in the workplace, is the most viable route to developing comprehension skills.”

However, in most current learning circumstances, didactic strategies for problem-based learning (PBL) or for the methodical study of cases are not implemented in engineering; and much less are practical cases designed for engineering physics; there are only cases designed for legal, business, medical and social work fields. This was confirmed in various databases, e.g.: Google Scholar, Scielo, Research Gate, Education Database, Redalyc, Doaj, Eric, Sage, Springer and Routledge; and the following keywords were used: Case method in Civil Engineering, case method in physics and engineering. However, no favorable results were found, only works that confuse “Case method” with Case study, as descriptive approximations of reality, but that do not carry out any approach implementing the Case method and much less give evidence of the Case used, or of the design process of this. Therefore, the above perpetuates the difficulty for engineering students to conceptually understand and thereby learn the principles of physics that support the design and construction of civil engineering works; not only does this generate a deficiency in the acquisition of interpretative and conceptual analysis skills, but it also generates deficiencies in the effective application of knowledge during the circumstantial resolution of practical problems (Malavé, 2016; Brenzini and Martínez, 2012).

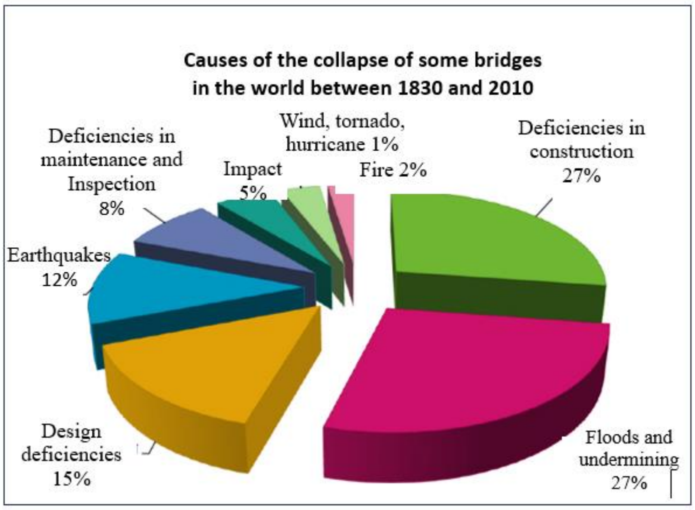
Even for DNV (2021), the lack of understanding of fundamental physical concepts in engineering constitutes one of the factors that generates poor execution of structural projects; it is one of the causes of design, construction, operation and maintenance failures in civil and architectural works. This problem leads to a lack of reliability of graduates of higher schools, which support the acquisition of generic and specific skills (Luna, 2015; Manpower, 2019). However, if students understand the physics principles involved in solving engineering problems, not only will they solve them better, it will also improve the employability of university graduates and avoid the loss of material resources and human lives due to structural collapses of civil works (Manpower, 2019; Quacquarelli Symonds, QS (2022). With the implementation of "Case studies" the conceptual construction attached to reality can be increased, through reasoned dialogue; and the likelihood of reducing conceptual distortion through imaginary ideas and the reduction of mechanized and unreflective learning. To do this, one must learn to design engineering case studies and apply the method.

An “ad hoc” example according to the College of Civil Engineers of Mexico (CICM) (2021), is the collapse of “line 12 of the Mexico City metro”, in its Tezonco-Olivos section, columns

12 and 13, which occurred on May 3, 2021 (General Archive of the Nation AGN, 2016/1969). Another example is in Cusba (2011), related to the causes of bridge collapses and their increase over time. This raises the following questions, in search of an answer to the origin of the collapse of elevated sections: a) could it be that the main cause of the collapse of elevated sections is related to the design of non-systemic structures?; b) If there are original faults in the design of the beams, does the structure collapse even when the foundation and column designs are well done? c) Is it possible that the collapse of elevated sections is due to construction rather than design causes? d) Is it possible that the collapse of elevated sections is due to sudden changes in the construction with respect to the original design requirements for the structure's serviceability and therefore the load-bearing elements are insufficient? Smith (1977), García (1992) and Muñoz (2011) also conducted research on the matter of a worldwide scope, from which they obtained data of the causes of collapse of some bridges in the world between the years of 1830 and 2010.

Emphasizing that collapses are a phenomenon that has not been studied with scientific rigor and sufficiency; Eight categories of failures were classified, with those related to construction deficiencies standing out. In addition to Chart 1, there are other failures in elevated sections, due to buckling, shear, torsion, displacement and tearing at the supports; according to the College of Civil Engineers of Mexico (CICM) (2021). And the Norwegian office of structural analysis "Der Norske Veritas" (DNV) (2021), proposes two analogous Case study methods: the "Systematic Causal Analysis based on Barriers" technique and the "Systematic Evidence Processing Method" to study structural collapses in engineering.

Chart 1. Causes of bridge collapses between 1830 and 2010, Source: Muñoz and Cusba, 2011



As can be seen in Chart 1, collapses due to deficiencies, especially in construction and design, have been increasing, which indicates the urgent need to implement effective teaching strategies, such as the "Case Method" and analogous strategies such as the "Systematic Method of Evidence Processing", in order to improve meaningful and inductive learning, with a view to developing conceptual understanding skills in context. With the understanding of the immediate and root causes of the appearance of types of structural deformation in elevated sections, barrier elements can be proposed, including according to DNV (2021): 1) deformation nullification elements, 2) containment elements once the deformations appear, in such a way that they do not increase; and 3) mitigation elements once the deformations have started and their progress has not been contained, what to do to ensure that their development is minimal and to provide the opportunity to implement corrective interventions that avoid extreme deformations that generate sudden collapses (DNV, 2021; Cusba, 2011).

2.2. The Case Study Characteristics

The Case entitled "Ignored Physics as a Deficiency in Engineering Design and Construction: Mexico City Metro Gold Line, Sudden Collapse", is a narrative of the events that occurred on Monday, May 3, 2021, related to the collapse of the structure of the elevated section; between columns 12 and 13 inter-stations Tezonco Olivos. As well as the analysis of the causes, problems and solution strategies, through methods analogous to the "Case method" proposed by the structural assessment office "Der Norske Veritas" (DNV, 2021), hired by the Government of Mexico City, to explain the facts inherent to the accident. As well as to dictate corrective, containment and operation mechanisms in relation to the structural, mechanical, constructive and live load components of the Golden Line of the Metropolitan.

Therefore, through the “Systematic Causal Analysis based on Barriers” (MACSBB) method, and the “Systematic Evidence Processing method” (MSPE); DNV (2021) sought to understand and scientifically argue the causes that led to the appearance of overloads and with them stresses in the materials of the structure, which in turn caused fatigue and extraordinary deformations in the beams, in the prefabricated tablets of the slab, in the joint welds, in the set squares and transverse reinforcement reinforcements between beams. Which culminated in the dysfunction of these load-bearing structural elements; and in the sudden collapse caused by the loss of the total stability of the structure (DNV, 2021; Cusba, 2011). In addition, DNV when analyzing the incident, distinguishes between facts, causes, problems, solutions and strategies to carry out the latter. It also classifies the causes into two types: a) root cause and b) immediate cause; in order to understand and argue the appearance of the types of structural deformation that occurred in the collapse of the Gold Line section. And with this, propose barrier elements of three types: 1) deformation nullification; 2) containment; 3) and mitigation (Cusba, 2011; DNV, 2021).

