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Scientific and popular texts: revealing principles of legitimation in Astronomy

Abstract

The communication of astronomical scientific knowledge is carried out through diverse discourses, each with its basis of legitimation. This article explores how these bases are constructed in different types of texts by applying the Specialization dimension of Maton's Theory of Legitimation Codes (TLC). Contrastive analysis is performed on two textual excerpts that address the concept of black holes: one from a university textbook (OpenStax) and the other from a textbook (OpenStax Astronomy) and another from a popular science material (NASA Science). The analysis reveals that the academic text predominantly operates under a Knowledge Code (RE+, RS-), where validity is based on the mastery of disciplinary knowledge and procedures. In contrast, the popular science text employs an Elite Code (RE+, RS+), legitimizing a tailored version of knowledge through source authority and strategies for connecting with a general audience. These findings demonstrate the usefulness of CLT in uncovering the tacit principles that shape communication in astronomy, offering implications for teaching, materials design, and the promotion of a critical understanding of science.

Keywords: Legitimation Code Theory (LCT), Specialization dimension, scientific texts, scientific communication, legitimation codes.

Volume 9 Issue 3 - 2025

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Received: May 30, 2025 | **Published:** July 15, 2025

Introduction

Knowledge in physics is constructed and communicated through various discourses, from highly specialized academic texts to popular science materials aimed at the general public. Each discursive context operates under underlying principles that determine legitimate knowledge and who can be recognized as a valid expert. Understanding these 'rules of the game' is crucial for understanding the nature of science and analyzing how access to scientific knowledge is facilitated or hindered and how public perceptions of these disciplines are shaped. The way astronomical concepts are presented, for example, can significantly influence future specialists' training and society's scientific culture.

However, the principles underlying the legitimation of knowledge in these different texts often remain tacit or not immediately apparent. Analytical tools are needed to uncover these hidden mechanisms and understand how different ways of communicating science may privilege specific knowledge and knowers. Analyzing these underlying codes is essential for critically reflecting on teaching practices, the design of educational materials, and scientific communication strategies in physics and astronomy. This article draws on Legitimation Codes Theory (LCT), developed by Karl Maton[1] to address this issue. Specifically, it will use the Specialization dimension of LCT, which offers a robust conceptual framework for analyzing how relationships are established between knowledge and its object (Epistemic Relations - ER) and between knowledge and its subjects (Social Relations - SR), and how the interaction of these relationships configures different legitimation codes.

The main objective of this work is to exemplify the application and analytical utility of the Specialization dimension of LCT through a contrastive study of two short texts that address the same astronomical concept: the event horizon of black holes. An excerpt from a university textbook (OpenStax) will be analyzed. Astronomy) and a popular science text from NASA. This analysis will seek to answer, implicitly, the following research question: How are different codes of Specialization, based on the interaction of Epistemic and Social Relations, manifested in two texts that, although they deal with the same astronomical concept, come from different contexts and have different communicative purposes?

To this end, the article is structured as follows: first, the theoretical framework will be presented, detailing the Specialization dimension of LCT. Next, the methodology used to analyze the selected texts will be described. Subsequently, the results of the analysis of each text and a comparative summary will be presented. Finally, the findings will be discussed with the relevant literature, implications for the teaching and communication of astronomy will be drawn, and the study's conclusions will be offered.

Theoretical framework: the specialization dimension of TCL

Introduction to the theory of Legitimation Codes (LCT)

This paper is theoretically and methodologically grounded in Legitimation Codes Theory (LCT), developed primarily by Karl Maton.[1] LCT is a realist sociological framework that seeks to explain social practices, including educational and knowledge production practices, based on the principles or 'codes' that underlie what is considered legitimate, valuable, or successful in a given context.[1] It offers a set of conceptual tools for analyzing how different forms of knowledge and types of 'knowers' are recognized and valued in various fields (Santos, 2022). LCT is organized into several interrelated dimensions (primarily Specialization, Semantics, and Autonomy), each providing a specific language for exploring different aspects of social practices. For this article, we will focus exclusively on the Specialization dimension, which allows us to analyze the bases of legitimation of knowledge and those who produce or carry it.

The specialization dimension in LCT

In the context of LCT, the Specialization dimension is beneficial for this analysis because it offers a precise language to unveil the tacit

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'rules of the game' that define validity in a context, an application that is robust in diverse fields of knowledge.[2,3] It allows for an integrated analysis of knowledge and knowers, examining the RE/SR interrelationship configuring legitimation.[1] Furthermore, its typical set of conceptual tools facilitates contrastive analysis between texts, such as the one we propose between OpenStax and NASA. Finally, understanding the codes of Specialization has practical implications for science teaching and communication. Identifying how these can affect access to knowledge is a central concern in studies such as those by Ellery[4] and Howard and Maton.[5] Thus, the Specialization will allow us to characterize how each selected astronomical text explicitly constructs its authority and relates to knowledge and its readers, enabling a discussion about the consequences of these different forms of legitimation.

The Specialization dimension of LCT[1] explores the basis on which social practices, knowledge, and actors are considered legitimate or specialized in a particular field. This dimension is based on the premise that every practice or knowledge is related to an object of study (what is known) and to a subject or actor (who knows or produces the knowledge). These relationships' relative strength or weakness determines the dominant 'code of specialization'.[1]

The choice of the Specialization dimension of Legitimation Codes Theory (LCT) as the analytical framework for this study is based on its proven ability to reveal the bases of legitimation in discourses on scientific knowledge.[1] Far from being neutral, texts embody principles about what knowledge is valid (Epistemic Relations) and who its legitimate subjects are (Social Relations).

