

Framing intuitive ideas in physics: A proposal grounded in frame semantics

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The theoretical framework *knowledge in pieces* (KiP), proposed by Andrea diSessa, holds that intuitive knowledge in physics is organized through small cognitive structures called *p-prims* (phenomenological primitives). One of the heuristic principles on which the KiP framework is built—the principle of redescription—suggests that the descriptive framework of *p-prims* can be fine-tuned. However, the theoretical development of *p-prim* descriptions has remained largely limited to informal linguistic expressions drawn from students’ explanations, without a clearly defined syntactic or semantic structure. This lack of systematicity has led to variations in the naming and conceptualization of *p-prims*, making their consistent identification and analytical use difficult. In response to this limitation, this paper proposes a formal schematization of *p-prims* based on Fillmore’s Frame Semantics, supported by tools such as FrameNet. Our proposal aims to make explicit the core and peripheral components of each *p-prim* and to clarify the conditions under which they are evoked. By providing *p-prims* with a well-defined linguistic structure, the KiP framework is strengthened, opening new possibilities for the automated analysis of students’ reasoning using artificial intelligence (AI), as well as for the design of visual representations to support the development of instructional materials. Theoretical, methodological, and technological implications of this proposal for future research in physics education research (PER) are also discussed.

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I. INTRODUCTION

In 1993, Andrea diSessa proposed the theoretical framework *Knowledge in Pieces* (KiP), which holds that intuitive physics is built from small knowledge structures called “phenomenological primitives” or *p-prims* [1]. These minimal knowledge units function as the fundamental building blocks upon which formal physics concepts are constructed. According to diSessa, students, when confronted with certain problems, produce robust and recurring responses—such as that an object in motion, once a force is applied to it, will move in the same direction as the applied force. However, these explanations do not imply that students possess a complete intuitive theory; rather, such explanations are formulated through the activation of local resources that are sensitive to perceptual features. Within the KIP framework, diSessa

argues that intuitive physics is the result of a complex and extensive cognitive process that cannot be explained as simple “readings” or “misreadings” of reality. Through *p-prims*, or through an organized set of them, individuals construct an abstract explanatory framework that, although significantly limited in its systematicity, stably guides spontaneous reasoning about physical phenomena [1].

To understand the cognitive mechanisms involved in reasoning about physical phenomena, diSessa introduces *p-prims* as hypothetical structures that are part of the complex knowledge system operating in human beings. These *p-prims* are called “phenomenological” because they correspond to intuitive ideas [2] that arise from superficial interpretations of experience with the environment and enable the construction of an informal vocabulary that gives meaning to such experiences. At the same time, they are “primitives” in two senses: on the one hand, they require no justification beyond the experience itself; on the other, they are minimal knowledge units stored in memory that form the basis of cognitive structure. diSessa points out that it is unlikely that *p-prims* can be defined using a standard lexicon that allows them to be reliably identified; that is, it would not be easy to unequivocally establish the objects or roles involved in a type of action:

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It is unlikely we can use standard lexicon (e.g., “identification of some class of objects engaged in a class of actions”) to securely define individual *p*-prims. [1] (p. 181)

Understanding how *p*-prims are organized from their fundamental components would allow us to move toward a more precise characterization of these cognitive units, facilitating their recognition and the analysis of the conditions under which they are evoked. In this regard, recent advances in the use of qualitative methodologies [4,5], big data science, deep learning, and linguistic theories [6–9] offer new opportunities to reinterpret and implement *p*-prims in broader contexts.

One such theory is frame semantics, proposed by Charles Fillmore [10,11], which holds that the meaning of a word or linguistic expression is linked to a “semantic frame” or broader conceptual structure. A *semantic frame* consists of a knowledge representation that involves a set of participants and situation-specific semantic roles [12], called *frame elements* (FEs), in addition to the predicates that organize these roles. Each *semantic frame* is evoked by a word or lexical unit (LU).

The computational development of this theory was realized in the FrameNet project [13], a web tool that serves as a resource that gathers an extensive database, including a large number of *frames*, their structural elements, and associated lexical units [14]. FrameNet enables *annotation* processes on a corpus of text; that is, based on a set of sentences or a body of text, the *semantic frames* evoked by specific expressions, as well as their components, can be identified, making it a useful tool for the structured semantic analysis of language.