Norske Veritas (DNV, 2021) addresses the Collapse Case through the following structure: a) Introduction and history (determination of the necessary Cause); b) environmental background (Root Cause); c) situation (Immediate Cause); and strategy (or prevention). Facets that involve the process of induction and analysis of the incident; which allows to build a more complete vision of the Case, by being able to characterize it, as well as enunciate and distinguish the logical sequence in which the events occurred, describe the process that they led to, and identify and distinguish the causes of the events, the effects or problems that arose and the proposed solutions. Even, identify the agents involved and clearly distinguish the temporal-spatial context in which the Case was developed (Ellet, 2017; DNV, 2021).

Also, by studying the Case methodically, it is possible to answer the questions raised by Cusba (2011) and DNV (2021) regarding the main causes of collapse of elevated sections.

To delve deeper into the Case of the collapse of the “Gold Line”, enter the following link for reading: https://drive.google.com/file/d/16C34y4pGzEYDMynlendGf4PWVOJ84vqR/view ;where you will find that the Case has a length of 6,064 words, 24 pages, and an estimated average reading time of between 200 to 300 words per minute; that is, between 20 and 30 minutes. The specific objectives of having a Case for study by engineering students are: a) to learn about a topic, build their own knowledge, read, explore, analyze, reflect, interpret and question individually and dialogically, the problems and situations given in relation to a portion of reality. Clarify the Case as a unit of real knowledge and go deeper to the point of finding solutions and courses of action; and then manage their knowledge actively; b) the professor, by assuming a mentor position, also manages active learning, through guiding and sharing their experiences, approaches and questions; c) and both the professor and the students, by implementing the "Case method", will be in a position to promote the development of interpretive skills, by making the process of understanding physical concepts more efficient.

2.3. Types of Cases for Learning in Engineering

Escobar,F. et al. (2022, p.10) emphasizes the development of "skills for inclusive and sustainable economies" in engineering; and urges the collection and use of data sources for their interpretation, analysis and "for efficient decision-making; however, to know how to use data, you must first size and understand it." This work has begun by venturing into some engineering fields and no longer so much in the field of social sciences; through the implementation of the "Case method" to learn the principles that support these factual fields, for example in Industrial Engineering, Systems Engineering and Robotics; this has been plausible, because teachers have adapted different "types of Cases" according to their relevance, to the disciplinary contents of each of the learning units that they teach, according to the Curricular structure and the educational model in which they are located. That is, according to Jiménez (2016, p.2), when doing research there are "many more variables of interest than just observational data, […] therefore, the case method is based on multiple sources of evidence, with data that must converge in a triangulation style". Therefore, to apply a type of Case to a type of engineering, it is necessary to understand that the "method" is useful to generalize theoretical propositions, but not always adequate in generalizations to populations (Jiménez, 2016).

Therefore, there are four types of Case designs according to their content: a) single-case design, as a unit of analysis; b) single-case design, with subunits of analysis; c) design involving multiple cases, but these being a unit of analysis; d) design with multiple cases, but each of them has subunits. The types of Cases vary in complexity, according to the subunits of analysis that can be derived from each Case or from each Subcase involved (Jiménez, 2016). There are also three types of Cases, according to their purpose: a) Intrinsic Case, "they are cases with their own specificities […], the case itself is of interest"; and it is not chosen for its representativeness with respect to other Cases; b) Instrumental Case, "they are Cases that aim to generalize from a set of specific situations […], they delve into a topic to refine a theory", and it is representative of other Cases when compared with these; c) Collective case, "[…] its interest focuses on a phenomenon, population or general condition, selecting several Cases for this purpose, which must be studied intensively" (Jiménez, 2016, p.7).

Also Jiménez (2016, p.7,8), mentions three other types of Cases according to their structure: a) Descriptive cases, which omit prior theoretical foundation and pre-established hypotheses, in such a way that the report provides initial basic detailed information on the characteristics of the object of study; b) Interpretive cases, in these there are hypotheses, with a view to being tested, by the detailed set of descriptions generated, and even developing conceptual categories; c) Evaluative cases, "involve description and explanation to reach judgments on the reality under study." Finally, Jiménez (2016, p.8), raises two other types of Cases, according to their methodological scheme: a) Cases with a qualitative approach, here "the objective of the research is understanding, focusing the inquiry on the facts; b) Cases with a quantitative approach, based on the search for "the causes, pursuing control and explanation.

3. Use of the Case Method in Learning

The "Case method" goes through the following steps: "1) the teacher poses questions on general principles regarding the topic; 2) the students give answers, which are refuted or discussed by the teacher; 3) a discussion between students takes place, guided by the teacher, to provoke confusion or discomfort among students, when they no longer see clearly what they were clearly and vehemently defending at the beginning of the dialogue; 4) after overcoming the moment of varied points of view, we move on to more refined definitions due to their more general or deductive level with respect to the topic analyzed; 5) the solutions that have allowed the universal principles of the topic to be clarified are selected" (Carrillo, 2019, p.3).

Also, Bernal (2017, p.3,4) comments that the "Case method" involves specific steps, referred to the methodology of the University of Ivey in Canada: 1) First class: the method is presented and teams of three students are formed; 2) The professor designs the Case, with an extension of no more than 40 pages; 3) second session: reading of the Case and "preparation of the short Cycle, individually" by the student; where a brief approach to the Case is made, by reading the opening and closing paragraphs, "doing a quick review of the subtitles, skimming the main body of the Case, reading the assigned questions, stopping to reflect and doing a quick review of […] tables and figures". Finally, he answers the questions: Who? – object of study, actors involved-; What? – issue, problem, decision-; Why? – causes of the problem-; Which ones? – deciding between proposed solution options-; When? -decide when to resolve the situation-; 4) third class: "preparation of the long cycle, in teams"; session in which "a detailed reading of the case is carried out, the problem is defined, data and information are analyzed, alternatives are generated, decision criteria are selected, the most effective alternative is evaluated and selected, and an action plan is developed."

Therefore, a methodologically based "Case Study" is defined as a student-centered learning method; in which the teacher will design a Case as a narrative of a real situation, which as an instrument, will allow the student to examine ideas and determine their validity, learn to "raise, analyze and compare different situations, arguments and decisions" thematic through interaction, dialogue and discussion among peers, and the teacher as a mediator "must adopt a position of ignorance, in order to force the student to assume the highest level of knowledge" (Carrillo, 2019, p.3; Hernández, 2014, p. 5,6).

