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Assessment of students' understanding of physical phenomena through argumentative qualities of written texts

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Abstract
We present a qualitative study aimed at devising a theoretical-methodological tool to assess students' conceptual understanding of physical phenomena through the argumentative qualities of their written texts. The proposed relationship between argumentation and understanding is elaborated through the notions of knowledge, purposes, methods, and communicative forms, as well as the use of data, warrants, modal qualifiers, claims, and rhetorical resources. In order to exemplify the tool's use, the current understanding of six students attending a physics seedbed course was assessed according to four levels: naïve, novice, apprentice, and mastery. We then discuss the possibilities and limitations of the tool and the need to broaden the assessment of students' understanding to include argumentative tasks in the classroom.

Keywords: teaching of physics, understanding assessment, argumentation, free fall, sound wave propagation

INTRODUCTION

Physics teaching usually privileges not only knowledge unrelated to students' daily experiences (McDermott, 2001) but also mechanical and rote mathematical methods and procedures oriented to the application of formulas (Flores et al., 2003). At the same time, it is rare in physics classes for students to communicate their understanding through written texts about physical phenomena. Frequently, students learn about physical phenomena with a low level of understanding (Driver et al., 1994; Oñorbe & Sánchez, 1996; Zacharia, 2007).

Various investigations report on students' understanding. Some of them propose that the assessment of understanding should consider the dimensions: contents, methods, purposes, and forms of communication (Blythe, 2002; Stone, 1999). Others report on the understanding of physical phenomena, showing that students, once finishing their primary or secondary school education, fail to understand the studied phenomena at an appropriate level (Abbott, 2003), among other reasons, because teachers rarely discuss errors and false beliefs, what could help improve conceptual understanding (Chiu et al., 2007; Ledezma et al., 2022). Students' conceptual understanding is expressed when they can apply their expert arguments to novel situations, while students with naïve conceptual understanding have difficulty solving new problems (Dai et al., 2019).

Some research suggests that conceptual understanding should be encouraged (Martínez-Garza et al., 2013), while other affirm that the conceptual understanding of physical phenomena is complex when it is related to other knowledge (Park & Liu, 2016). Unfortunately, teaching does not usually consider students' beliefs important to achieve conceptual changes from naïve scientific ideas (Yeo & Zadnik, 2001). Some students finish their education with intact intuitive knowledge of physics. Related to this, some researchers point out the importance of the relationship between

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Contribution to the literature

- This paper studies students' understanding of physical phenomena through the analysis of students' written text and its argumentative qualities.
- This paper uses elements of argumentation to study the teaching of physical concepts and uses them to understand the complexity of teaching physics to promote students' understanding.
- A theoretical-methodological tool is shared to assess the written argumentation during the teaching and learning of physics.

mathematical understanding and conceptual understanding of physical phenomena (Basson, 2002; Kaya, 2018).

Other investigations report on the production and assessment of texts written by students in science classes to identify levels of argumentation on physical phenomena (Gutiérrez, 2017), students' difficulties when using scientific language (Macías & Maturano, 2017), or reasons given by teachers when communicating scientific knowledge to their students in a rhetorical perspective (Fagúndez & Castells, 2012). However, in physics class, it is usual for the teacher to claim that a student has understood a particular phenomenon without assessing his/her understanding through argumentation in written texts.

In the specialized literature, different instruments are proposed to assess students' understanding of physical phenomena, for example, interviews, open question or multiple-choice tests (Benegas & Zavala, 2013). In some cases, teachers routinely use mathematical knowledge in assessments and exclude conceptual understanding (Flores et al., 2003). In other cases, the assessment resorts to questions about physical phenomena without testing the student's arguments (Flores et al., 2003).

We consider in this study that theoretically articulating the assessment of understanding, the argumentative components, and the rhetorical resources that students use in written texts could inform a theoretical-methodological tool for teachers to use in the classroom to assess students' conceptual understanding trough their written texts. We have not found in the literature research reports on tools with this orientation.

We present a qualitative study aimed at devising a theoretical-methodological tool to assess students' understanding of free fall and sound waves propagation through the argumentative qualities of their written texts. We claim that the assessment of understanding could indicate the learning of mathematical knowledge about physical phenomena (Osborne, 2001) and conceptual understanding.

To this end, examples of understanding assessment of six students participating in the study are presented. The data analysis was carried out by studying the argumentative qualities of the texts written on free fall and propagation of sound waves.

UNDERSTANDING

In this study, we define understanding as "[…] being able to carry out a variety of actions or performances that demonstrate that one understands the subject and at the same time broadens it and can assimilate knowledge and use it in an innovative way" (Blythe, 2002, p. 40). In other words, "[...] understanding is the ability to think and act flexibly based on what one knows" (Stone, 1999, p. 70), "the ability for flexible performance" (Stone, 1999, p. 70). This ability for flexible performance requires the current understanding of notions and relationships as well as their mathematical interpretations (Ponce, 1997).

We understand by *knowledge* the "information at hand" (Stone, 1999, p. 69) and by *understanding performance* "all the cases in which the student uses what he knows in a new way" (Blythe, 2002, p. 40). Likewise, "understanding performances allow students to go beyond the information given to create something new by reconfiguring, expanding and applying what they already know, as well as extrapolating and building on that knowledge" (Blythe, 2002, p. 88).

To assess the understanding of a physical phenomenon in texts written by students, we use the dimensions: content, methods, purposes, and communicative forms (Hetland et al., 2003; Mansilla & Gardner, 1999; Perkins, 1999; Stone, 1999).

Stone (1999) defines each dimension, as follows:

> "The content dimension assesses the extent to which students have transcended intuitive or unschooled perspectives and the extent to which they can move flexibly between examples and generalizations in a coherent and rich conceptual web" (p. 230).

That is, "to what extent do students' performances demonstrate that tested theories and domain concepts have transformed their intuitive beliefs?" (p. 231).

> "[…] the methods dimension assesses students' ability to maintain a healthy skepticism about what they know or are told and their use of reliable methods to construct and validate true, morally acceptable, or valid claims and works. valuable from the aesthetic point of view" (p. 232).

That is, "to what extent do students display a healthy skepticism towards their beliefs and knowledge presented in sources such as textbooks, public opinion, and media messages?" (p. 234).

The purpose dimension "assesses students' ability to recognize the purposes and interests that guide the construction of knowledge, their ability to use knowledge in multiple situations, and the consequences of doing so" (p. 235).

> "The communication dimension assesses students' use of symbol systems (visual, verbal, mathematical, and bodily-kinesthetic, for example) to express what they know, within established genres or types of performance. For example: writing essays, performing a musical comedy, giving a presentation, or explaining an algorithm" (p. 237).

In this study, the use of content, methods, purposes, and communicative forms dimensions allows for establishing relationships between argumentation and understanding, as follows:

The contents are knowledge that the student uses to give the reasons for a particular phenomenon. Specifically, they are information about a physical phenomenon, which is used for argumentative purposes. This information at hand is brought into play in the form of data, warrants, and claims that are communicated in an argument.

Methods are orderly and systematic ways of proceeding to arrive at certain conclusions in a justified way. When using a specific method, students operationalize their knowledge to refer to a physical phenomenon through rhetorical resources, such as examples, models, illustrations, and metaphors. According to disciplinary standards, the relevance of the methods provides strength to the arguments for persuasive or convincing purposes.