Epistemic Relations (ER)

Epistemic Relations (ER), within the framework of LCT, refer to the links that a social practice or discourse establishes with its particular object or focus of study.[1] That is, epistemic relations question the 'what' of knowledge: to what extent knowledge or practice is oriented toward a specific object of study, with its constitutive principles, procedures, theories, and specialized methods. As various authors who apply this dimension point out,[6] analyzing ERs allows us to understand legitimate knowledge in a given area. The strength of these relationships can vary, which has significant implications for the nature of knowledge and practices:[1]

a) Strong RE (RE+): Indicates that a practice or discourse places considerable emphasis on specialized, formalized knowledge about its object of study. This is manifested in using precise technical terminology, applying formal theories and models, adhering to rigorous methodological procedures, and presenting a delimited and structured body of knowledge. In RE+ contexts, what is said and how it is said, in terms of validated disciplinary knowledge, is crucial to legitimizing the practice or actor.

b) Weak ERs (ER-): These suggest that practice or discourse downplays or is not primarily grounded in formal specialized knowledge about a particular object of study. In these cases, legitimation is not predominantly based on mastery of specific theories, methods, or disciplinary content. However, it may rely on other principles, such as personal experience, more general approaches, or non-formally codified knowledge.[1]

In text analysis, such as that proposed in this paper, identifying the strength of RE involves examining how scientific discourse is constructed, the type of language used, the conceptual density, the forms of argumentation, and the sources of knowledge validation invoked.

Social Relations (SR)

Complementary to Epistemic Relations, Social Relations (SR) refers to the links that a practice or discourse establishes with its subjects, that is, with the authors, actors, or audience involved.[1] SR questions the 'who': to what extent does the legitimation of a practice or discourse depend on the subjects involved, their attributes, dispositions, experiences, status, or identity?

Like RE, the strength of Social Relationships can vary:

a) Strong SRs (SR+): Indicate that a practice or discourse strongly emphasizes the attributes of the subject or knower. Legitimacy depends significantly on who the individual (or group) is, what characteristics they possess, what experiences they have had, or what community they belong to. This may manifest in a discourse that values personal dispositions (e.g., creativity, charisma, particular 'perspective'), the authority invested in specific roles or figures (e.g., 'scientists say', 'experts assert'), or emotional connection and identification with the audience.

b) Weak SRs (SR-): Suggest that a practice or discourse downplays specific attributes of the subject or knower. Legitimation is based less on who the individual is and more on other principles, such as knowledge itself or perhaps the situation or context. In discourses with SR-, the author may adopt an impersonal tone, and the audience may be constructed as generic or universal without appealing to their particular social or identity characteristics.

When analyzing astronomy texts, exploring SRs will allow us to understand how the author's figure is constructed (implicit or explicit), how the reader is addressed, and what type of 'knower' is considered legitimate or sought to be formed in each discursive context. Studies that apply LCT in educational and outreach contexts[4,5] frequently highlight the importance of SRs for understanding access to knowledge and communication effectiveness.

Specialization codes: the interaction between RE and RS

The Specialization dimension of LCT argues that the basis of legitimation of a practice or discourse can be understood through the interaction between the strength of its Epistemic Relations (ER+/-) and its Social Relations (SR+/-). This interaction gives rise to a Cartesian plane that allows us to identify four principal specialization codes,[1] each representing a different underlying principle about what or who counts as legitimate:

i. Knowledge code code : RE+, RS-):

In this code, legitimation is based on possessing specialized and formalized knowledge, skills, principles, and procedures (RE+). What matters is the mastery of 'what' is known and 'how' it is known within a particular discipline or field. The knower's social characteristics or personal dispositions are secondary or less relevant to legitimation (RS-). As explored in various studies on science education and curriculum,[7,8] this code is often prevalent in natural science teaching, where students are expected to acquire a specific body of knowledge and methods:

ii. Knower code code: RE-, RS+):

Here, legitimation is primarily based on who the subject is: their attributes, dispositions, experiences, particular 'gaze,' or membership in a specific social group (RS+). Formalized knowledge or specialized procedures about a particular object of study are less important or subordinated to the qualities of the knower (RE-). This code assesses

Citation: Cutrera G. Scientific and popular texts: revealing principles of legitimation in Astronomy. *Phys Astron Int J.* 2025;9(3):174–183.
DOI: 10.15406/paij.2025.09.00383

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the 'type' of person one is or must be to be considered legitimate. Research in fields where dispositions or identity are crucial (e.g., some areas of the arts or humanities or certain types of social activism as analyzed by Glenn[9] about views on climate change) can reveal the operation of Knower Codes.

iii. Elite code (Elite code: RE+, RS+):

This code legitimizes based on specialized knowledge and skills (RE+) and the 'right' knower attributes or dispositions (RS+). To be considered legitimate, one must know' and 'be' the right kind of person. As Maton[1] explains, this can be found in fields where technical expertise must be accompanied by a particular 'ethos,' a lineage or set of valued dispositions. High-level scientific communication or training for research leadership roles might tend toward this code, where both epistemic excellence and certain personal or belonging qualities are expected.

iv. Relativist code: RE-, RS-):

In this code, neither formal specialized knowledge (RE-) nor specific attributes of the knower (RS-) are the primary basis for legitimation. The basis for legitimation may be more fluid and contextual, depending on other principles such as power, absence or weakness. Maton[1] suggests that this code can lead to a situation where 'anything goes' or, conversely, where the basis for legitimation is opaque or defined by factors unrelated to the Specialization itself.

Understanding these codes allows for a more precise analysis of the tacit "rules of the game" that operate in different contexts, including how science is taught, learned, and communicated to the public. Identifying the dominant code in a text or practice reveals what is being valued and what is being promoted or excluded.

Methodology

Research design

This study is framed within a qualitative research approach.[10] The primary analytical tool used is Karl Maton's[1] Legitimation Codes Theory (LCT), focusing on its Specialization dimension. The objective is to conduct a contrastive and illustrative analysis of two short texts that address the same astronomical concept (black holes and their event horizons) from presumably different sources and with different communicative purposes. Through this analysis, we seek to exemplify how the Specialization dimension can reveal the underlying codes that legitimize knowledge and knowers in different discourses on physics and astronomy.

Selection of texts (Corpus analysis)

For this article's illustrative and contrastive purposes, two brief text excerpts have been selected that address the concept of black holes and, more specifically, their event horizons. Both texts come from publicly available sources and, a priori, represent two distinct communicative approaches to astronomical knowledge.