However, sometimes there is a confusion that addressing a "Case study" only consists of addressing reality by making a description of it as it is, but without implementing the method that allows developing the scheme of thought that proposes to distinguish between facts, problems, causes and solutions (Garvin in Hernández, 2014). There are even those who confuse the "Case method" with the "Case Methodology"; here, it must be clarified that, although they seem to be similar concepts, they are not. On the one hand, the "Case method" is a set of specific and ordered techniques or procedures "that allow to guide the sharpness of the mind to discover and explain" the principles that govern a phenomenon (Aguilera, 2013, p. 7). However, the "Methodology" implies the set of complementary methods to the "Case Method"; e.g. general methods, such as descriptive, inductive, analytical and deductive; or specific methods, such as questionnaires, documentary review, expert collaboration, surveys, field logs, interviews, observational, video and photographic records, the Socratic method, debate and argumentation, data triangulation; as well as the set of constructs that explain the scope of the method, which tends to "make coherent what is disorganized […]" (Aguilera, 2013, p.8).

3.1. Genesis of the Use of Cases in the Educational System

Previous research focused on the time of Pericles in the 4th century BC, with Socrates and his case analysis or Mayeutics, then the Medieval Scholastic Casuistic method and the Renaissance Heuristic method implemented by Galileo (Vázquez, 2000). Finally at the end of the nineteenth century in 1870, the dean of the law school at Harvard University (2019) in the United States of America, Christopher Columbus Langdell; proposed replacing Dwight's method, that is, “replacing the […] tradition of studying law by simply listening to professors lecture in class and repeating […] what they said; or going beyond asking students to prepare classes by reading textbooks, to look for thematic interpretations, and assess knowledge by oral presentations or exams”; Instead, Langdell proposes using a method with an inductive empirical approach, based on analyzing and reflecting on cases of judicial resolutions, to infer the principles of legal practice. Which he considered could exercise essential skills for the real practice of the profession, including: diagnose, decide and act (Hernández, 2014, p. 5). Consequently, the characteristics of the "method" proposed by Lagdell that have made it relevant are: a) ask students to read real cases instead of textbooks; b) reason through examples; c) verify the quality of the ideas around a topic through the Socratic method (Garvin in Hernández, 2014). And regionally Llano (1998) promoted the Case method in Central America.

4. Methodology Used in the Case Design

Unlike a case of social work, law or business where interpretation is an essential methodological part, because the events are not only closely related to objective entities, but also to subjective agents. In cases of medicine and engineering, methodologically interpretation is not enough, it is also necessary to carry out causal explanation based on physical principles inherent to the field of sciences, both factual and formal (Aguilera, 2013). Since the explanation of engineering phenomena goes beyond interpretations and social principles; it is also necessary to understand the physical laws that support them, and whose validity has already been scientifically validated "a priori". And with this, apply the principles effectively, to solve recurring problems involved in engineering circumstances.

Social cases seek to delve into the meaning; while physics and engineering cases delve into the causal foundations of the questions posed (Aguilera, 2013). The social part focuses on the assessments of the interactions of the agents involved, and the physical part on the principles of the phenomena, with prescriptive views. However, in engineering, due to the comprehensive nature of its knowledge, applying both approaches is important (Aguilera, 2013). Therefore, the SRVE Methodology was used to design the Engineering Case “Ignored Physics and Inadequate Engineering Design and Construction of the Golden Line Sudden Collapse”, the methodology called “SRVE” is proposed, by its acronym in Spanish; which refers to the process of: 1) Structuring sections of the Case; 2) Peer review of the Case; 3) Validation by expert judges; and 4) Evaluating by student users. For the design of the Case, three Cases were read: Decoding the DNA of the Toyota production system (1999); Elephant Pumps (2008); and California Products, (2018); review of accident expert reports (DNV, 2021); writing of the first draft of the Case in three sections: background, situation and prospects. A sample of 7 judges was chosen to validate and 56 students to evaluate the case, both statistically representing 10% of the population of 70 engineering professors and 560 architecture students.

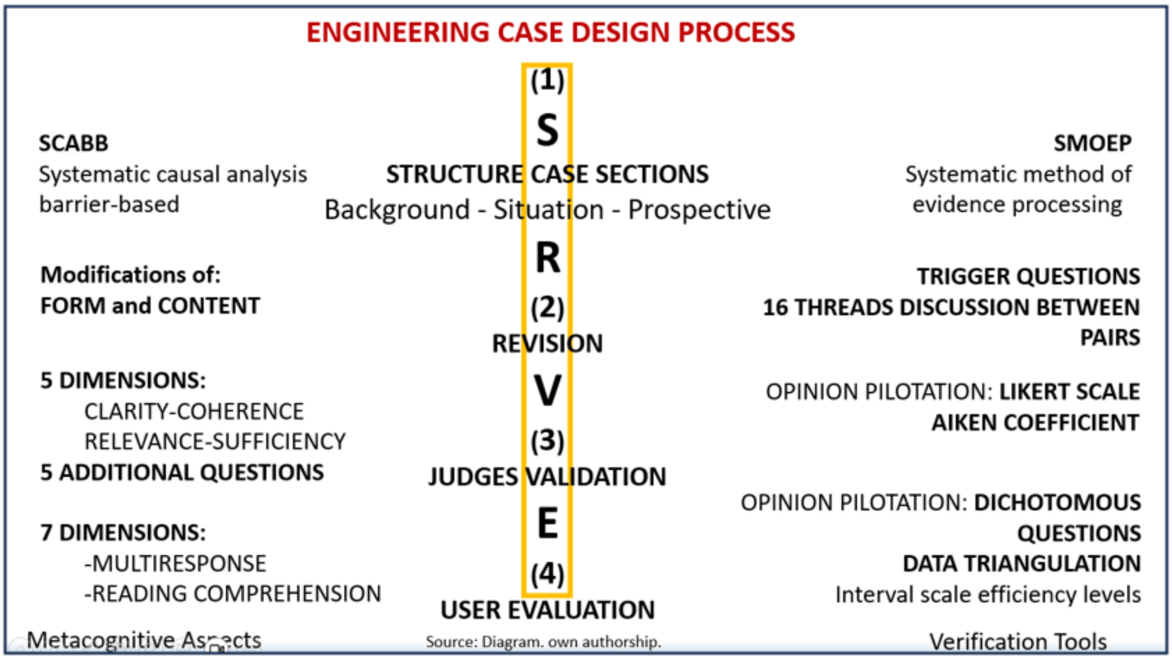


Figure 1. Case design methodology in four steps, source: own elaboration

4.1. Case Structuring

The structuring stage of the draft Case was carried out through the “systematic method of evidence processing” (MSPE) and the “systematic causal analysis method based on barriers” (MACSBB); both analogous to the “Case Analysis Methodology” (MEAC) based on the “Case Method” (DNV, 2021). In section 1) background, the causes of the appearance of the Golden Line of the Mexico City Metropolitan and its original characteristics are described, including: length in meters of its convoys, number of cars in each convoy, average height of the elevated sections, average separation between columns of each elevated section, number of sections comprising line 12, average width of the track for convoy circulation, average number of convoys that circulate in each section and their directions. Characteristics of the cars, including their weight, length, width, height and rolling system; also types of materials used in the construction of the super and infrastructure of each section. Finally, characteristics of the soil and foundation are described, important data to infer the physics principles involved. In section 2) situation, the “immediate causes” or events that motivated the joint deformation of the structural system of the “Tezonco-Olivos” section columns 12 and 13 are described and analyzed. The minor deformations that occurred in specific locations of the structural elements are listed. And with this, the “root causes” of each of these deformations are investigated. And in section 3) the containment, mitigation, operation and maintenance strategies are analyzed to prevent future collapse events.