The purposes are objectives, not necessarily explicit, that a student intends to achieve with knowledge in a given situation. For example, in the case of written texts, the purpose may be to convince or persuade through arguments. Arguments with persuasive purposes are based on beliefs and personal views about physical phenomena, while arguments with convincing purposes are based on knowledge about physical phenomena (Perelman & Olbrechts-Tyteca, 2006).

The communicative forms are written, spoken, and gestural ways, among others, that the student uses to express to others his/her knowledge about a certain phenomenon. In our case, students have expressed their understanding of physical phenomena through written texts.

Therefore, for the assessment of a student's understanding of a physical phenomenon through the argumentative qualities of their written texts, we analyze the contents, methods, purposes, and communicative forms that they use.

Written Text and Its Argumentative Qualities

Within this study, a text is argumentative when its purpose "...is to convince [or persuade] the reader to accept or share certain points of view [...]" (Díaz, 2009, p. 34). Some argumentative qualities of a written text are its argumentative indicators, its argumentative components, and the rhetorical resources used by the author.

On the one hand, we identify the use of linguistic/explicit argumentative indicators. These indicators are words that serve to distinguish portions of arguments, and inferentially unite one or more arguments (Van Eemeren et al., 2007). Some examples of argumentative indicators are in addition, like, then, therefore, among others.

Moreover, an argumentative written text presents specific components. These components are claims, data, warrants, modal qualifiers, backings, and rebuttals (Castro et al., 2021; Durango-Urrego, 2017; Toulmin, 2007):

(1) claims are the statements of which the arguer expects to persuade or convince;

(2) data are intersubjectively accepted statements;

(3) warrants are knowledge used to justify the inferential connection between data and claims, in this study, warrants can be beliefs or knowledge of the physical phenomena;

(4) modal qualifiers are words that specify the degree of certainty about a claim. In this study, these can be classified into absolute modal qualifiers, which fulfill the function of generalizing a certain claim, for example: even more, each; and relative modal qualifiers, which fulfill the function of particularizing a certain claim, for example: more or less;

(5) backings in this study are theories of physics that support the warrants; and

(6) rebuttals are exceptional conditions in which the warrants do not allow the passage between the data and the claim.

Finally, rhetorical resources are used in argumentation when someone wants to persuade or convince others of a claim. Following Castro et al. (2021) and Durango-Urrego (2017), the rhetorical resources we consider are examples, illustrations, models, and metaphors. An example is a particular case used to point to an instance of a physical phenomenon; an illustration is a drawing that supports an argument; a model is a point of reference to imitate, to appeal to; and a metaphor is a comparison between the situation under scrutiny and a known situation in order to provide greater meaning (Perelman & Olbrechts-Tyteca, 2006).

Assessment of Understanding and Argumentative Qualities of Written Texts

We draw on Stone's (1999) notion of understanding and Durango-Urrego's (2017) notion of argumentative qualities to establish four levels of student understanding performance: naïve, novice, apprentice, and mastery.

Naïve level

Students use their beliefs about physical phenomena in their arguments, and trial and error as a method to validate their claims. They barely relate their daily experiences with their understandings built in the classroom. They use rhetorical resources such as examples and illustrations. They use some form of representation to describe only some aspects of the physical phenomenon, not always adequately. The students' written texts do not clearly evidence either persuasive or convincing argumentative purposes.

Novice level

Students combine beliefs with physical knowledge in their arguments and use some method in a mechanical way. They connect some of their understandings built in the classroom with their everyday experiences and use some form of representation to describe some aspects of the physical phenomenon. They use rhetorical resources in their methods, such as: example or illustration. The students' written texts show persuasive, argumentative purposes.

Apprentice level

Students use knowledge about physical phenomena in their arguments and some methods adaptively to build their knowledge. They use their understandings built in the classroom in original ways in everyday experiences. They use one or more forms of representation to describe in a quantified way some aspects of the physical phenomenon. They use rhetorical resources in their methods, such as: example or illustration, but also model or metaphor. Students' written texts evidence both persuasive and convincing argumentative purposes.

Master's level

Students link knowledge of physical phenomena with everyday experiences in their arguments to develop and critique disciplinary knowledge. They use a variety of methods in sophisticated ways. They flexibly use different forms of representation to describe aspects of the physical phenomenon quantitatively and qualitatively. They use rhetorical resources in a sophisticated way in their methods, such as: example and illustration, but also model and metaphor. The students written texts evidence convincing argumentative purposes.

METHOD

The study is guided by a qualitative methodology with a hermeneutic approach (Sánchez, 1998). Its aim was to devise a theoretical-methodological tool to assess students' understanding of free fall and sound waves propagation through the argumentative qualities of their written texts. Eight students from a tenth-grade physics course and seven from an eleventh-grade physics course participated in the fieldwork. The 15 students participated voluntarily in a physics seedbed course taught by the first author. We exemplify the use of the proposed tool and its results through the analysis of the written texts of three tenth-grade students and three eleventh-grade students whose names were replaced by pseudonyms.

The data collection was carried out in two phases. In the first phase, the teacher taught the tenth-grade students about free fall and the eleventh-grade students about sound wave propagation. Experimentation and conceptualization of the phenomena were part of the teaching process. In the second phase, students were asked to write an argumentative text to explain the physical phenomenon to elementary school children. The written texts constitute the body of data collected for the study.

The written texts were transcribed for analysis. Occasionally, bracketed clarifications were added to give sense or meaning to what was said (e.g., Transcript 3: line 10). The data analysis unit that served as evidence to assess understanding consisted of each of the sentences written by the participants in their texts. Contents, methods, purposes, and communicative forms were identified in the texts, as well as argumentative indicators and argumentative qualities: data, claims, warrants, backings, modal qualifiers, and rebuttals, and rhetorical resources: example, illustration, model, and metaphor.

The data analysis involved three successive actions by the researchers:

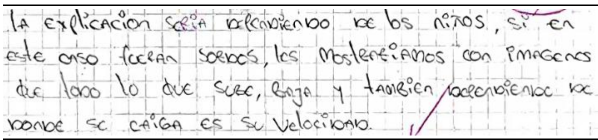
(1) identifying argumentative qualities in the written texts,

(2) identifying the rhetorical resources that the participants used to persuade their possible audiences through their texts, and

(3) assessing understanding through the understanding levels identified in the written texts.

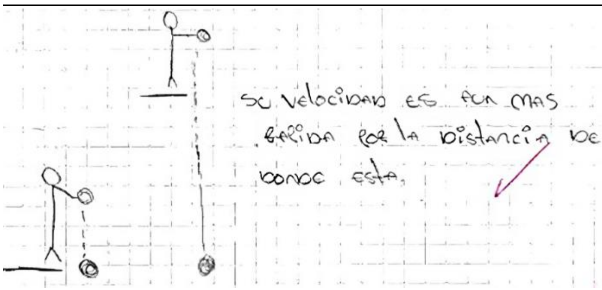
To systematize the analyses, we use two types of tables: some related to the written text of each participant, their respective transcription and underlining of some words in italics that correspond to argumentative indicators, and other tables that serve to

Table 1. Text written by María-1



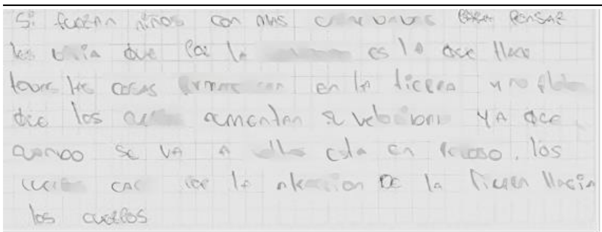
Transcript 1
[1] The explanation would depend on the children; <u>*if*</u> in
[2] in this case, they were deaf; we would show them *images.*
[3] that everything that goes up comes down <u>*and also*</u> depending on.
[4] *where you fall is your speed.*

Table 2. Text written by María-2



Transcript 2
[5] His speed is *even more*
[6] swept by the distance of
[7] where is it?