Text 1: Extract from a university textbook

The first text has been extracted from the university-level textbook ' Astronomy ' published by OpenStax, a widely used open educational resource. Specifically, the selected paragraphs belong to Chapter 24, Section 5, entitled 'Black Holes '. This text has been chosen because it represents an academic-formative discourse, presumably aimed at university science students, where an emphasis on conceptual precision and formalism typical of the discipline would be expected.

Text 1 (OpenStax Astronomy, Ch. 24.5):

"The event horizon is the boundary of the black hole; calculations show that it does not get smaller once the whole star has collapsed inside it. The region separates the things trapped inside it from the rest of the universe. Anything coming from the outside is also trapped once it comes inside the event horizon. The horizon's size depends only on the mass inside it. If the Sun, with its 1 mass of 1 M_{Sun}, were to become a black hole (fortunately, it can't—this is just a thought experiment), the Schwarzschild radius would be about 3 kilometres; thus, the entire black hole would be about one-third the size of a neutron star of an equivalent mass. Feed the black hole some mass, and the horizon will grow, but not much.

The event horizons of more massive black holes have larger radii. For example, if a globular cluster of 100,000 stars (solar masses) could collapse into a black hole, it would be 300,000 kilometres in radius, less than half the radius of the Sun. If the entire Galaxy could collapse into a black hole, it would be only about 10^{12} kilometres in radius—about a tenth of a light year. Smaller masses have correspondingly smaller horizons: for Earth to become a black hole, it would have to be compressed to a radius of only 1 centimetre less than the size of a grape. "A typical asteroid, if crushed to a small enough size to be a black hole, would have the dimensions of an atomic nucleus."

(Source: OpenStax, *Astronomy*. Retrieved from:)[11]

Text 2: Excerpt from disclosure NASA scientist

The second text was taken from the official NASA website (National Aeronautics and Space Administration), specifically from its scientific outreach section on the universe, which is dedicated to black holes. It was selected because it represents a public discourse on science communication aimed at a general, non-specialist audience, where an adaptation of language and a different approach would be expected to facilitate understanding and interest.

Text 2 (NASA Science - Universe - Black Holes, "Overview" section):

"Black holes are among the most mysterious cosmic objects, much studied but not fully understood. These objects are not holes. They are huge concentrations of matter packed into very tiny spaces. A black hole is so dense that gravity beneath its surface, the event horizon, is strong enough that nothing – not even light – can escape. This region of no escape is called the event horizon. It is a boundary that contains all the matter that makes up the black hole.

We do not know much about black holes, like what matter looks inside their event horizons. However, there is much that scientists know about black holes."

(Source: NASA. *Black Holes*. Retrieved from:)[12]

Analysis procedure from the TCL Specialization dimension

Since the corpus of this study comprises both an academic training text and a popular science text originating from a recognized scientific institution, it is anticipated that both types of discourse will maintain a positive epistemic relationship (RE+) with astronomical knowledge. Variations will be expected more in the intensity, degree of formalization, and mode of presentation of this knowledge (resulting in more or less intense or adapted RE) than in a shift towards weak epistemic relationships (RE-) since both texts, by their nature, refer to and seek to legitimize knowledge originating in the specialized scientific field.

Citation: Cutrera G. Scientific and popular texts: revealing principles of legitimation in Astronomy. *Phys Astron Int J.* 2025;9(3):174–183.
DOI: 10.15406/paij.2025.09.00383

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The two selected texts were analyzed following a systematic procedure guided by the principles of the Specialization Dimension of the Legitimation Codes Theory.[1] The objective was to identify how each text constructs and legitimizes knowledge (Epistemic Relations) and knowing subjects (Social Relations) to infer the dominant specialization code. The process consisted of the following interrelated stages:

A. Familiarization with the texts: Multiple and detailed readings of each of the two extracts were conducted to gain a deep understanding of their content, argumentative structure, and possible communicative purpose in the context of their source.

B. Identification of Epistemic Relations (ER): In this stage, the analysis focused on identifying how each text establishes a relationship with the knowledge it presents about black holes. Indicators of the strength of Epistemic Relations (ER+ or ER-) were sought, paying attention to aspects such as:

a) The use of specialized terminology versus every day or simplified language.

b) The presence of formal definitions, abstract principles, physical laws or mathematical formalism (RE+), in contrast to the use of analogies, metaphors or more concrete and narrative explanations (which could indicate a different or "translated" RE).

c) The degree of explicitness and detail describing astronomical mechanisms or processes.

d) The sources of legitimation of knowledge invoked (e.g. "calculations", "the mathematics of general relativity", "scientists know", observation).

e) Conceptual density and level of abstraction of the discourse.

C. Identification of Social Relations (SR): The analysis then focused on how each text builds a relationship with the producers and recipients of knowledge (the subjects or "knowers"). Indicators of the strength of Social Relations (SR+ or SR-) were sought, considering elements such as:

a) The tone of the speech (e.g. impersonal and objective vs. personal, dialogical or exhortative).

b) The use of pronouns that build a relationship with the reader (e.g., "we," "you," or the absence of these for a generic reader).

c) The reader is positioned as a learner who must decode complex knowledge, as an interested citizen, as a future specialist, etc.

d) The invocation of authority: whether the authority resides primarily in knowledge itself (RS-) or whether the attributes, experience, or dispositions of the scientists or the author of the text are emphasized (RS+).

e) The presence of elements that seek to generate affinity, emotional commitment or identification on the reader's part.

D. Inference of specialization codes: Once the RE and SR in each text were analyzed, their interaction was interpreted to propose the dominant specialization code. Following Maton (2014), the four principal codes were considered:

a) Knowledge code (RE+, RS-): Legitimacy is based on possessing specialized knowledge and skills, regardless of who the knower is.

b) Knower code (RE-, RS+): Legitimacy is based on who the subject is and their attributes or dispositions rather than on formal knowledge.

c) Elite code (RE+, RS+): This code requires specialized knowledge, the "right kind" of knowledge.

d) Relativistic code (RE-, RS-): Neither specialized knowledge nor particular attributes of the knower are the primary basis of legitimation.

e) It will be argued, for each text, which of these codes (or a particular combination or emphasis) best describes its basis of legitimation.