In this work, we draw on Fillmore’s frame semantics as a theoretical standpoint on *framing*, and we propose a systematic redescription of *p*-prims using the formalism of frame semantics. Based on the identification of *semantic frames* conceptually similar to the *p*-prims described by diSessa, we propose a redescription through a reschematization that makes explicit the core and peripheral elements of each *p*-prim in order to clarify the specific circumstances under which they are evoked. This proposal seeks to enrich the KiP framework by providing *p*-prims with a clear and coherent syntactic structure, which not only facilitates their identification and analysis in physics education research (PER) but also opens up the possibility of linking them with computational tools based on machine learning (ML) or artificial intelligence (AI), thereby expanding their scope and applicability in interdisciplinary contexts.

Here we select four *p*-prims documented in the literature—**Force as a mover**, **dynamic balance**, **overcoming**, and **dying away**—as case studies, whose original descriptions were reformulated to include lexical units that could be annotated using the FrameNet Brasil webtool. Based on the semantic analysis, the frame elements present

in each description were identified, and new structured schematizations of the *p*-prims were proposed.

This article is organized as follows: Sec. II is aimed at describing *p*-prims as theoretical and conceptual elements that form the basis on which the KiP framework is built, along with some theoretical extensions of this framework.

In Sec. III, we present a selection of *p*-prims that will later serve as case studies, in which we will apply our schematization method.

Section IV offers a brief overview of cognitive linguistics and cognitive semantics in order to provide a theoretical context for our schematization proposal.

In Sec. V, we present the theoretical framework of frame semantics, on which our proposal is based, and in Sec. VI, we introduce FrameNet, the computational implementation of frame semantics.

Section VII constitutes the core of this article, detailing the methodology used for the annotation and schematization of the *p*-prims and presenting the resulting schematizations of the selected cases, structured in terms of their core and peripheral elements.

In Sec. VIII, we present a brief but illustrative set of examples that demonstrates how our proposal is applied using a set of sentences in which the core and/or peripheral elements corresponding to each analyzed *p*-prim are identified.

Finally, in Sec. IX, we conclude the article with a discussion of the theoretical and methodological implications of the proposal, as well as projections for future research in science education and natural language processing (NLP).

II. INTUITIVE IDEAS AS THE BUILDING BLOCKS OF PHYSICS KNOWLEDGE

Research on conceptual change often considers concepts as a single unit of knowledge that is evoked as a whole when learners attempt to make sense of their explanations about certain natural phenomena [15]. However, a different perspective suggests shifting the level of analysis toward a view in which knowledge is not a single robust unit but rather a system composed of several smaller elements, with a more complex substructure that gradually changes as the learner approaches expert knowledge [16,17]. In this approach, the activation of knowledge elements in a particular context can be productive or unproductive regardless of the level of expertise.

In 1993, Andrea diSessa proposed the theoretical framework of KiP [1], which states that *intuitive physics* is composed of small knowledge structures called phenomenological primitives or *p*-prims. In diSessa’s perspective, intuition is defined as a set of elementary knowledge units with an experiential basis—the *p*-prims—that are automatically activated in specific situations and serve as a sense of mechanism through which certain phenomena are explained. The way diSessa conceives

intuition differs from interpretations that understand intuitive physics as a coherent alternative theory (e.g., McCloskey *et al.* [18,19]), since it does not assume that students possess stable theoretical structures that must be replaced by formal physics [1]. Rather, from diSessa's standpoint, "intuitive physics" is a dynamic repertoire that can be developed and refined through scientific instruction. Thus, the meaning of the word *intuitive* is here understood as a particular set of *p-prims* that each student mobilizes from their bodily and everyday experience and not as a simplified, universal, or intrinsically accessible form of physics.

p-prims are hypothetical knowledge structures that are part of a broad and complex cognitive system. Their purpose is to offer an explanation of the cognitive mechanisms involved when people reason about physical phenomena and are considered the fundamental building blocks upon which formal physics concepts are constructed. Understanding a cognitive structure from its small constituent elements allows us to approach the organization of a learner's knowledge, since these small, atomic knowledge elements are activated based on the context, configuring themselves in different ways according to the situations in which students evoke them [20,21]. From a heuristic perspective, the KiP framework situates *p-prims* at an intermediate level between everyday experience and formal scientific concepts. This view allows us to trace a sense of *continuity* [22] between the interpretation of natural phenomena and the construction of disciplinary knowledge [23]. According to diSessa, *p-prims* originate from what he calls a *sense of mechanism*, a cognitive disposition characteristic of the human mind that drives us to seek causal explanations for the events we observe. Through this sense of mechanism, people make judgments about how things work, evaluating the likelihood that an event occurs. This allows us to make both predictions and postdictions about the physical world [1,24].