Table 3. Text written by María-3



Transcript 3
[8] <u>*If*</u> they were children with more capacities to think
[9] I would tell them *that gravity is what makes [what]*
[10] all things remain on earth <u>*and do not*</u> float,
[11] *that the bodies increase their speed* <u>*since*</u>
[12] *when it is going to be released, it is at rest, the*
[13] *bodies fall due to the attraction of the earth towards*
[14] the bodies.

summarize the assessment of understanding through the argumentative text written by each participant.

The initial data codification and analysis were performed by one researcher and subsequently triangulated by the rest of the team's researchers to clarify interpretations and achieve intercoder reliability (Fusch et al., 2018).

DATA ANALYSIS AND RESULTS

Assessment of María's Understanding

In the initial part of her text, María uses two argumentative indicators (**Table 1**), one expresses cause-effect [Transcript 1: 1], and the other expresses that the free fall of a body has at least two conditions [Transcript 1: 3]. Likewise, María uses a warrant that relates to the height and speed of free fall of a body but does not explicitly mention that its final speed increases with a greater falling height [Transcript 1: 3-4].

María uses the rhetorical resource illustration to emphasize that the speed of a body in free fall increases when the body falls (**Table 2**); however, the representation in the illustration is not accurate. The use of argumentative indicators shows the relationship between variables that converge in free fall, while the use of warrants shows that the student has understood concepts related to the phenomenon. Also, the use of rhetorical resources allows the student to show the methods she uses to validate the knowledge she has understood.

In another part of the text, María uses the rhetorical resource illustration (**Table 2**) to argue about the free fall of bodies near the earth's surface. The use of this rhetorical resource is intended to persuade deaf students. The student combines her beliefs with her knowledge about free fall. María mentions the relationship between the height from which an object is dropped and its speed. But, she does not explicitly state that the greater height of fall, the greater its final speed.

In the final part of the text, María uses three argumentative indicators (**Table 3**): one with a sense of cause-effect [Transcript 3: 8]; another for negation [Transcript 3: 10], and the third to introduce the cause by which a body in free fall increases its speed [Transcript 3: 11]. María uses three warrants:

(1) the mention of terrestrial gravity as the reason why bodies do not float [Transcript 3: 9-10],

(2) the initial speed of a body in free fall [Transcript 3: 11-12], and

(3) the terrestrial attraction and the free fall of bodies [Transcript 3: 13-14].

María offers other opinions and uses a rhetorical resource to persuade deaf children with her argument. In conclusion, María presents a novice level of understanding because she links beliefs with physical knowledge. María refers to some daily experiences, but

Table 4. Assessment of understanding through the argumentative text written by María

Argumentative indicators	If … [Transcript 1: 1]. and also … [Transcript 1: 3]. If … [Transcript 3: 1]. … and not … [Transcript 3: 3]. … since … [Transcript 3: 4].
Physical contents	Rest, speed, gravity, and free fall.
Methods	Systematic & orderly way to arrive at justified claims through the illustration.
Purpose	The argumentative purpose is persuasive in the illustration, although it is difficult to make a good representation of the body speed increase in free fall. The text written by the participant is aimed at children who are deaf and have the ability to think.
Forms of communication & audience	Written text Deaf children [Transcript 1]. Children with abilities to think [Transcript 3].
Rhetorical resources	Illustration. This rhetorical resource is presented in **Table 2**.
Argumentative components	Data: About free fall. Warrants: "Depending on where the body falls from is its speed" [Transcript 1: 3-4]. "By gravity, it is what makes [that] all things remain on earth and do not float" [Transcript 3: 2-3]. That bodies increase their speed since when it is going to be released, it is at rest [Transcript 3: 4-5]. "Bodies fall by the attraction of the earth" [Transcript 3: 5-6]. Absolute modal qualifiers: all [Transcript 1:3]. it is even more [Transcript 2: 1]. Claim: Statements about fall of a body for deaf children and children with more abilities to think.
Novice understanding level	It combines beliefs with physical knowledge [Transcript 1: 3-4]. Connect the understandings with everyday experiences [Transcript 1: 3-4]. Use some representation to describe some aspect of physical phenomenon [Transcript 2: Illustration]. Use the rhetorical resource illustration [Transcript 2: Illustration]. The written text evidences a persuasive, argumentative purpose [Transcript 1: 1-2, Transcript 2: Illustration, & Transcript 3: 8].

it is difficult for her to represent them mathematically in the illustration. Also, she uses some physical knowledge related to rest, speed, gravity, and free fall (**Table 4**).

Assessment of Juana's Understanding

In her text (**Table 5**), Juana conceptually confuses free fall with downward throw, but uses the concept of rest to argue the phenomenon when a body begins to fall. For the initial speed of a body in free fall, she assigns a numerical value of 0 m/sec., which corresponds to a warrant that is related to physical and mathematical aspects. Juana also states that the stone loses all its speed when it reaches the ground but does not refer to the collision between stone and ground as its justification.

Juana uses seven argumentative indicators; the first one indicates cause [Transcript 4: 2]; the second and third, persuasive purposes [Transcript 4: 9-11]; the fourth and fifth refer to statements about numerical values of the velocity of a body in free fall after one and two seconds [Transcript 4: 15]; the sixth, constitutes an inductive reasoning from two particular cases for the value of the speed [Transcript 4: 15-16]; and the seventh indicates a breaking point in her argument when she states that when the body falls and hits the ground, its speed becomes zero [Transcript 4: 18]. Juana uses the rhetorical resource example to strengthen the argument that the speed of a body in free fall increases by 9.8 m/sec. every second. These examples are evidenced in the three speed values of the body in free fall.

Regarding the argumentative components, Juana uses as data that close to the earth, terrestrial gravitational attraction influences bodies in free fall. Furthermore, from her argument, one could infer that the speed of a body in free fall increases by 9.8 m/sec., for each second elapsed in the fall of the body.

Juana uses four warrants:

(1) the initial speed of the body is 0 m/sec. [Transcript 4: 4-8],

(2) one second after falling, its speed is 9.8 m/sec. [Transcript 4: 9-11],

(3) the speed of a body in free fall increases [Transcript 4: 11-12], and

(4) two seconds into the free fall of a body, its speed is 16 m/sec. [Transcript 4: 12-16].

Although in this last speed value, she makes a mistake when adding 9.8 and 9.8.