E. Contrastive analysis: Finally, the specialization profiles identified in Text 1 and Text 2 will be compared to highlight the differences and similarities in their strategies for legitimizing astronomical knowledge, relating them to their contexts of origin and potential audiences.

Analysis and results

This section analyses the two selected texts, applying the Specialization dimension of the Legitimacy Codes Theory. Each text's Epistemic Relations (ER) and Social Relations (SR) will be examined to infer its predominant specialization code.

Text analysis 1: Excerpt from openstax astronomy

OpenStax university textbook Astronomy (Chapter 24.5):

Text 1:

"The event horizon is the boundary of the black hole; calculations show that it does not get smaller once the whole star has collapsed inside it. The region separates the things trapped inside it from the rest of the universe. Anything coming from the outside is also trapped once it comes inside the event horizon. The horizon's size depends only on the mass inside it. If the Sun, with its 1 mass of 1 M_{Sun}, were to become a black hole (fortunately, it can't—this is just a thought experiment), the Schwarzschild radius would be about 3 kilometres; thus, the entire black hole would be about one-third the size of a neutron star of an equivalent mass. Feed the black hole some mass, and the horizon will grow—but not much.

The event horizons of more massive black holes have larger radii. For example, if a globular cluster of 100,000 stars (solar masses) could collapse into a black hole, it would be 300,000 kilometres in radius, less than half the radius of the Sun. If the entire Galaxy could collapse into a black hole, it would be only about 10^{12} kilometres in radius, about a tenth of a light year. Smaller masses have correspondingly smaller horizons: for Earth to become a black hole, it would have to be compressed to a radius of only 1 centimetre less than the size of a grape. "A typical asteroid, if crushed to a small enough size to be a black hole, would have the dimensions of an atomic nucleus."

Epistemic Relations (ER) in text 1

The text establishes a strong connection to specialized knowledge in astrophysics (indicating a RE++). This is demonstrated through several indicators:

a) Use of technical terminology and disciplinary concepts: The text introduces and uses terms such as "M Sun", "neutron star", "black hole", "event horizon", "Schwarzschild radius", "globular

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cluster", "solar masses", "Galaxy", and "light year". These terms belong to the specialized lexicon of physics and astronomy.

b) Reference to fundamental principles and models: Although a theory such as "general relativity" is not explicitly named, the text relies on its principles and results. "Calculations" are mentioned to support claims about the event horizon ("*calculations show that Item does not get smaller once the whole star has collapsed inside it*"), which involves the application of established physical models.

c) Definitions and descriptions based on physical properties: The event horizon is functionally described as "*the boundary of the black hole*" and "*the" region that separates the things trapped inside Item from the rest of the universe*". A fundamental property is established: the size of the event horizon "*turns out to it depends only on the mass inside it*". They are described processes physicists as he collapse stellar ("*once the whole star has collapsed inside it", "could collapse to a black hole*").

d) Quantification and hypothetical examples based on physical models: Quantification and thought experiments are used extensively to illustrate concepts. For example:

e) "*If the Sun, with its mass of 1 MSun, were to become a black hole... the Schwarzschild radius would be about 3 kilomet*res".

f) "*Doubling the mass will make the black hole 6 kilometres in radius*."

g) "*If a globular cluster of 100,000 stars (solar masses) could collapse to a black hole, it would be 300,000 kilometres in radius*."

h) "*If the entire Galaxy could collapse to a black hole, it would be only about 1012 kilometres in radius*."

i) "*For Earth to become a black hole, it would have to be compressed to a radius of only 1 centimet*re." These examples demonstrate the application of physical and quantitative models to explain the properties of black holes.

j) Delimitation of the scope of models or statements within the scientific paradigm: The clarification "(*fortunately, it can't, this is just a thought experiment*)" in considering the Sun becoming a black hole, while not pointing out a theoretical gap, reinforces the scientific nature of the discourse by clearly distinguishing between an illustrative thought experiment and naturally occurring physical processes according to current models (the Sun does not have enough mass for such a purpose). This demonstrates a practice of scientific demarcation.

k) Conceptual density and abstraction: The concepts presented are abstract (e.g., " event horizon " as a non-physical border, but with real consequences, the idea of "Schwarzschild" radius" as a calculated property, the direct relationship between mass and the size of this horizon). The text hopes that the reader can follow a logical argument based on these abstract concepts and underlying physical principles to understand the scale and nature of black holes.

Social Relations (SR) in text 1

Regarding Social Relations, the analyzed text tends to minimize the explicitness of the knower's specific attributes (indicating an SR- about personal dispositions or particular social identities). Legitimation rests predominantly on knowledge itself (as seen in the analysis of RE++) rather than on who the author or the reader is regarding their characteristics. However, the text does construct a particular type of implicit "legitimate knower," one who can and should adapt to the demands of the scientific discourse presented.

The indicators of this RS-configuration (with an implicit disciplinary expert) are:

a) Impersonal and objective tone: The text predominantly maintains an expository and formal tone. For example, phrases like "*calculations show that Item does not get smaller* "or" *The horizon's size depends only on the mass inside It* "present knowledge as facts without a strong mark of subjectivity from the author.

b) Use of pronouns and verb forms: The text avoids using a "We" that explicitly refers to the scientific community or seeks to create closeness with the reader. He uses the third person or constructions impersonally ("*It is the region...*", "*Anything coming from the outside is also trapped ...*"). Although an imperative form appears, such as "Feed the black hole some mass ...", this is used to illustrate a physical principle in a generalized way (directed to a "one" or "anyone performing the thought experiment") and not to establish a personal relationship with the reader. No direct use of "you" or "you" addresses an individual.

c) Reader Positioning: The reader is expected to be able to follow abstract and technical reasoning and understand specialized terminology. Although the text uses analogies to help understand scales ("*about one-third the size of a neutron star*", "a *little less than half the radius of the Sun* ", "*less than the size of a grape*", "*the dimensions of an atomic nucleus*"), these They serve to anchor concepts complex and do not reduce the demand cognitive significantly. The clarification "*fortunately, it cannot — this is just a thought experiment*)" when talking about the Sun manages the reader's expectations and delimits the hypothetical nature of the example, presupposing a certain familiarity with basic astronomical facts. The ideal reader is committed to the logic and conventions of the scientific field.