4.2. Case Review

As a second phase, the review of the Case is an implicit stage in the process of building it; after the design, according to DNV (2021) and before validation by judges, according to Escobar (2022). The review criteria supported the modifications of form and content made to the Case; with the purpose of improving its dimensions of: (a) clarity, (b) coherence, (c) relevance, (d) sufficiency and (e) metacognitive and professional transcendence. Which was carried out on the Wordpress (2022), through 16 discussion threads between peers; to see the process consult the link: https://n9.cl/hilosdiscusioncasolineadorada, with the key:

"lineadorada". As a result of the review, the following aspects are obtained: a) the Case was reduced in length from 8,591 to 6,064 words; from 58 to 24 pages; b) in the sections of the Case, an attempt was made to start with questions to carry out the approach in the reading; c) non-essential portions of text and tables were eliminated, such as the section on the history of the metro and the section on the immediate cause; d) all abbreviations of technical terms and associations are referenced with full text; e) newspaper sources were reduced, only for illustrative figures. Technical sources were kept to support figures, tables and graphs; f) errors in the designation of units were corrected; g) in the root cause section of the Case, the infographic was replaced by a conceptual table that graphically summarized the content; in the root cause section, the summary table was eliminated and the analysis of the 23 causes that originated the accident was maintained; h) the introduction section was summarized to make the content of the Case more succinct; i) technical references from the Construction Regulations of Mexico City, Title VI structural safety were incorporated.

4.3. Validation of the Case by Judges

Escobar (2022) was taken as a reference in the proposal of the four dimensions or categories of validation by judges of the collapse case; for example, for the introduction section: a) Clarity: the section is clear, has adequate semantics and syntax; b) Coherence: the section is completely related to the technical situation described; c) Relevance: the section is very relevant and should be included; d) Sufficiency: all sections of the Case are sufficient. Also, "Google forms" was used to carry out the survey and efficiently manage the responses, and a form was sent via email to experts, to see it you can consult the following link: https://forms.gle/PteTeiQWmykiFMzB8. Regarding the validation criteria, these are related to numerical categories expressed on an ordinal scale of 4 polarized items, one negative, two intermediate and one positive, for each dimension and section of the Case. In addition to the four dimensions of validation, five additional questions were posed to explore the didactic-professional relevance of the Case; 1) The Case is related to the work reality; 2) The Case will be attractive for physics and engineering students; 3) Not all the information necessary to analyze the Case is in the text; 4) Readers of the Case will have to do some research, inferences, judgments and arguments based on the information learned; 5) The Case has more than one perspective of analysis and acceptable solution proposal. For the survey, a "Likert" scale of three items was used: a) totally agree; b) agree; c) neither agree nor disagree; d) totally disagree.

The statistic used to quantify validity of the case by judges is the Aiken Coefficient, adapted from Escurra (1998); which allows to verify the level of efficiency of the reagents used in the form to probe appreciation by judges. It really verifies that each question is measuring the value assigned for each dimension, in each section of the case, see formula (1) in the following:

Aiken's V. coefficient formula, source Escurra (1998)

$$V = \frac{S}{[n * (c - 1)]} \tag{1}$$

The formula is composed of: V=Aiken coefficient, S=sum of numerical values assigned by each of the 7 judges surveyed, for each validated criterion; Si=specific numerical value, assigned by each judge, for each criterion, n= number of judges, c=number of criteria evaluated. The number of judges surveyed is seven, the number of values of the ordinal scale considered for each dimension is four: 0, 1, 2, 3; and the values of (S) and (si), are the sum of numerical values assigned by judges and numerical value for each criterion; see Tables (1), (2):

Table 1.

Description of 4 validation dimensions, Source: Escobar, 2022

CRITERIA EVALUATED IN THE 4 SECTIONS: Introduction, history, root cause and perspective			
1.-Clarity	2.-Coherence	3.-Relevance	4.-Sufficiency
0=It is not clear	0=has no logical relationship.	0=section can be deleted	0=all sections are insufficient.
1=requires quite a bit of modification.	1.-has a tangential relationship.	1=the section has some relevance.	1=not all sections correspond in their entirety.
2=requires very specific modifications.	2.-has a moderate relationship.	2=relatively important section.	2=some sections need to be increased.
3=It is clear, it has semantics and syntax.	3.-completely related.	3=very relevant deserves to be included	3=all sections are sufficient.

Table 2.

Description of the 5 additional questions, Source: Escobar, 2022

5 ADDITIONAL QUESTIONS TO THE CASE:					
1.-Related to work reality	2.-Attractive physics and engineering	3.-Not all the information it's in the text	4.-With what has been learned, judgments and investigations will be made	5.-More than one solution proposal and analysis	3=Totally agree 2=agree 1=Neither agree nor disagree 0=Totally disagree

Each response was assigned a value, according to a Likert scale. With these values, a validation code is built for each section of the case; the efficiency ranges for evaluations obtained by the Aiken coefficient are: from 0 to 0.30 deficient, from 0.30 to 0.49 not very efficient, 0.50 to 0.69 regularly efficient, from 0.70 to 0.85 efficient, from 0.85 to 1.00 very efficient, Escobar (2022). Finally, the reason for validating by judges lies in the importance of knowing the opinion of experts, whose job is to teach and whose "expertise" in the academic and professional field is backed by their material or intellectual production.

4.4. Case Evaluation by Users

As part of the case construction process, a user evaluation was required; the instrument to make this measurement is based on the characteristics that a case should have according to Ellet (2017). The 3 sections of the Case were evaluated by surveying a sample of 56 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). In this process, the same 4 dimensions of validation by judges are repeated and 2 dimensions are added: multi-response and reading comprehension.

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, a survey work was constructed, which can be consulted at the following link: https://forms.gle/Tes4zh5gSf4ruqm38. The dimensions and questions for user evaluation are listed below (Escobar, 2022; Ellet, 2017): 1) relevance; 2) sufficiency; 3) clarity; 4) coherence; 5) multiple response: 5.1) does proposing several solutions to the Case problem invite you to get involved in clarifying the causes of the facts?; 5.2) According to the characteristics of the Case, can you answer the following questions?: a) how did the events occur?, b) can you identify causes of facts, problems and solutions?, c) do you identify the agents involved?, d) do you identify the space-time context?; 6) Reading comprehension: 6.1) which aspect would you choose to evaluate your reading?: a) do I briefly clarify the essential characteristics of the Case?, b) do I state most of its characteristics, c) do I state the sequence of all the essential characteristics, facts, problems and solutions.