Positioning *p-prims* at an intermediate level between the sensory world and formal physics concepts has allowed other authors to expand diSessa's perspective toward one in which these knowledge elements diversify in terms of their characteristics and proximity to formal concepts. This enables a continuity to be traced along the path the learner follows toward expert knowledge [20,25,26].

During the learning process, learners evoke knowledge elements either in isolation or in *clusters*, depending on the context, in order to provide explanations and make sense of certain *events* or situations they encounter while learning. In this sense, learners use these knowledge elements as *resources* that are activated or deactivated depending on the context and that vary in type and characteristics. This new way of understanding knowledge elements, known as the resources framework, was proposed by David Hammer [25,26] and is built on the

foundations of KiP. The resources framework posits the existence of both conceptual resources and epistemological resources. Conceptual resources differ from *p-prims* in terms of their characteristics and focus; that is, conceptual resources do not represent primitive knowledge but are closer to formal knowledge of a topic and are therefore located in a layer nearer to formal physics concepts. Epistemological resources, on the other hand, are related to how learners conceive the generation of knowledge based on their beliefs about the nature of knowledge and how it is obtained.

Knowledge in pieces and the *resources framework* are proposals grounded in the productive use of prior knowledge. This has led some authors to integrate both frameworks or, more specifically, to incorporate *p-prims* within the *resources framework* [4,27]. In these integrative perspectives, knowledge elements are situated in the intermediate layer that separates the sensory world from formal concepts. *p-prims*, conceptual resources, and epistemological resources coexist within the learner's cognitive structure and exist in different states of activation [27,28].

III. CONTEXTUALIZED DESCRIPTIONS OF INTUITIVE IDEAS THROUGH COMMONSENSE LANGUAGE

In PER, interpretative approaches are predominantly used to analyze excerpts from interview transcripts or from video recordings of teaching and learning processes [5,29], in which a cycle of review and agreement is followed among coders regarding the categorization of hermeneutic units.

Regarding the language students use when verbalizing their intuitive ideas about physics, diSessa points out that:

P-prims are only weakly linked to language (there is no conventional lexicon for them), and a lot of their properties flow from their contextuality, exactly when they are invoked or not invoked. [30] (p. 12)

Some of the *p-prims* schematized by diSessa are structured in terms of attributes such as an agent, a patient, or a result. In addition, they contain recognizable pattern types, such as violence or damping in motion, as well as certain syllogisms and slogans like "equal and opposite reaction." diSessa [1] presents an extensive list of *p-prims* [31] and provides an interpretative framework for schematizing the intuitive ideas verbalized by students. These descriptions are abstractions and interpretations presented in a language accessible to the PER community.

According to their characteristics, *p-prims* are presented as verbal representations of learners' intuitive ideas in the context of Newtonian physics and are classified into three groups: force and agency, constraint phenomena, balance

and equilibrium or Imbalance and reequilibration. All p-prims are labeled with a tentative name and a brief description.

The Ohm p-prim is well known in the KiP literature [1,21,30,32,33] and is described as follows:

An agent or causal impetus acts through a resistance or interference to produce a result. It cues and justifies a set of proportionalities, such as “increased effort or intensity of impetus leads to more result”; “increased resistance leads to less result.” These effects can compensate each other; for example, increased effort and increased resistance may leave the result unchanged. [1] (p. 217)

This p-prim is related qualitatively to the well-known Ohm’s law for electrical circuits. Ohm’s law describes a proportional relationship between the electric current I in a conductor and the potential difference (voltage) ΔV applied across the conductor, $I \propto \Delta V$. The constant of proportionality is related to the electrical resistance R of the conductor, so Ohm’s law is mathematically represented as $I = \Delta V/R$. This expression allows for a causal interpretation in which electric current is the result of applying a voltage difference across a conductor, and the intensity of the current is modulated by the electrical resistance, associating a lower current with a higher resistance.

As schematized by diSessa, the Ohm p-prim is used to justify a set of proportional relationships between the effort made by an agent, the resistance that *opposes* or *interferes* with the agent’s effort, and the result produced. Drawing an analogy between Ohm’s law and the Ohm p-prim, we can infer that the result is the electric current; the resistance corresponds to the electrical resistance of the material—produced by collisions between electrons in the conductor and the metal atoms in their path—and the potential difference acts as the agent or impetus. What matters here is that the Ohm p-prim and Ohm’s law can be understood from a causal perspective [32]; that is, the potential difference is an independent element that causes the electric current, and the result (the current) is modulated by the electrical resistance.