d) Authority based on disciplinary knowledge: A text's authority does not emanate from the author's personal qualities (which are not present individually) but from the scientific knowledge presented, validated implicitly by physical models and explicitly by reference to calculations. The objectivity and factual presentation of information reinforce this basis of authority.

e) Few elements of personal or emotional connection: Although there are some expressions like " *fortunately, it can't [the Sun become a black hole* "that introduces a slightly more personal nuance or shared relief, these are exceptional. Using analogies with everyday objects ("grape") can facilitate understanding. However, the general tone of the text remains focused on the exposition of the disciplinary content without seeking a deep emotional connection.

f) Consequently, the Social Relations in this text are weak (SR-) in that the particular characteristics or dispositions that an individual must 'be' to access knowledge are not emphasized beyond the capacity and willingness to engage with the demands of scientific-academic discourse. The focus is on 'knowing what' (knowledge about black holes and the event horizon) and 'knowing how' (understanding the application of physical principles and models) rather than on 'who knows'. The Social Relations and SRs identified for text 1 are summarized in Figure 1.

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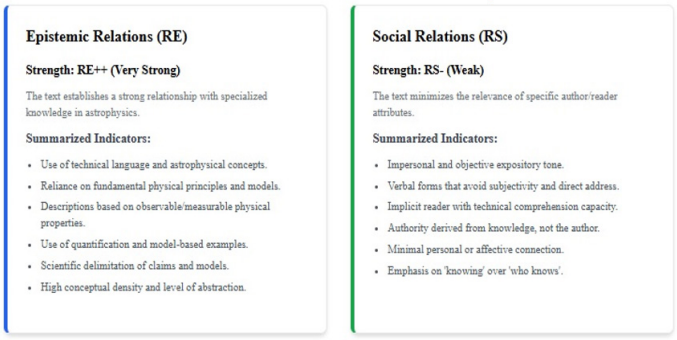

Figure 1 Epistemic relations (ER) and social relations (SR) for text 1. Source: own elaboration.

Text specialization code 1

Considering the preceding analysis, where a strong Epistemic Relationship (ER+) was identified with the specialized knowledge of astrophysics and a relatively weak Social Relationship (SR-) in terms of the emphasis on particular attributes of the knower, it is proposed that the text on the event horizon (extracted from OpenStax Astronomy) operates predominantly under a Code of Knowledge.

a) A Knowledge Code legitimizes practices and actors based on specialized knowledge, principles, procedures, and discourses specific to a particular field (RE+). At the same time, the subject's social characteristics, personal dispositions, or identity are secondary or subordinate to that knowledge (RS-). In the analyzed text, this is manifested as follows:

b) The validity of the statements is supported by consistency with established astrophysical models (which underlie concepts such as the Schwarzschild radius), the application of validated procedures ("calculations" are explicitly mentioned), and the use of precise technical and conceptual language (e.g., "event horizon," "MSun", "Schwarzschild radius"). What is said (the content) and how it is said (the specialized discourse) is central.

c) No appeal is made to the author's personal experience, nor are any particular attributes or dispositions explicitly sought in the reader beyond their ability and willingness to understand and apply the principles of physics and astronomy as presented in the text (for example, by following the quantitative examples on event horizon sizes for the Sun, globular clusters, or the Earth). The "legitimate knower" has mastered this body of knowledge and its forms of expression, regardless of other social or personal characteristics.

d) The text seeks to instruct the reader in a specific body of knowledge (the properties of the event horizon, its relationship to mass) and forms of reasoning specific to the discipline (such as thought experiments and scale comparisons), assuming that authority resides in this knowledge (evidenced by the calculations' results) and not in the author's figure or the reader's innate qualities.

e) Therefore, the analyzed text exemplifies a discourse where what "counts" is the mastery of what (astrophysics knowledge about black holes) and how (the discipline's calculation methods, models, and languages), characteristic of a Knowledge Code. This code is frequently found in natural science teaching, where priority is given to transmitting and acquiring a well-defined and structured body of knowledge.

Text analysis 2: excerpt from NASA science

Let us first recall Text 2, taken from the "Overview" section of the NASA Science page on black holes:

Text 2:

"Black holes are among the most mysterious cosmic objects, much studied but not fully understood. These objects are not holes. They are huge concentrations of matter packed into very tiny spaces. A black hole is so dense that gravity beneath its surface, the event horizon, is strong enough that nothing – not even light – can escape. This region of no escape is called the event horizon. It is a boundary that contains all the matter that makes up the black hole.

We do not know much about black holes, like what matter looks inside their event horizons. However, there is much that scientists know about black holes."

Epistemic Relations (ER) in text 2

Text 2, from NASA Science, presents a relationship to specialized knowledge (ER) that is significantly adapted for a general audience while based on the same scientific concepts as Text 1. Notably, although the presentation of knowledge is less formalized and dense than in the academic text, Text 2's Epistemic Relations remain positive (ER+). This is because the legitimacy of its claims remains anchored in validated, specialized scientific knowledge of astronomy; the text seeks to communicate findings and concepts from this field, not derive its authority from principles outside of it (such as non-expert personal opinion or everyday experience, which would characterize an ER-).

Thus, instead of a weak ER (ER-) in the sense of a disconnection from specialized knowledge, we observe an adapted or mediated ER+. This mediation is oriented toward conceptual accessibility for a broad audience rather than toward demonstrating the internal rigour of theories or mathematical formalisms, which did characterize the markedly strong ER (which we could call ER++) of Text 1.

The indicators of this RE+ adapted in Text 2 are:

Simplified language and direct explanations: Phrases like "*These are objects are not holes*" to clarify possible misconceptions simply. Density and gravity are easily explained*: "Huge concentrations of matter packed into very tiny spaces. A black hole is so dense that gravity just beneath its surface... is strong enough that nothing -not even light- can escape.*"

a) Absence of explicit mathematical and technical formalism: Unlike Text 1, there are no references to specific calculations or the underlying mathematics, presenting knowledge as a set of facts and key concepts without the need to show their formal derivation.

b) Functional and descriptive definitions, but scientifically based: The event horizon is defined as *"this region of no escape* "and "*a boundary that contains all the matter that makes up the black hole*." These describe its function and nature based on scientific knowledge, although the abstract physical principles are not explained in detail.

c) Informative emphasis on the known and the unknown: The text explicitly addresses the limits of knowledge (" *There is much we do not know ...") and what is known (" there is a lot that scientists do know .. .* "), presenting science as an ongoing process in an accessible way and without undermining the epistemic basis of what is claimed to be known.