In the user validation process, also through interval coding, the values of the table proposed by Ellet (2017) were applied to verify the level of efficiency of each category of the Case, according to the results of the survey form applied.

Table 3.
Efficiency level of case characteristics when investigating users, source: Ellet, 2017

Feature Category	Justification (coding)	No. question form Google-result statistic
1. 1. The problem that arises in the case is relevant. Codification **(relevance) significance.**	If between 80 and 75% of students assign a yes, then the case is being evaluated as relevant.	Question 1 100% if you consider the case is relevant.
2. 2. Sufficient information from which conclusions can be derived. **Coding (sufficiency).**	If between 80 and 75% of students assign a yes, then the case is evaluating enough.	Question 2 96.4% = yes enough. Question 4 92.9% = yes enough.
3. 3. There are several alternative answers. Coding **(multi response) multi factual reality.**	If between 80 and 75% of students assign a yes, then the case is evaluating as reality multi factual.	Question 7 92.9% yes multiple response. Question 9 92.9% yes multiple response. Question 10 67.9% yes multiple response.
4. 4. Non-linear-non-causal organization. Coding **(apparent disorganization, multidirectionality, simultaneity) COHERENCE**	If between 80 and 75% of Students assign a yes, then the case is evaluating as coherent with reality.	Question 3 40.0%=yes coherence. Question 5 35.7%=yes coherence. Question 8 98.2% = yes coherence.
5. 5. There are information gaps, coding **(not semantics, not syntax). CLARITY**	If between 80 and 75% of students assign a no, then the case is evaluating as clear.	Question 6 21.4%=unclear. 78.6%=yes clear.

In Table 3, percentage levels higher than 90% are observed for the user ratings of each of the reagents according to the dimension of the Case of the “Google forms” form; which represents high levels of relevance, sufficiency and multi-response of the designed Case. Only in the dimensions of Coherence and Clarity were levels below 78.6% obtained for clarity and below 40% for coherence, which is explained in greater detail in the results section; however, this does not imply that the Case is poorly designed, but rather that the level of complexity of this is high and therefore, the effort demanded to penetrate the reality of the Case is greater and therefore requires greater cognitive work. In addition, the reasons for validating the Case by users are due to the importance of exploring the perception of students regarding the efficiency of the designed Case, as a tool to address and generate learning. Since students, in addition to having different learning styles, are an essential part when implementing the "Case method", it is necessary that they have a Case that is sufficiently well designed both in disciplinary correspondence, as well as appropriate to the heterogeneity of ways of learning and managing knowledge (Felder & Silverman, 2002).

That is, have a Case that can enhance, through the method, competencies of conceptual understanding and discursive coherence.

Therefore, the Case of the "collapse of the Gold Line of the Mexico City Metro" can be adapted to other engineering courses such as Topography, Mining, Industrial, Computer Systems, Robotics; by adapting the method to their disciplinary content, since most engineering courses "per se" generate data and practical processes, aspects in which the "Case method" provides sufficient and efficient support for learning.

However, according to Jiménez (2016), in order to use a Case for learning in engineering or other professional careers, or even at different educational levels such as at the high school level in physics or analytical geometry subjects, it is necessary to take into account the type of Case that is most suitable not only for the students' learning styles, but also for the disciplinary and curricular content of the subject. For example, Cases can be chosen according to their content, purpose, structure or methodological aspect.

Some Cases, depending on the objectives of the learning unit, may contain multiple dimensions and agents involved, or intrinsic due to their specialty, instrumental or collective, if the purpose is to reach deductions or guiding principles. They can even be descriptive, interpretive or evaluative, depending on what is required. Whether it is to characterize, categorize, or analyze or reach judgments. Cases can even be qualitative or quantitative, depending on the nature of the results to be obtained (Jiménez, 2016), without forgetting the premise of the "Case method" that makes it applicable at different educational levels and fields of knowledge: "recognizing that another's argument may be more solid or compelling scientifically" (Ellet, 2007).

Finally, the resources, both human and material, used for the validation and evaluation of this inquiry were: a sample of experts in the field of academic and professional practice, preferably professors of structural mechanics subjects; and whose professional performance has been in the project and design of structures. Also a sample of civil engineering students, from the learning units of "strength of materials and statics", both at the foundation level, from the Higher School of Engineering and Architecture (Esia) of the National Polytechnic Institute (IPN, 2003). Classroom space, computer, cell phone, email, “Google forms”, “Google Drive”, Microsoft Office Excel and Word, “Word Press” platform and printed and media documentary compendium were used.

5. Results

5.1. Results Validation Judges by Dimensions

Based on the validations carried out by 7 judges, engineers and higher education professors; the following results are presented. Applying a Likert-polarized measurement scale; of a negative item located on the left and a positive one on the right; and two intermediate ones; which are related to an ordinal scale of four items (0,1,2,3), according to validation criteria.

Chart 2. Evaluation of the introduction section, source: own elaboration

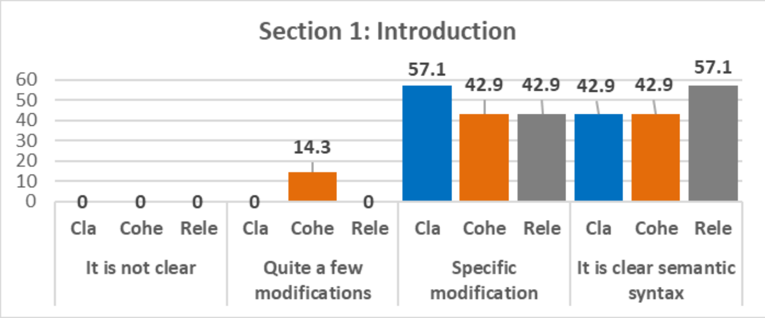
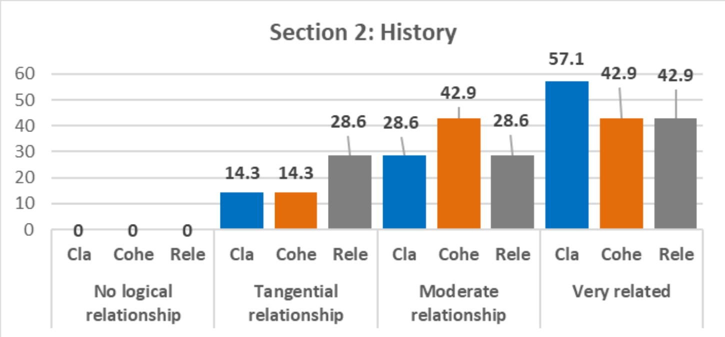


Chart 3. History section evaluation, source: own elaboration



Since in Chart (2), 57.1% respond that the introduction requires specific modification and 42.9% say that it has adequate semantics and syntax; it is inferred that the section is clear. 42.9% indicate that the introduction is moderately related and 42.9% that it is very related to the situation described, therefore, the section tends to be coherent. 42.9% say that the introduction is relatively important and 57.1 indicates that it is very relevant and should be included, it is inferred that the section is relevant. In Chart (3) 28.6% indicate that the section requires a specific modification, 57.1% that it has adequate semantics, then the story is clear. Since 42.9% indicate that the section is moderately related to the technical situation, and 42.9% say that it is completely related, it is inferred that it is coherent. 28.6% say that the section is relatively important and 42.9% that it is very relevant and should be included, so it is inferred that the story tends to be relevant.