Table 5. Text written by Juana

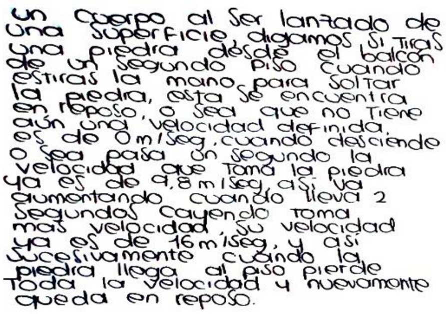
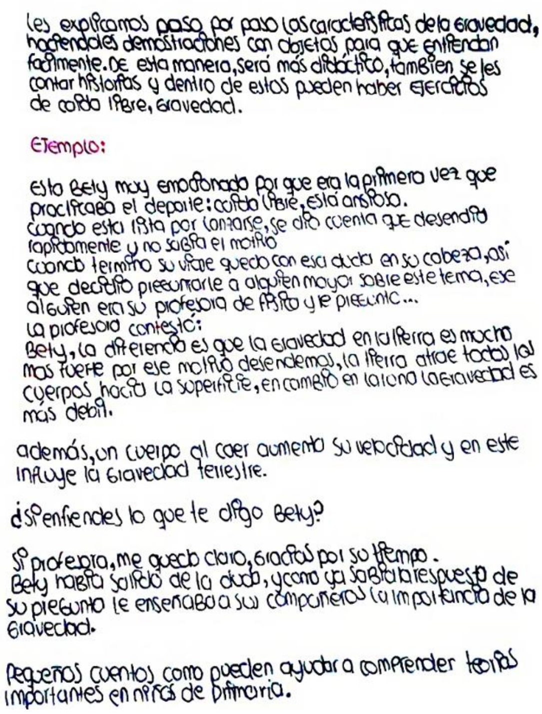
	Transcript 4
 Un cuerpo al ser lanzado de una superficie, digamos si tiras una piedra desde el balcon de un segundo piso cuando estiras la mano para soltar la piedra, esta se encuentra en reposo, o sea que no tiene aún una velocidad definida, es de 0 m/seg, cuando desciende o sea pasa un segundo la velocidad que toma la piedra ya es de 9,8 m/seg, así va aumentando cuando lleva 2 segundos cayendo toma mas velocidad, su velocidad ya es de 16 m/seg, y así sucesivamente cuando la piedra llega al piso pierde toda la velocidad y nuevamente queda en reposo.	[1] A body being thrown from [2] a surface, say *if* you pull [3] a stone from the balcony [4] of a second story when [5] you stretch out your hand to let go [6] the stone, it is found [7] at rest, that is, it has no [8] still a defined speed, [9] is 0 m/sec when descending [10] *that is*, spend a second [11] the speed that the stone takes [12] is already 9.8 m/sec, so it goes [13] increasing, when it takes 2 [14] seconds falling takes [15] more speed, your speed [16] *is already* 16 m/sec, and *so on* [17] successively when the [18] the stone hits the floor, and loses [19] full speed and again [20] is at rest.

Table 6. Assessment of understanding through the argumentative text written by Juana

Argumentative indicators	If … [Transcript 4: 2]. so no … [Transcript 4: 7]. that is … [Transcript 4: 9]. It's already … [Transcript 4: 11 & 15]. and so on … [Transcript 4: 15 & 16]. and [Transcript 4: 19].
Physical contents	Speed, velocity, free fall, and gravitational attraction.
Methods	Systematic & orderly way of proceeding to arrive in justified way at certain claims through examples.
Purposes	Persuasive: show through an example the increase in speed when a body falls from a certain height.
Forms of communication & audience	Written text Primary children [Transcript 4].
Rhetorical resources	Examples. They are used to argue how the speed of a body in free fall increases.
Argumentative components	Data: On free fall and terrestrial gravitational attraction towards bodies in the vicinity of its surface. Warrants: "When you stretch your hand to release the stone, it is at rest; that is, it does not yet have a defined speed, it is 0m/sec." [Transcript 4: 4-8]. "A second passes, and the stone's speed is already 9.8 m/sec." [Transcript 4: 9-11]. "Thus [the speed] is increased" [Transcript 4: 11-12]. "When he has been falling for 2 seconds, he picks up more speed, his speed is already 16 m/sec., & so on" [Transcript 4: 12-16]. Absolute modal qualifiers: [Transcript 4: 8 & 19]: Still, all of it. Claim: Speed of a body in free fall increases by 9.8 m/sec., for each second, elapsed in fall of body.
Novice understanding level	It combines beliefs with physical knowledge [Transcript 5: 8-9]. Connect understandings to everyday experiences [Transcript 4: 2-6]. Use some form of mathematical representation to describe some aspects of the physical phenomenon [Transcript 4: 9-17]. Use the rhetorical resource example [Transcript 4: 9-17]. The written text evidences a persuasive, argumentative purpose [Transcript 4: 9-17].

In this text, Juana uses various argumentative indicators for explanatory purposes and to introduce the rhetorical resource example. In conclusion, Juana presents a novice level of understanding because she uses some physical knowledge regarding speed, velocity, free fall, and gravitational attraction. Likewise, she refers to a few experiences of her daily life related to the free fall of a body. She uses the examples as rhetorical resources, but not the illustrations (**Table 6**).

Table 7. Text written by Juana


les explicamos paso por paso las caracteristicas de la gravedad, haciendoles demostraciones con objetos para que entiendan facilmente. De esta manera, será más didáctico, también se les contar historias y dentro de estos pueden haber ejercicios de caida libre, gravedad.

Ejemplo:

Esta Bety muy emocionado por que era la primera vez que practicaba el deporte: caida libre, está ansioso.
Cuando esta lista por lanzarse, se dio cuenta que descendía rapidamente y no sabia el motivo
Cuando termino su viaje quedo con esa duda en su cabeza, así que decidió preguntarle a alguien mayor sobre este tema, ese alguien era su profesora de física y le preguntó...
La profesora contestó:
Bety, la diferencia es que la gravedad en la tierra es mucho mas fuerte por ese motivo desendemos, la tierra atrae todos los cuerpos hacia la superficie, en cambio en la luna la gravedad es más debil.

además, un cuerpo al caer aumenta su velocidad y en este influye la gravedad terrestre.

¿Entiendes lo que te digo Bety?

Si profesora, me quedo claro, gracias por su tiempo.
Bety había salido de la duda, y como ya sabía la respuesta de su pregunta le enseñaba a sus compañeros la importancia de la gravedad.

Pequeños cuentos como pueden ayudar a comprender teorías importantes en niños de primaria.

Transcript 5

[1] We explain step by step the characteristics of gravity,
[2] Demonstrating them with objects so that they understand easily.
[3] In this way, it will be more didactic; they can also be told
[4] stories, and within these, there may be free fall exercises,
[5] gravity.
[6] Example:
[7] Bety was very excited because it was the first time, she
[8] practiced the sport: free fall, she is anxious.
[9] When she was ready to launch, she realized that she was descending
[10] quickly and <u>*did not know*</u> the reason.
[11] When he finished his trip, he was left with the doubt in his head, so
[12] that decided to ask someone older about this topic, that someone
[13] was his physics teacher and asked him …
[14] The teacher replied:
[15] Bety, the difference is that gravity on earth is much
[16] stronger, for this reason, we descend, the earth attracts all
[17] bodies towards the surface, instead of on the moon, gravity is
[18] weaker.
[19] Also, a falling body increases its speed and [in] this influences the
[20] terrestrial gravity.
[21] Do you understand what I'm telling you, Betty?
[22] Yes, teacher, it was clear to me; thank you for your time.
[23] Bety had left doubt, and since she already knew the answer to her
[24] question taught his peers the importance of
[25] gravity.
[26] Short stories like these can help understand theories
[27] significant in primary school children.