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DOI: 10.15406/paij.2025.09.00383

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d) Less conceptual density to facilitate general understanding: Although key concepts are introduced, their interrelationship is less complex than in Text 1, facilitating understanding for a non-specialist audience.

e) This characterization of an adapted ER+ is crucial since it is this positive relationship with scientific knowledge (albeit mediated) that, when interacting with the strong Social Relations (SR+) analyzed below, will configure the basis of legitimation of the popularization text. Legitimacy is sought by clarifying the exposition of selected scientific knowledge and the source's authority (NASA) and not by shifting from specialized knowledge toward other legitimizing principles.

Social Relations (SR) in Text 2

Unlike Text 1, NASA Science Text 2 establishes significantly more explicit and stronger Social Relationships (SR) with its audience (SR+). The goal appears to inform eng, age, and connect with a general, non-specialist audience.

The following indicators evidence this:

a) Accessible and direct tone: The text uses a tone that seeks clarity and connection. Phrases like "*These objects are not holes*" aim at intuitive understanding and clarify possible preconceived ideas straightforwardly.

b) Construction of a "we" and reference to "scientists": The second paragraph is particularly revealing: "*There is much we do not know about black holes ... However, there is a lot that scientists do know ...*". The "We" here can be interpreted as a broader "we" (society, humanity) that shares curiosity and does not know everything, creating common ground with the reader. Immediately after, the "scientists " are positioned as the holders of validated knowledge. This establishes a clear social relationship: a group of experts (RS+) who research and know and an audience to whom this knowledge is communicated.

c) Positioning the reader as an interested audience: The text is aimed at a curious reader interested in the cosmos but not necessarily possessing advanced scientific training. Explanations are offered that are designed to be understood without excessive technical effort. The initial statement, "*Black holes are among the most mysterious cosmic objects, much studied but not fully understood*", appeals directly to curiosity and general interest.

d) Authority of the source and the "experts": The legitimacy of the discourse is based on NASA's authority as a renowned scientific institution and, explicitly stated in the second paragraph, on the figure of "scientists" as agents of knowledge. This is a form of SR+, where knowledge is validated through its producers and communicators.

e) Dissemination and connection intent: The overall purpose of the text is informative: to make a complex topic accessible. This implies a conscious effort to build a social bridge with the reader, recognizing their perspective and seeking to satisfy their interest.

f) In short, Text 2 actively builds a relationship with its readers, recognizing them as an interested general audience and establishing scientists (and, by extension, NASA) as authoritative sources of knowledge. It emphasizes this audience's ability to grasp basic concepts if presented appropriately and seeks to awaken or sustain their fascination with the universe. These characteristics point to SR+, where the knowers' attributes and position (scientists and the audience) are relevant to the communication. Figure 2 summarizes the SR and SR identified for Text 2.

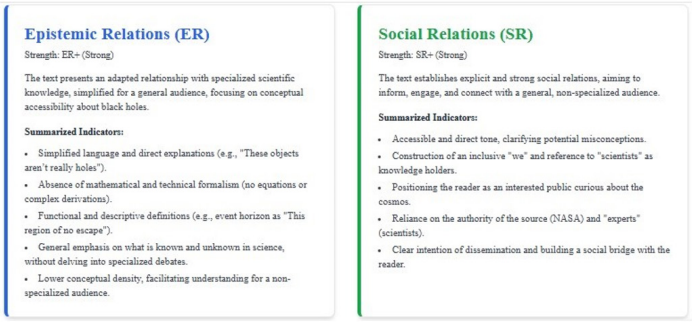

Figure 2 Epistemic relations (ER) and social relations (SR) for text 2. Source: own elaboration.

Text specialization code 2

An analysis of Text 2 (NASA Science) has revealed a particular configuration of its bases of legitimacy. On the one hand, it presents Epistemic Relations (ER) with scientific knowledge that is adapted or translated (ER+); that is, validated scientific concepts and facts are transmitted but simplified and stripped of their formal complexity to make them accessible to a general audience. On the other hand, it establishes explicit and strong Social Relations (SR+), seeking to connect with the reader, recognizing their perspective, and positioning the "scientists" and NASA itself as authoritative sources of knowledge.

Considering this interaction—where both knowledge (albeit adapted) and the attributes and relationships of knowers (scientists as source, public as interested recipient) are important for legitimation—it is proposed that Text 2 operates under an Elite Code. In this context, the code does not refer to a social elite in the traditional sense but to the legitimation of a particular type of knowledge (simplified and validated science) transmitted by authorized knowers (scientists/NASA) to a broad public that seeks to be 'initiated' or kept informed and engaged in science.

This Elite Code (RE+, RS+) is manifested in Text 2 as follows:

a) The transmission of scientific knowledge, which is considered fundamental and reliable (RE+), such as the nature of black holes or the concept of the event horizon, is valued. Although simplified, the epistemic basis comes from the specialized scientific field.

b) At the same time, who communicates and how they communicate are crucial (RS+). NASA's authority and the figure of the "scientists" are fundamental to the message's credibility. Accessible language and strategies to generate interest (" mysterious") are crucial. Cosmic objects ") are important attributes of this communication.

c) The text seeks to cultivate a particular type of "informed knower" in public: someone who understands the basic concepts of science, trusts scientific sources, and values the knowledge they produce. This legitimizes a relationship between science (and its institutions/actors) and society.

d) This code also explicitly recognizes what is "not known" alongside what is "known" (second paragraph). It presents science honestly while maintaining the authority of scientists as those who manage and advance that knowledge.