The above results in graphs 2 and 3 indicate that the introduction section is better perceived than the history in its evaluated dimensions, because judges consider that the history as a necessary cause is less relevant to the immediate causes and root causes that the introduction addresses, in order to understand the technical situation analyzed in the case. And this consideration is due to the causal criterion of facts, since according to the theory of causal facts of a complex reality, historical causes do not have a direct relationship with immediate causes, rather the root causes are the ones that do (DNV, 2021).

Chart 4. Root cause section validation, source: own elaboration

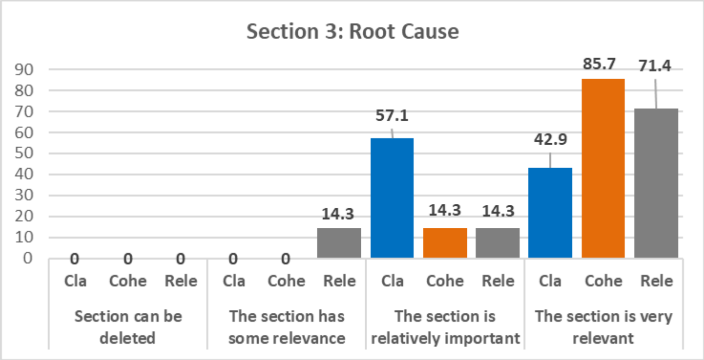
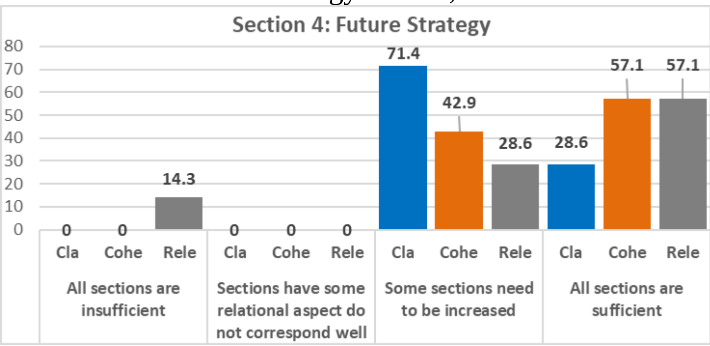
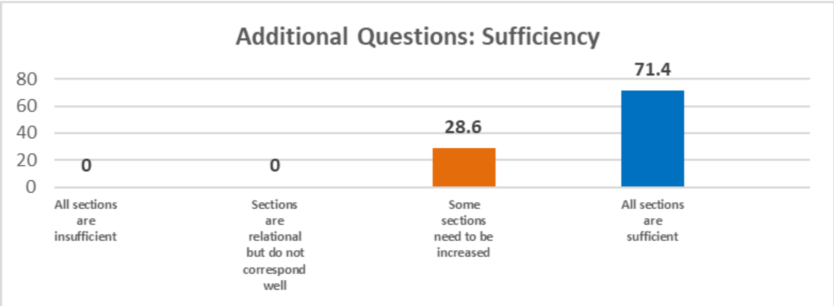


Chart 5. Validation of strategy section, source: own elaboration



In Chart (4) 57.1% indicate that the section requires a specific modification, and 42.9% that the root cause has adequate semantics and syntax, then the root cause tends to be clear. Since 85.7% respond that the section is fully related to the technical situation it measures, it is inferred that the root cause is coherent. And 71.4% say that the section is very relevant and should be included, then the root cause is relevant. In Chart (5) 71.4% say that the section requires a specific modification and 28.6 indicate that it has semantics, it is inferred that the future strategy tends to be clear. 42.9% indicate that the section is moderately related to the technical situation described and 57.1% that it is very related, it is inferred that it is relevant. Charts 4 and 5 present similar results for the root cause and future strategies sections, in their evaluated dimensions; because the sections have a directly proportional relationship according to the judges' criteria and the theory of causal facts (DNV, 2021).

Chart 6. Validation, for all sections, source: own elaboration



Since in Chart (6) 71.4% indicate that all sections of the case are sufficient, it is inferred that the case has content integrity. Clarifying that the 3 dimensions measure the sections of the case in a singular way, while the sufficiency dimension measures the 4 sections of the case in a general way. For the values of the 5 additional questions, validation trends were found with high percentages, between ranges of 42.9%, 57.1% and 71.4%, related to the Likert scale of: "agree" and "totally agree"; it is inferred that the 5 additional questions highlight the functionality of the case at a professional and metacognitive level. When comparing the four graphs of the validated sections of the case for three of its singular dimensions, positive evaluations are observed with an upward trend and to the right of the histograms, it is inferred that the case is clear, coherent and relevant. Also, it was observed that the judges validate between ranges of 42.9% for each of the last two positive levels of the Likert scale, which indicates that the case is not 100% clear or coherent, which represents the nature of the reality reported in the case, not linear, causal, or ordered in its entirety, Ellet (2017).

In Chart 6, the sufficiency dimension is for all sections of the case and 28.6% consider that the case needs some sections to be increased, this is due to the complex nature of reality, but also because the case should not have all the answers, students must do extra research; Because a case should not have all the answers, but should teach you how to think about how to investigate these answers in a relational way (Ellet, 2017).

5.2. Results Validation of Judges by Coefficient V. Aiken

The following tables were created to organize the data collected for each of the reagents that recorded evaluation criteria by judging, for each dimension and section of the case.