Assessment of Ruth's Understanding

Ruth states that she would explain free fall by means of a model; by using the model, she intends to persuade elementary school children about how a body falls (**Table 7**).

Likewise, she relates free fall to skydiving and uses the concept of accelerated movement, which corresponds to a warrant. She also mentions that the protagonist of the story in her writing did not know that when a body falls, its speed increases, and to answer this question, she refers to her teacher. Thus, the protagonist of her story appeals to the academic authority linked to physical knowledge to obtain an explanation and, putting herself in the voice of the teacher, mentions the importance of earth's gravity to attract bodies. This statement corresponds to a warrant.

Ruth uses four argumentative indicators; the first indicates that the protagonist of the story does not know why the speed of a body in free fall increases [Transcript 5: 10]; the second indicates consequence, in the sense that the protagonist of the story looks for her teacher to explain free fall; the third to compare an idea that she develops in previous lines of text [Transcript 5: 15-16]; and the fourth to express the difference between terrestrial gravity and lunar gravity [Transcript 5: 17]. Ruth uses the free fall sport model and, in conclusion, establishes characteristics of free fall. Ruth initially uses a belief by mistaking free fall for downward throw [Transcript 5: 8-9]. Ruth also uses four warrants:

(1) a body in free fall descends rapidly [Transcript 5: 3-4],
(2) terrestrial attraction [Transcript 5: 16-17],
(3) gravity on the moon compared to terrestrial [Transcript 5: 17-18], and
(4) the increase in velocity of a body in free fall [Transcript 5: 19-20].

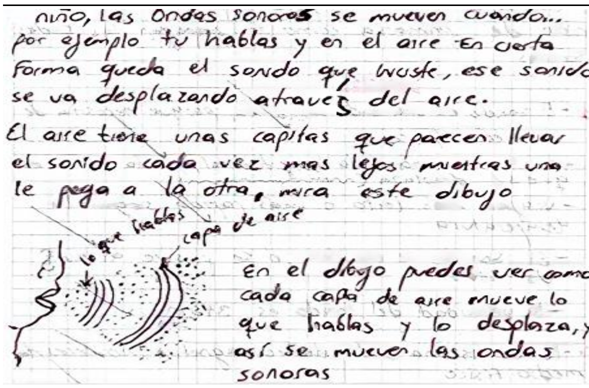
Additionally, Ruth uses modal qualifiers to qualify her claims [Transcript 5:15-16, 16, 17].

Ruth uses the rhetorical resource model (**Table 7**) possibly to achieve a persuasive purpose. The model refers to the fact that the protagonist of the story turns to her teacher to explain the characteristics of free fall. In conclusion, Ruth presents a novice level of understanding because she uses some warrants as knowledge: terrestrial gravity, lunar gravity, and speed. In addition, Ruth refers to specific experiences in her daily life to establish relationships with free fall when she mentions skydiving; however, she does not use mathematical concepts to explain the body's speed in free fall. Finally, she uses the rhetorical resource model; however, her inferences are limited since she confuses free fall with downward throw and does not present mathematical knowledge associated with free fall (**Table 8**).

Table 8. Assessment of understanding through the argumentative text written by Ruth

Argumentative indicators	and I did not know … [Transcript 5: 10]. so … [Transcript 5: 11-12]. instead … [Transcript 5: 17]. Furthermore …, and … [Transcript 5: 19].
Physical contents	Gravity, lunar gravity, and speed.
Methods	Systematic & orderly way of proceeding to arrive in justified manner at certain claims through model.
Purposes	Write an argumentative text about free fall to be read to primary school children.
Forms of communication & audience	Written text Primary children [Transcript 5: 1-5].
Rhetorical resources	Ruth uses the rhetorical resource model. She proposes that the protagonist of her written text, who does not know about free fall, go to her teacher so that she can explain the phenomenon to her.
Argumentative components	Data: About free fall. Warrants: "Rapidly descended …" [Transcript 5: 3-4]. gravity on earth is much stronger, which is why we descend [Transcript 5: 15-16]. "The earth draws all bodies to the surface…" [Transcript 5: 16-17]. "On the other hand, gravity is weaker on the moon" [Transcript 5: 17-18]. "body when falling increases its speed and [in] this influences terrestrial gravity" [Transcript 5: 19-20]. Absolute modal qualifiers: it is much more … [Transcript 5: 15-16]. all [Transcript 5:16]. it is more [Transcript 5:17]. Claim: Characteristics of free fall through a written text that is based on a sport.
Novice understanding level	It combines beliefs with physical knowledge [Transcript 5: 8-9]. Connect your understandings to everyday experiences [Transcript 5: 7-13]. Use some representation to describe some aspects of physical phenomenon [failure to find evidence]. Use the rhetorical resource model [Transcript 5: 11-14]. The written text evidences a persuasive argumentative purpose [Transcript 5: 8-14].

Table 9. Text written by Carlos

	Transcript 6
	[1] Boy, sound waves move when… [2] <u>*for example*</u>, you speak <u>and</u>, in the air, <u>*[of] certain*</u> [3] <u>*the form*</u> remains the sound you made, *that sound* [4] *moves through the air*. [5] The air has layers that seem to carry [6] the sound further and further away, while a [7] hits the other, <u>*look at this drawing*</u> ... [8] <u>*In the drawing*</u>, you can see how [9] each layer of air moves what [10] you speak <u>*and*</u> scroll it, <u>*and*</u> [11] <u>*this is how*</u> the waves move [12] sound waves.

Assessment of Carlos's Understanding

Carlos uses three argumentative indicators (**Table 9**) to:

(1) introduce an example about mechanical waves [Transcript 6: 2],

(2) explain sound like a mechanical wave [Transcript 6: 2-3], and

(3) appeal to a drawing that serves as a rhetorical resource illustration to amplify his argument of sound like a mechanical and longitudinal wave [Transcript 6: 7, 8].

Carlos uses as data that the sound propagates in the air and advances in its direction of propagation and refers to two characteristics of sound waves: mechanical and longitudinal (**Table 10**). Carlos uses a belief when he refers to "every layer of air moves what you speak" [Transcript 6: 9-10]. Carlos also uses two warrants:

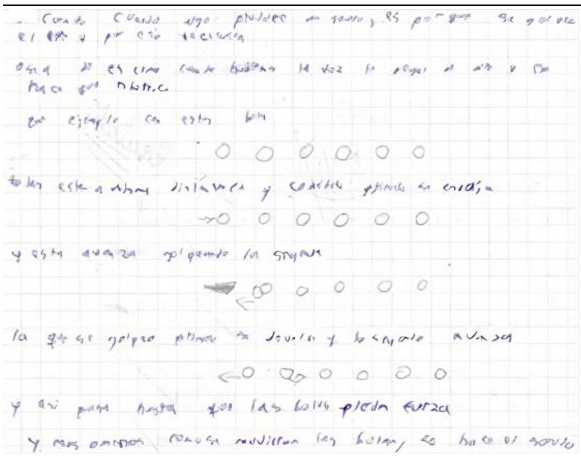
(1) sound requires air for its propagation, which expresses the mechanical characteristic of sound [Transcript 6: 3-4, 9] and

(2) sound moves longitudinally [Transcript 6: 5-7].