Text 2, therefore, is not based solely on 'knowing what' (as a pure knowledge code), nor predominantly on the 'who is' of the reader or author (as a pure knower code). Instead, it legitimizes a particular form

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of (adapted) scientific knowledge promoted by authoritative knowers. It is directed at an audience that seeks to integrate them into a basic understanding and appreciation of science. This type of Elite Code is common in high-quality science communication, where a balance is sought between fidelity to the scientific content and effective audience connection.

Comparative summary of the specialization codes

The analysis of the two selected texts reveals significant differences in their bases of legitimation, which translates into the predominance of different codes of Specialization. While Text 1 (OpenStax Astronomy) operates under a Knowledge Code (RE+, RS-), Text 2 (NASA Science) operates under an Elite Code (RE+, RS+). These differences are evident when comparing their Epistemic and Social Relations:

Construction of knowledge (Epistemic Relations):

a) Text 1 (OpenStax) presents knowledge about black holes with a high degree of formality and abstraction (RE++). It uses precise technical terminology (“ Schwarzschild radius”, “singularity”), relies on fundamental principles (“general relativity”), and validates procedures (“ calculations show”,” mathematics ... predicts”). The complexity and conceptual density are high, and the reader is expected to adapt to the requirements of this specialized discourse.

b) Text 2 (NASA): Offers adapted and simplified knowledge (RE+). While the concepts are scientifically valid (black hole, event horizon), they are presented in an accessible manner, avoiding mathematical formalism and complex technical jargon (“ These objects are not holes”, “region (of no escape”). Epistemic legitimacy is based on conceptual clarity and the source’s authority rather than on the explicitness of the internal structure of scientific knowledge. Even the discussion about the “known” and “unknown” is handled in a general way.

Construction of the knower and the audience (social relations):

a) Text 1 (OpenStax) establishes weaker Social Relations (SR—) regarding personalization. The tone is impersonal, and the author’s figure is diffuse. The reader is positioned as a disciplinary apprentice who must acquire the field’s conceptual and linguistic tools. Authority resides fundamentally in the discipline’s knowledge and procedures. The “we” used (“ *We do not have a theory* ...”) is a scientific-academic “we.”

b) Text 2 (NASA): Builds stronger and more explicit social relationships (RS+). The tone is more direct and seeks to engage the reader (“mysterious cosmic objects”). It is aimed at a general, non-specialized audience, seeking to clarify concepts and awaken interest. The authority is personified by “scientists” and the institution (NASA). The “we” (“*we do not know*”) can be interpreted as more inclusive of the general reader’s perspective on the mystery, although the knowledge of “scientists” is then delimited.

c) Bases of Legitimation and Resulting Codes:

d) In Text 1 (Knowledge Code), legitimacy is based on what is known (the corpus of astrophysics) and how it is acquired (through theory and calculation). What matters is mastery of specialized knowledge.

e) In Text 2 (Elite Code), legitimation is based on a combination: validated (albeit simplified) scientific knowledge is valued. It is crucial to who transmits it (authoritative sources such as NASA/scientists) and to whom it is addressed (an intended audience to be informed and engaged). A particular form of scientific knowledge is legitimized for a broad audience, mediated by experts.

f) While the OpenStax academic text legitimizes knowledge that requires an introduction to the specialized codes of physics and astronomy, the NASA popular text legitimizes an adapted version of that knowledge, emphasizing the source’s authority and connection to a broad audience. The two serve different functions: one trains future specialists or in-depth experts, and the other seeks to create a scientifically informed and culturally engaged citizenry in the advances and mysteries of science. Figure 3 summarizes the comparison of the codes associated with both texts.

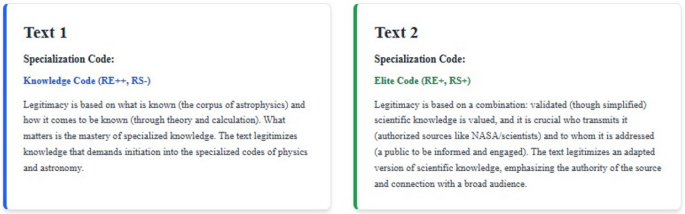

Figure 3 Specialization codes for the analyzed texts. Source: prepared by the authors.

Discussion

The analysis revealed how two texts addressing the same astronomical topic -black holes and their event horizons- use different codes of expertise to legitimize their present knowledge and relationships with their audiences. Text 1, representative of an academic-training discourse (OpenStax Astronomy), is aligned with a Knowledge Code (RE++, RS-). In this code, the emphasis is strongly on Epistemic Relations: the validity of discourse is based on its adherence to the principles, theories (such as General Relativity), mathematical formalisms, and procedures of physics and astronomy. The legitimate ‘knower’ can decode and operate within this specialized system, minimizing the relevance of their social attributes or personal dispositions beyond this technical capacity.

In contrast, Text 2, which originates from a science outreach context (NASA Science), operates under an Elite Code (ER+, RS+). While validated scientific concepts are conveyed here (Epistemic Relations adapted for accessibility), legitimation also depends crucially on Social Relations. These RS+ are manifested in the source’s authority (NASA and the figure of the ‘scientists’) and in constructing a connection with the general public, which is intended to inform and interest. This elite code refers to promoting a particular scientific knowledge (selected and simplified) by ‘authoritative experts’ for an audience that is believed to have the capacity and interest to understand the foundations of science.

The fundamental difference lies in the “rules of the game” that each text proposes. Text 1 demands immersion in the internal structure and language of scientific knowledge, while Text 2 offers a “translated” version of that knowledge, validated by the authority of the person who delivers it and designed to be understandable by a broader spectrum of “experts.” This suggests that “knowledge” about astronomy is constructed and valued differently depending on the communicative context and its purposes: training specialists versus creating a scientific culture among the general public.

The characterization of Text 1 (OpenStax) as a Knowledge Code resonates strongly with Maton’s[1] description of how knowledge is legitimized in many scientific fields and higher education. This

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emphasis on the mastery of disciplinary principles and procedures (RE+) with relatively lesser importance of the attributes of the knower (RS-) is a constant in the analyses of texts and pedagogical practices in science. For example, Georgiou's (2014) work on thermodynamics shows how access to knowledge in university physics is strongly linked to a student's ability to operate within this type of code, where abstract principles and formal procedures are central. Similarly, Wartha and Melo's[8] analysis of the natural science curriculum matrix illustrates how the documents guiding teaching tend to prioritize knowledge's logical and conceptual structure (RE++). Our analysis of the OpenStax text, with its conceptual density, formal language, and appeal to the 'mathematics of general relativity,' clearly exemplifies this type of code.