Table 4.
Judges' validations and summary table, section 1, source: own elaboration

SECTION 1: INTRODUCTION	Criteria for evaluation of the didactic sequence	Judge 1	Judge 2	Judge 3	Judge 4	Judge 5	Judge 6	Judge 7	Σ x criteria	V (Aiken)	Assessment
V=S/[n*(c-1)]	Clarity	3	3	2	3	2	2	2	17	0.81	efficient
	Coherence	3	3	2	2	1	2	3	16	0.76	efficient
	Relevance	3	3	2	2	3	2	3	18	0.86	very efficient
Todas las Secciones	Sufficiency	3	3	3	2	3	2	3	19	0.90	very efficient

Summary table	Clarity	Coherence	Relevance	Sufficiency
S=	17	16	18	19
si=	x	x	x	x
n=	7	7	7	7
c=	4	4	4	4
V(Clarity)=	0.80952381	0.81		
V(Coherence)=	0.76190476	0.76		
V(Relevance)=	0.85714286	0.86		
V(Sufficiency)=	0.9047619	0.90		

Table 5.
Judges' validations-summary table, section 2,3,4, additional questions, source: own elab

SECTION 2: HISTORY	Criteria for evaluation of the didactic sequence	Assessment	SECTION 3: ROOT CAUSE	Criteria for evaluation of the didactic sequence	Assessment	SECTION 4: PROSPECTIVE CASE	Criteria for evaluation of the didactic sequence	Assessment
V=S/[n*(c-1)]	Clarity	efficient	V=S/[n*(c-1)]	Clarity	efficient	V=S/[n*(c-1)]	Clarity	efficient
	Coherence	efficient		Coherence	very efficient		Coherence	very efficient
	Relevance	efficient		Relevance	very efficient		Relevance	efficient

ADDITIONAL QUESTIONS TO THE CASE	Criteria for evaluation of the didactic sequence	
V=S/[n*(c-1)]	Work reality	very efficient
	Attractive students	very efficient
	Not all information	efficient
	Investigation will be done	efficient
	Various solutions	efficient

Since the results obtained in Tables (5) and (6) for the introduction and remaining sections of the case indicate levels of efficiency, it is inferred that the statistician indicates efficient evaluations of the case very similar to the histograms, indicating sufficiency of understanding and content analysis. That is to say, the reagents constructed for the piloting of expert opinion fulfill the function for which they were designed.

They efficiently gather the judges assessment in relation to each of the dimensions of the case: clarity, coherence, relevance and sufficiency, for each of the analysis sections: necessary cause, root cause, immediate cause and future strategies.

5.3. Users Evaluation Results

Chart 7. Triangulation of data dimensions coherence and sufficiency, source: own elaboration

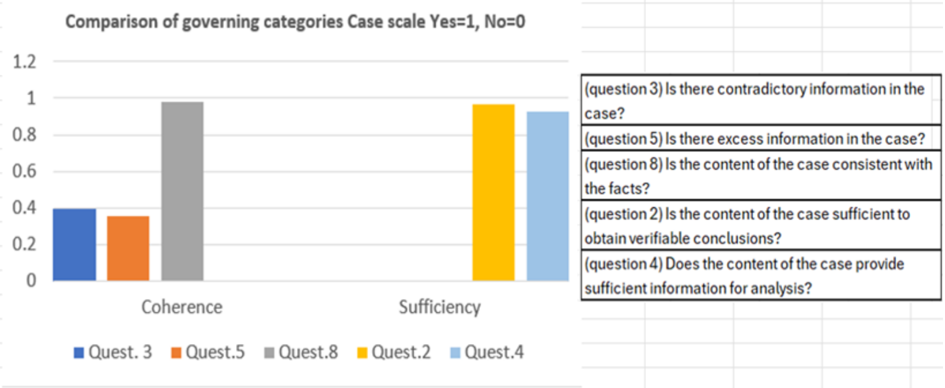
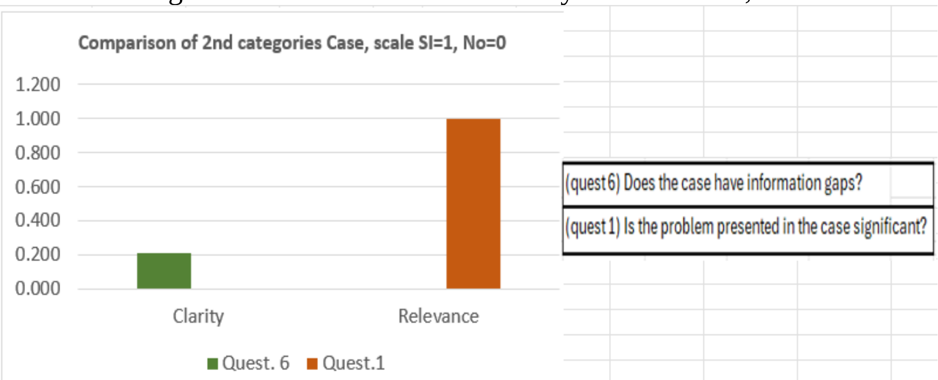


Chart 8. Triangulation of data dimensions clarity and relevance, source: own elaboration



In Chart (7), questions 3 and 5, 40% indicate coherence, there is disparity with questions 2 and 4 that 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 (8) 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. In Charts 7 and 8, they indicate that students perceive that the case is not entirely coherent and clear, and this is because reality is complex, multidimensional, which implies a task of in-depth reading and complementary research.

Chart 9. Triangulation of data dimensions coherence and relevance, source: own elaboration

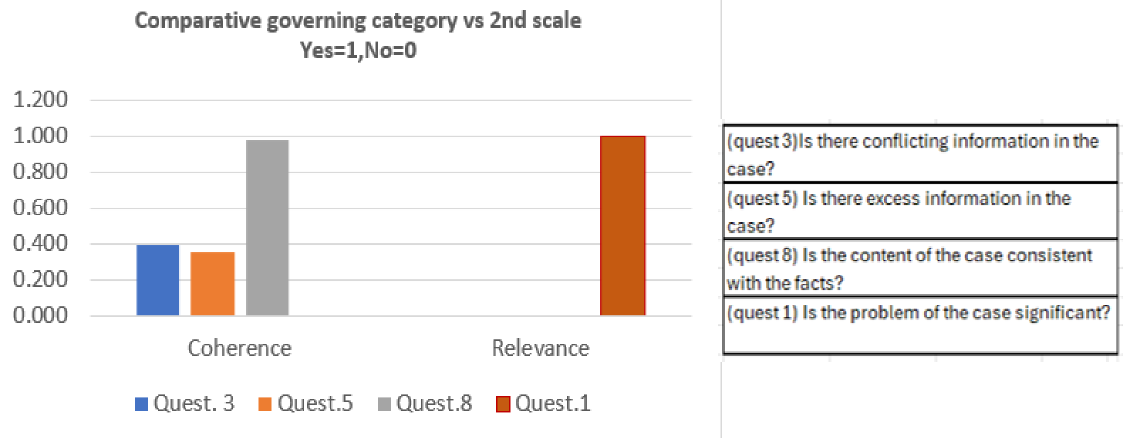
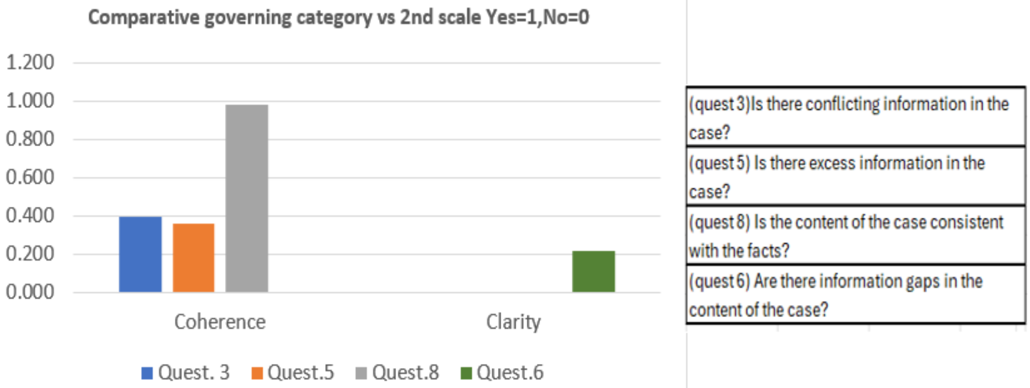