Table 10. Assessment of understanding through the argumentative text written by Carlos

Argumentative indicators	for example … [Transcript 6: 2]. look at this drawing … [Transcript 6: 7]. in the drawing … [Transcript 6: 8]. and [Transcript 6: 10]. and so … [Transcript 6: 10-11].
Physical contents	Sound wave and longitudinal wave.
Methods	Systematic & orderly way of proceeding to arrive in a justified manner at certain claims through example & illustration.
Purposes	The text written by Carlos shows a persuasive purpose.
Forms of communication and audience	Written text. Primary children [Transcript 6:].
Rhetorical resources	Carlos uses an illustration. This illustration is presented in **Table 9**.
Argumentative components	Data: Sound waves are produced in the air. Warrants: "that sound travels through the air" [Transcript 6: 3-4]. "air has caps that seem to carry sound further & further, while one hits the other" [Transcript 6: 5-7]. "every layer of air moves what you speak" [Transcript 6: 9]. Absolute or relative modal qualifiers: [in] a certain way … [Transcript 6: 2-3]. that seem … [Transcript 6: 5]. each [Transcript 6: 9]. Claim: The longitudinal characteristic of sound waves.
Novice level of understanding	It combines beliefs with physical knowledge [Transcript 6: 9-10]. Connect your understandings with everyday experiences [Transcript 6: 1-12]. It uses a form of graphical representation to describe some aspects of the physical phenomenon [see illustration **Table 9**]. Uses the rhetorical resource illustration [Transcript 6: 8-12]. The written text evidences a persuasive argumentative purpose [Transcript 6: 7-12].

Table 11. Text written by Pablo

	Transcript 7
	[1] When something makes a sound, *it is because* it is hit [2] the air, and *that is why* it is heard. [3] *I mean*, it is like when one hears his voice, he hits the air and that [4] makes it bounce [5] *for example*, with these balls: [6] o o o o o o o [7] *they are all* the same distance apart, and when the first one is hit, [8] ⇨o o o o o o o [9] it advances, hitting the second. [10] ⇦ o o o o o o o [11] The one-hit first is returned, and the second one advances. [12] ⇦o o o o o o [13] And so it goes until the balls lose strength. [14] *and more or less*, as the balls moved, the sound was made

Carlos uses two types of modal qualifiers to qualify his statements, two relatives [Transcript 6: 2-3, 5] and one absolute [Transcript 6: 9].

To argue the phenomenon of the propagation of sound waves, he uses the rhetorical resource illustration. This resource shows that sound is a mechanical and longitudinal wave since it states that it propagates in the air and that each layer of air "hits one another." It can be concluded that Carlos presents a novice level of understanding since he uses some knowledge through warrants that link data with claims in his text, such as sound waves, mechanical waves, and longitudinal waves. Carlos uses a daily experience to argue sound waves' mechanical and longitudinal characteristics. This everyday experience is evidenced through the use of examples and illustrations (**Table 9**).

Assessment of Pablo's Understanding

Pablo uses the rhetorical resource illustration to persuade the children of the phenomenon produced by the propagation of sound waves (**Table 11**).

Table 12. Assessment of understanding through the argumentative text written by Pablo

Argumentative indicators	it is because [Transcript 7: 1]. and so … [Transcript 7: 2]. that is …, and … [Transcript 7: 3]. such as … [Transcript 7: 5]. and … [Transcript 7: 7 & 11].
Physical contents	Sound, air, longitudinal wave, and mechanical wave
Methods	Systematic & orderly way of proceeding to reach certain claims in a justified way through example, illustration, & metaphor.
Purposes	Persuasive & convincing purposes.
Forms of communication & audience	Write an argumentative text about free fall to be read to primary school children. Primary children [Transcript 7: 1-5].
Rhetorical resources	Illustration: Line 6, line 8, line 10, and line 12 of **Table 11**. Metaphor: The propagation of sound waves in the air is compared to the hitting of balls.
Argumentative components	Data: Sound waves are produced in the air. Warrants: "When something produces a sound, it is because it hits the air, and that is why it is heard" [Transcript 7: 1-2]. "When his voice is heard, it hits the air, and bounces back" [Transcript 7: 3-4]. Absolute or relative modal qualifiers: All, more, or less [Transcript 7: 7 & 14]. Claim: The longitudinal characteristic of sound waves.
Apprentice understanding level	Uses knowledge, in his arguments, about physical phenomena, and he uses some methods adaptively to build knowledge [Transcript 7: 1-2, 7: 3-4]. Uses his understanding built in classroom in original ways in everyday situations [Transcript 7: 1-14]. Uses one or more forms of representation to describe in a quantified way some aspects of the physical phenomenon [Transcript 7: 6, 8, 10, 14] Uses rhetorical resources in his methods like illustration, but also metaphor [Transcript 7: 6, 8, 10, 12]. The written texts evidence persuasive & convincing argumentative purposes [Transcript 7: 1-14].

In this illustration, he implicitly employs a warrant that treats sound as a longitudinal wave. Pablo uses six indicators. The first expresses how a sound is produced in the air [Transcript 7: 1]; the second, a cause [Transcript 7: 2]; the third treats sound like a mechanical wave [Transcript 7: 3]; the fourth introduces in the text a rhetorical resource example to argue the longitudinal character of the sound [Transcript 7: 5], and the fifth and sixth are used to add information to that already discussed [Transcript 7: 7, 11].

Pablo uses as data that sound is produced in air and as a claim that sound is both a mechanical wave and a longitudinal one. In addition, he uses two warrants, one about the importance of air in producing a sound [Transcript 7: 1-2], and another about the blowing of air layer by layer to transmit a sound [Transcript 7: 3-4]. As modal qualifiers, Pablo uses an absolute [Transcript 7: 7] and a relative one that expresses doubt in his statement [Transcript 7: 14].

Pablo tries to persuade and convince the children with his ideas and the rhetorical resources used. In this sense, he uses illustration and metaphor in the written text. Finally, it is concluded that Pablo presents an apprentice level of understanding since he relates an everyday experience with a sound wave's mechanical and longitudinal characteristics; he also uses illustrations to explain these characteristics in detail. In addition, he uses examples, illustrations, and metaphors to explain these characteristics (**Table 12**).

Assessment of Alex's Understanding

In his text, Alex addresses primary school children through the use of an example and two metaphors (**Table 13**). He uses two argumentative markers for clarification purposes [Transcript 8: 3, 6]; argumentative indicators to add information to what was previously provided [Transcript 8: 7, 8]; indicators that introduce a rhetorical resource: example or metaphor [Transcript 8: 13-14, 19], and other argumentative indicators that introduce causes for the claims advanced in the written text [Transcript 8: 10, 12].

Alex uses the rhetorical resource example to argue about the propagation of waves. This example is extended by the use of two metaphors. In one metaphor the need for air in humans to breathe is compared to sound waves to propagate, and in the other, the propagation of waves is compared to a competitive race in athletics.

Alex uses as data that sound waves propagate in the air; in addition, he establishes a conclusion that the air is a necessary condition for propagation and that waves propagate longitudinally.