Along these same lines, Santos's[6] research on the initial training of natural science teachers is particularly relevant. Investigating the Specialization Codes in this context makes it possible to understand how her study shows how Knowledge Codes can predominantly guide training programs. If future teachers are expected to primarily master disciplinary scientific content (RE++), this would reflect the logic of legitimation observed in Text 1 and would have consequences for how these future teachers might tend to reproduce these codes in their teaching practices. Cornell and Padayachee's[13] work on the postgraduate training of theoretical physicists also emphasizes the appreciation of highly specialized knowledge mastery (RE++). However, it introduces nuances regarding knowledgeable attributes (RS+) emerging at advanced stages, suggesting possible transitions toward Elite Codes in research training.

In contrast, Text 2 (NASA), which we have characterized as Elite Coded (RE+, RS+), exhibits a distinct legitimation strategy fundamental to public-directed scientific communication. Here, specialized knowledge (RE+) is 'translated' or simplified, and legitimation relies crucially on the authority of the source (NASA, 'scientists') and the building of a relationship with the audience (RS+). This finding speaks to the work of Ellery,[14] who analyzes access to scientific knowledge and the legitimation of knowers, highlighting that it is not only 'what' is known that matters but also 'who' can be a legitimate knower. The NASA text actively participates in this dynamic by positioning 'scientists' as those who 'know' and the public as interested recipients. Adapting the RE in the NASA text is a strategy to broaden the reach of this 'elite' knowledge, where 'elite' refers to those who access a validated (albeit simplified) understanding through authoritative channels.

Deliberate 'code shift'[1] is intended to facilitate comprehension for different audiences. In this sense, Howard and Maton's[5] ideas on ' code Clash and code match in educational technology contexts offer an interesting framework. Suppose an individual is accustomed only to the highly specialized code of Text 1. In that case, they might experience difficulties when confronted with contexts that value other forms of relating to knowledge or knowledge. Effective science communication, such as that pursued by Text 2, can be understood as an effort to 'code match' with a broader audience.

Hatisaru's[15] study of perceptions of STEM specialization among academics, which identifies the prevalence of Knowledge Code views and the emergence of Knower or Elite Codes, is consistent with our findings. Our analysis of the two texts suggests that even within the same domain, such as astronomy, different bases of legitimation are used depending on the communicative purposes. OpenStax Text 1 aligns with the 'knowledge code' view, while NASA Text 2 illustrates a movement towards an 'elite code' for public communication.

Finally, the versatility of the Specialization dimension in analyzing the 'rules of the game' in diverse fields of knowledge is widely documented. Works such as those by Carvalho, Dong, and Maton[3] on knowledge in Design or those by Arbee, Hugo, and Thomson,[2] although situated in disciplines distinct from ours, demonstrate the power of LCT to reveal how knowledge is structured and legitimized. This reinforces the idea that codes of Specialization are a transversal phenomenon in the organization and transmission of knowledge.

The analysis of the codes of expertise in the OpenStax and NASA texts suggests important implications. First, it highlights the need for science educators to know the codes underlying their materials. While essential for rigour, an exclusive predominance of the Knowledge Code (RE+, RS-) could hinder access for students less familiar with its demands. As suggested by the teacher education literature (e.g., Santos, 2020), reflexivity about these codes is crucial for inclusive pedagogical practice, which could involve strategic code-switching to connect with diverse learners.

Second, for science communication, the Elite Code (RE+, RS+) in the NASA text illustrates an effective strategy for the general public. However, it is vital to reflect on what knowledge is simplified and how science and scientists are represented[14] to promote critical understanding. Finally, understanding these codes can help avoid 'code clashes'[5] when individuals move between formal and popular science discourses, fostering a more nuanced view of how scientific knowledge is constructed and legitimized.

This study, focusing on two text extracts, is illustrative, and its findings cannot be generalized. However, it demonstrates the usefulness of the Specialization dimension of LCT for analyzing discourses in astronomy. Future lines of research considered most promising could include investigating students' and teachers' perceptions of how different codes of Specialization affect their teaching and learning experiences in specific astronomy contexts, delving into lines such as those of Georgiou[7] or Hatisaru.[15] Likewise, it would be enriching to apply other dimensions of LCT (such as Semantics or Autonomy) in combination with Specialization to gain an even more comprehensive understanding of discourses in physics and astronomy and how they construct meaning and power.

Conclusion

This article aimed to illustrate the usefulness of the Theory of Legitimation Codes (TLC) Specialization dimension in analyzing the bases of knowledge legitimation in different types of astronomy texts. The contrastive analysis of an excerpt from a university textbook and a popular science text, both focusing on black holes, revealed different "rules of the game" regarding what is valid knowledge and who can be a legitimate knower in each context.

The main findings indicate that academic texts predominantly operate under a Knowledge Code (RE+, RS), where legitimation is based on mastery of astrophysics' language, concepts, and specialized procedures. In contrast, popular science texts employ an Elite Code (RE+, RS+), which legitimizes an adapted version of scientific knowledge through the authority of the source (NASA and the "scientists") and through strategies that seek to connect and inform a general audience. These differences in codes reflect the different communicative purposes: rigorous disciplinary education versus creating an accessible scientific culture. This work's main contribution is demonstrating how applying the LCT's Specialization dimension offers a robust language and systematic methodology for uncovering the tacit principles underlying the construction and communication of knowledge in physics and astronomy. By making these codes visible, opportunities are opened for deeper reflection on teaching practices, the design of educational materials, and scientific outreach strategies to promote more equitable access and a more critical understanding of

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science. Ultimately, understanding the codes that legitimize knowledge in the sciences is critical not only for specialists and educators but also for fostering a society that can more informedly and thoughtfully engage with scientific knowledge and its implications.

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