Chart 10. Triangulation of data dimensions coherence and clarity, source: own elaboration



In Chart (9) there is low triangulation (Cisterna, 2005) 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 involved in depth. Chart (10) similar to the triangulation between coherence and clarity. In Charts 9 and 10, the values for clarity and coherence are similar to those in Chart 7 and 8, due to the complex nature of reality and the multi-causal theory inherent to it. However, expert judges consider the case to be relevant because it has a direct relationship with the technical situation described.

Chart 11. Triangulation of data dimensions of sufficiency and relevance, source: own elaboration

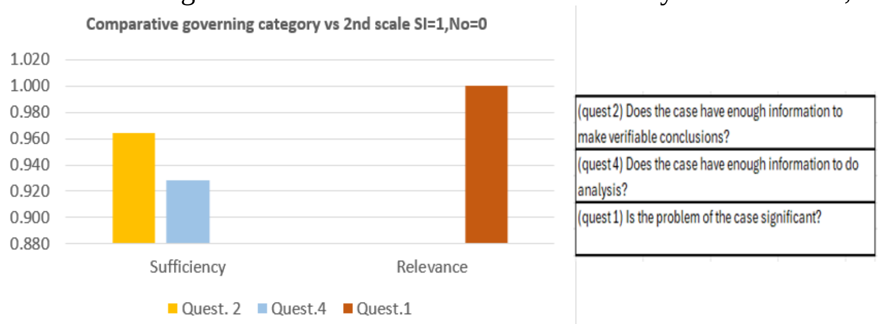
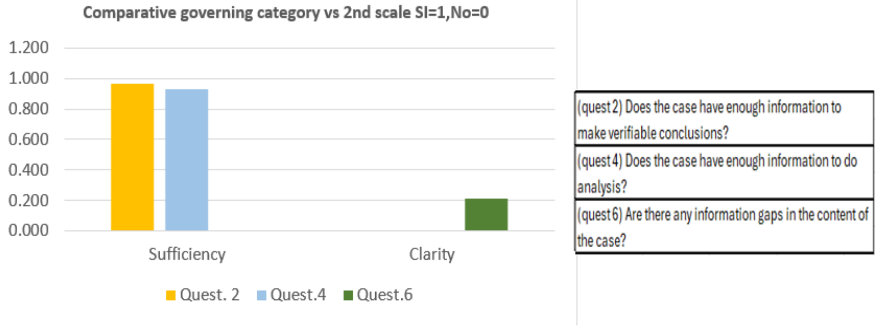


Chart 12. Triangulation of data dimensions of sufficiency and clarity, source: own elaboration



In Chart (11) sufficiency and relevance are correlated with 96 and 100%, and in Chart 12 the level of triangulation between sufficiency and clarity is low, 20% perceive information gaps vs 80% who do not. Therefore, the steps to carry out the evaluation were: a) design the Case for engineering; b) determine user sample; c) design form based on analysis dimensions proposed by Ellet (2017); d) application of the form; e) construction of graphic statistics with the results obtained from the survey; f) interpretation of results is written; g) data triangulation is carried out for each of the dimensions of the Case, according to Cisterna (2005); h) interpretation of results is written. Finally, the steps for validation were the following: a) design of the Case; b) sample of judges; c) design of form according to Escobar dimensions (2022); d) application of form to experts; e) construction of graphic statistics; f) interpretation of results; g) the validity of the results is verified by the Aiken coefficient, according to Escurra (1988); h) reinterpretation.

6. Limitations of the Case Methodology

The limitation of case studies is that unless there are other recently examples, there is nothing to compare them, because most of the time, only a single case study is being carried out, not several. Another limitation is the difficulty in generalizing the results of a case study to other contexts, or to a broader population. There is even a high risk of bias, since the personal opinions of the researcher can influence the research, since case studies resort to qualitative inferential and interpretive work at various times (DNV, 2021).

Another aspect is the difficulty in convincing readers accustomed to clear statistical answers, since case studies involve deep inductive work. Another aspect is the difficulty in convincing readers accustomed to clear statistical answers, since case studies involve deep initial inductive work, and then inferential analytical deductive work, which implies gradually becoming familiar with a reality divided in its study into as many clear and simple parts as possible, and then carrying out relational work that generates individual and general meaning (DNV, 2021).

7. Conclusions

In light of the theory presented and the results from the data obtained, the research question of how to design an engineering case linked to physics was answered; and the objective of designing the case considering the collapse of the “Golden Line of the Mexico City Metropolitan” was achieved, as well as the description of its characteristics based on its supporting method. In such a way that the case was validated and evaluated with optimal levels of relevance and sufficiency; in addition, both users and judges agreed with acceptable evaluations, due to approximate disparities of 40-60%, that the case is not 100% consistent with a logic inherent to a simple, linear, ordered and idealized reality. Rather, the case is consistent with a complex, multi-focus and apparently disordered reality, but when analyzed in depth, logical content with multiple edges is perceived, but all with a relational sense.

Therefore, the effectiveness of the Case design in understanding the physical concepts applied to engineering was evidenced; because it has been designed in a methodological and systematic way, through its sections and structural dimensions. With the research carried out, other research related to the relevance of the "case methodology" can be generated, to qualify and quantify levels of understanding of Physics principles in Engineering. And to answer a pending research question: how does the case methodology modify the understanding of physics concepts in engineering students? However, within the limitations of the method, it is of little application in engineering and the existence of designed cases is also limited. It is necessary to work with the “ERVE” model and with the method, for its integration in engineering subjects.

And this depends on the type of object of study of each engineering and of each curriculum inherent to it. That is, on the characteristics of the object of study and its variability as a phenomenon, and therefore on the difficulties that it presents to achieve the engineering objectives. An ad hoc example is the principles of physics, which as an object of study, regulate and allow the realization of bridge and overpass projects, subject to the law of gravity and the laws of forces, work and efforts. The implementation of the method, in its dialogic work, must also be adapted to the type of learning prevailing in the students; whether it is kinesthetic, auditory, visual or even analytical, inferential, argumentative or descriptive, in accordance with the prevailing rational scheme developed in the students.

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