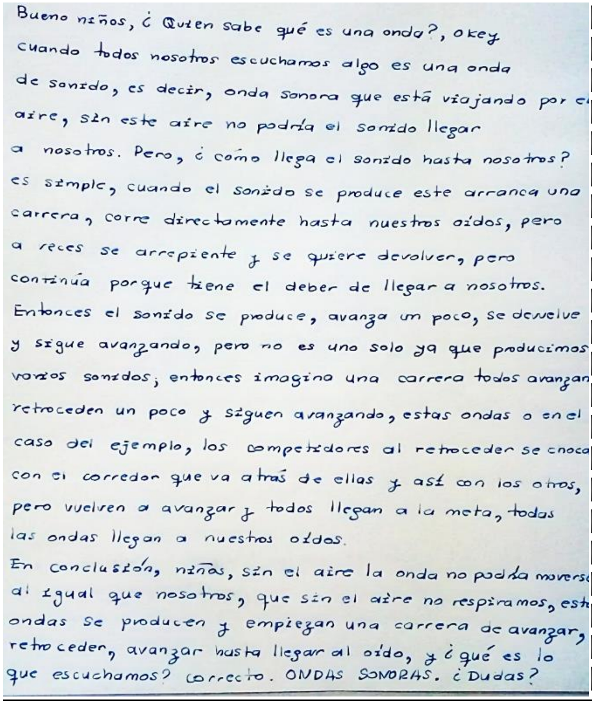
In Alex's text, following warrants can be identified:

(1) sound as something we hear [Transcript 8: 2-3],

(2) sound as it travels through the air [Transcript 8: 3-4], and

(3) the necessity of air for a sound to move [Transcript 8: 18].

Table 13. Text written by Alex


Bueno niños, ¿Quien sabe qué es una onda?, okey
cuando todos nosotros escuchamos algo es una onda
de sonido, es decir, onda sonora que está viajando por e
aire, sin este aire no podría el sonido llegar
a nosotros. Pero, ¿cómo llega el sonido hasta nosotros?
es simple, cuando el sonido se produce este arranca una
carrera, corre directamente hasta nuestros oídos, pero
a veces se arrepiente y se quiere devolver, pero
continúa porque tiene el deber de llegar a nosotros.
Entonces el sonido se produce, avanza un poco, se devuelve
y sigue avanzando, pero no es uno solo ya que producimos
varios sonidos; entonces imagina una carrera todos avanzan
retroceden un poco y siguen avanzando, estas ondas o en el
caso del ejemplo, los competidores al retroceder se choca
con el corredor que va atrás de ellos y así con los otros,
pero vuelven a avanzar y todos llegan a la meta, todas
las ondas llegan a nuestros oídos.
En conclusión, niños, sin el aire la onda no podría movers
al igual que nosotros, que sin el aire no respiramos, est
ondas se producen y empiezan una carrera de avanzar,
retroceder, avanzar hasta llegar al oído, y ¿qué es lo
que escuchamos? correcto. ONDAS SONORAS. ¿Dudas?

Transcript 8
[1] Well, kids, who know what a wave is? Ok
[2] When we all hear something, it is a wave
[3] of sound, that is, a sound wave that is traveling through the
[4] air, without this air, the sound could not reach
[5] to us. But how does sound reach us?
[6] is simple, when the sound is produced, it starts a
[7] run, run straight to our ears, but
[8] sometimes he regrets it and wants to return, but
[9] continues because it has a duty to reach us.
[10] Then the sound is produced, goes forward a little, returns
[11] and it continues to advance, but it is not one since we produce
[12] various sounds; then imagine a race everyone advances,
[13] go back a little and keep going; these waves or in the
[14] case of the example, the competitors, when going back, collide
[15] with the runner behind them and so with the others,
[16] but they advance again and all reach the goal, all
[17] the waves reach our ears.
[18] In conclusion, for children, without air, wave could not move,
[19] just like us, who without air do not breathe, these
[20] waves are produced and start a race forward,
[21] back, forward until you reach the ear, and what is the
[22] what do we hear? Correct, sound waves. Doubts?

Furthermore, Alex only uses absolute qualifiers to qualify his claims, indicating that he is confident about them [Transcript 8: 4, 12, 16, 18].

He uses examples and metaphors to convince the children with his arguments. It is concluded that Alex presents an apprentice level of understanding because he uses some knowledge manifested through the use of warrants, such as sound, mechanical and longitudinal waves. Alex uses two metaphors that show relationships between everyday experiences and sound waves. These daily experiences are evidenced through the comparison established between an athletic race and the need for air in human breathing (**Table 14**).

Table 14. Assessment of understanding through the argumentative text written by Alex

Argumentative indicators	It is to say … [Transcript 8: 3]. It is simple … [Transcript 8: 6]. but [Transcript 8: 7 & 8]. then [Transcript 8: 10 & 12]. in the case of the example … [Transcript 8: 13-14]. in conclusion … [Transcript 8: 18]. just like … [Transcript 8: 19].
Physical contents	Sound waves, mechanical waves, and longitudinal wave
Methods	Systematic and orderly way of proceeding to arrive, in a justified way, at certain claims through examples and metaphors.
Purposes	The text proposed by Alex evidence persuasive and convincing argumentative purposes.
Forms of communication & audience	Written text Primary children [Transcript 8: 1-5].
Rhetorical resources	Example: The propagation of sound waves is argued through competitors' races. Metaphor 1: Comparing need for air to propagate sound waves & human respiration [Transcript 8:5-15]. Metaphor 2: The propagation of sound waves is compared to the race of competitors in athletics [Transcript 8: 18-20].
Argumentative components	Data: Sound waves are produced in the air. Warrants: "When we hear something, it is a sound wave" [Transcript 8: 2-3]. "sound wave traveling through the air" [Transcript 8: 3-4]. "without the air, the wave could not move" [Transcript 8: 18]. Absolute modal qualifiers: could not [Transcript 8: 4 & 18]. all [Transcript 8: 12]. all [Transcript 8: 16].

Table 14 (continued). Assessment of understanding through the argumentative text written by Alex

Argumentative components	Claim: Air is a necessary condition for the propagation of sound waves. Sound waves propagate longitudinally.
Apprentice understanding level	Uses in his arguments, knowledge about physical phenomena [Transcript 8: 2-3, 3-4, & 18], & adaptively uses some methods to construct knowledge [metaphor 1 & metaphor 2]. Uses his understandings built in the classroom in original ways in everyday experiences [Transcript 8: 5-15 & 18-20]. Uses rhetorical resources in his methods such as: example and illustration, but also metaphor [Transcript 8: 5-15 & 18-20]. The written text evidence persuasive and convincing argumentative purposes [Transcript 8: 1-23].

DISCUSSION

The analysis presented shows that the argumentative qualities of the written texts allow assessment of the students' understanding of free fall and sound wave propagation based on their knowledge, methods, purposes, and forms of communication.

Mathematical knowledge endowed some texts written by students with argumentative soundness, in agreement with the results of Basson (2002) and Kaya (2018). However, these authors did not consider the relationship between mathematical aspects and understanding; in our case, mathematical aspects are included, although numerical in nature. Moreover, we use a theoretical framework of dimensions and levels to assess understanding. In this sense, the effort was focused on methodologically articulating understanding assessment with the argumentative qualities of written texts.

Regarding the argumentative indicators used in the texts, the following were identified: in addition, like, so, so on, in a certain way, instead, in conclusion, then, that is, it is because, or maybe not, but, for example, yes …, and so, and no, and I did not know, and because of that, and also, since. These argumentative indicators made it possible to distinguish portions of arguments; however, it was a difficult task to identify the structure of the arguments according to Toulmin's (2007) argumentative model, possibly because the students did not have prior instruction on the construction of arguments.

Regarding the argumentative components, the analysis shows the use of warrants as evidence of knowledge or beliefs, and the use of relative modal qualifiers as evidence of doubts. We were able to identify the use of various modal qualifiers that allowed qualifying the claims communicated by the students. The modal qualifiers used in the written texts were even more, each, it is more, it is much more, it could not, all, more or less, that they seem, and in a certain way.

Regarding rhetorical resources, the written texts show that students explicitly considered the audience they are addressing. The rhetorical resources identified were examples, models, illustrations, and metaphors. Furthermore, we did not find a written text where these four rhetorical resources were used simultaneously, hence no student was placed at the mastery level. Similarly, in addition to beliefs about the physical phenomena, all students referred to knowledge they constructed during or prior to the course, thus none of them was assigned the naïve level. That is, we did not obtain empirical evidence for the assessment of understanding at the mastery or naïve levels.

Table 15 summarizes the analysis of the six participants' texts.

Regarding the relationship between understanding and the argumentative qualities of the written texts, participants managed to overcome a naïve level of understanding by minimally using some mathematical ideas to understand the free fall of bodies and the propagation of sound waves. However, no student

Table 15. Summary of data analysis

Understating and argumentative qualities of written texts		Text written by					
		María	Juana	Ruth	Carlos	Pablo	Alex
Argumentative components	Argumentative indicators	✓	✓	✓	✓	✓	✓
	Warrants	✓	✓	✓	✓	✓	✓
	Absolute modal qualifiers	✓	✓	✓	✓	✓	✓
	Relative modal qualifiers						✓
Rhetorical resources	Illustration	✓			✓	✓	
	Example		✓			✓	✓
	Model			✓			
	Metaphor						✓
Understanding levels	Naïve						
	Novice	✓	✓	✓	✓		
	Apprentice					✓	✓
	Mastery						

achieved the mastery level (Driver et al., 1994; Oñorbe & Sánchez, 1996; Zacharia, 2007), thus all of them were placed at the novice or apprentice level. On the novice level, students make minimal use of examples and models; likewise, they establish few relationships between the physical phenomena and everyday experiences. On the apprentice level, students use a maximum of two rhetorical resources simultaneously: examples, illustrations, or metaphors. These rhetorical resources allow students to show relationships with their daily experiences with free fall and the propagation of sound waves.

The theoretical-methodological tool articulated elements of the theory of understanding, the written text, and its argumentative qualities. This articulation was specified in the levels of understanding: naïve, novice, apprentice, or mastery, and in the tables that they present to summarize the analysis of the argumentative qualities of the written texts (**Table 4**, **Table 6**, **Table 8**, **Table 10**, **Table 12**, and **Table 14**). Specifically, the tables show argumentation indicators, physical content, methods, purposes, forms of communication and audience, rhetorical resources, argumentative components, and the individual level of understanding. The request to the participants by the teacher when writing an argumentative text to explain a physical phenomenon to primary school children was vital as a methodological instrument to collect information; likewise, it served to obtain other types of different written texts because usually in Traditional teaching only asks questions related to the mathematical understanding of a physical phenomenon.

At least three limitations are recognized in this study. The first is related to the theoretical use of some relevant though specific dimensions of understanding to interpret the levels of understanding that students expressed in their written texts. An alternative theoretical approach that considers additional dimensions could provide different results. The second refers to the fact that the participants were asked to express their ideas in written form and did not engage in verbal rhetorical or dialectical debate. In future studies we plan to incorporate instances in which students must express their ideas verbally.

Finally, the third refers to the qualitative nature of the research, which involved a sample of only six students, which does not allow the results to be generalized. Therefore, we propose for future research to use quantitative and mixed methods to tackle this issue and allow for various types of triangulations, such as data triangulation and methodological triangulation (Fusch et al., 2018).

CONCLUDING REMARKS

Regarding the study's aim, to devise a theoretical-methodological tool to assess students' conceptual understanding of physical phenomena through the argumentative qualities of their written texts, it can be affirmed that the argumentative qualities of students' written texts allowed us to assess their understanding of free fall and propagation of sound waves through according to the proposed levels. This assessment was achieved through the theoretical and methodological articulation of the notions of understanding and argumentative qualities of written texts. The use and identification of argumentative components proposed by Toulmin (2007) made it possible to characterize the texts as argumentative, although it was not always possible to identify the entire structure of the arguments.

The use of students' written texts to explain physical phenomena to primary school students helps the teacher understand other points of view that might have not been considered during teaching. These other points of view relate directly to students' everyday experiences. In a detailed way, the use of written texts allows knowing other physical contents, methods, and purposes that the teacher has probably not mentioned and are part of the students' understanding. Likewise, the written texts allow to identify the use of rhetorical resources and the way in which they are used to express understanding of knowledge.

Students' understanding of a physical phenomenon is usually assessed by reproducing knowledge taught in class in a written assessment where mathematical concepts are put into play through problems that include questions. The theoretical and methodological discussion of two perspectives, understanding and argumentation, allowed to provide a theoretical-methodological tool to the research and teaching community. Specifically, this tool is useful for those teachers who intend to assess their students through different communicative forms; in our case, through written texts and the articulation between the dimensions of understanding (content, methods, purposes, and forms of communication) and argumentation. In this study, the arguments were characterized by their argumentative components: data, claims, warrants, backings, modal qualifiers, and rebuttals, by the use of rhetorical resources, and by the audience to whom the written text is addressed.

We provide a theoretical-methodological tool to assess students' understanding through written texts with a broad task: write an argumentative text about free fall or sound wave propagation to explain these phenomena to elementary school children. This task allowed the students to evidence not only their mathematical understandings of these phenomena but also their conceptual understandings of physics and their everyday experiences and common sense about them.

Table 4, **Table 6**, **Table 8**, **Table 10**, **Table 12**, and **Table 14** serve future researchers to systematize the argumentative interpretation of texts and assess student understanding of physical phenomena. These can also be used as assessment tools to support the physics teacher while teaching. We suggest that in future research, they be used, discussed, and adapted to other studies.

As a future research line, we suggest assessing understanding through argumentation focusing on other forms of communication different from written texts. For example, it would be interesting to assess the understanding of physical phenomena through dialogic argumentation in classroom talking. In this study, refutation was scarce, which is expected because of the nature of the requested task. In contrast, in a dialogic argumentation, rebuttals may be more common and serve as another criterion for assessing students' understanding by levels.

We recommend that practicing physics teachers use written texts to promote argumentation about physical phenomena since written texts evidence a latent understanding that teachers may not be aware of. Similarly, we recommend that researchers who study argumentation in physics teaching carry out empirical studies with argumentative texts, not only written but dialogic, and establish other indicators of understanding physical phenomena through dialogic argumentation.

Finally, we can affirm that written argumentation is an important rational and reasonable activity for the understanding of physical phenomena since it allows students to use their knowledge, methods, and purposes to support points of view as well as rhetorical resources to convince or persuade others with their claims. A rational activity because it allows the epistemic construction of physical knowledge to be put into play, and a reasonable activity because it allows the students' points of view and experiences to be put into play when building their knowledge of physical phenomena in the classroom.

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting findings and conclusions are available upon request from the corresponding author.

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