Situations explained by the Ohm p-prim are numerous and occur in a variety of contexts, as long as they involve agency, an effect, and an impediment [1,21,30]. Pushing, pulling, or lifting a heavy object to move it faster or slower or opposing a particular point of view in a discussion are examples found not only in physical situations but also in psychological contexts. A clear physical example of this type of proportional relationship is found in Newton’s second law, $a = F/m$. The force F represents the action exerted by an external agent, and as a result of its action on an object of mass m , the object acquires an acceleration a [34].

The force as a mover p-prim is described by diSessa as a vectorial extension of the **Ohm p-prim** [17], in a context where the result of an entity’s agency over another leads to the directed motion of the latter:

A directed impetus acts in a burst on an object. Result is displacement and/or speed in the same direction. [1] (p. 217)

According to diSessa, this p-prim is characterized by the attribute of *violence*, meaning that the motion of an object is generated by an action occurring in a short period of time and with great intensity. A circumstance in which the **force as a mover p-prim** might be activated is when throwing an object, provided that the object is initially at rest.

In Ref. [35], the authors provide a similar description, in the context of an object’s motion, based on the descriptions by diSessa [1] and Hammer [21]:

An object’s motion is by directed a force applied. [35] (p. 579)

Hammer [21] offers an alternative description and label for the **force as a mover p-prim**, expanding the context in which it can be evoked. Hammer renames this p-prim as *actuating agency* and describes it as follows:

Actuating agency is involved in understanding an initial cause of some effect, when the effect outlasts the cause, in the way that a toss causes the motion of a ball, the strike of a hammer causes a bell to ring, or, perhaps, a traumatic event causes anxiety. [21] (p. 103)

With this description, replacing the concept of force with that of agency, Hammer seeks to extend the scope of the **force as a mover p-prim** to situations that, in addition to involving physical forces, also include psychological contexts in which an agent can change the course of a patient’s actions, for example, when attempting to persuade someone to change their opinion or when an action changes the course of a sequence of events.

The dynamic balance p-prim is evoked in contexts where:

A pair of forces or directed influences are in conflict and happen to balance each other. [1] (p. 222)

Later, it is slightly modified to explicitly include the result of the balance between influences:

Is the state where two competing influences (forces) exactly cancel each other, resulting in no effect. [36] (p. 688)

In this latter description, diSessa makes explicit that the balancing of influences results in their mutual cancelation, and thus, the outcome of dynamic balance is a null effect.

The overcoming p-prim is used in situations involving a “struggle” between two influences, where ultimately one of them “prevails.” diSessa describes it as

One force or influence overpowers another. [1]
(p. 222)

This description is later complemented by adding a couple of subtle elements that help frame the situation in which this p-prim is evoked:

If one of the influences in a dynamic balance increases or the other diminishes, the stronger influence “overcomes” the other and “gets its way.” [36] (p. 688)

In this formulation, diSessa places the **overcoming** p-prim within the context of **dynamic balance**. However, this serves only as context, since **overcoming** expresses a nonzero result between the competing influences. It also integrates an element evoked by the phrase *gets its way*, suggesting that the “dominant” influence achieves an outcome or “goal.”

The dying away p-prim is evoked in the explanation of situations where the motion or action upon an object gradually fades or disappears. DiSessa’s discussion of this p-prim is tied to the idea of *impetus*; that is, a force or *drive* inherent to a moving object, and as this force or drive fades, so does the motion [1]. DiSessa contextualizes this p-prim in relation to object motion:

All motion, especially impulsively or violently caused, gradually dies away. [1] (p. 219)

Although this description is explicit in reference to motion, it could be extended to the case of a force, as in the analysis by student J of the upward vertical launch of a coin [36]. The authors analyze the explanations given by student J about what happens when the coin is thrown upward. The student indicates that the force with which the coin is propelled is present during the upward path but gradually fades along with the motion as the coin approaches its highest point. This is interpreted by the authors as a circumstance explained by the **dying away** p-prim.

Jones [37] provides a slightly different description from diSessa’s:

Dying away is an abstraction about scenarios where some initial condition slowly fades away. [37] (p. 13)

In this description, the term *initial condition* departs from the idea of *impetus* originally used to contextualize

this p-prim. The term *initial condition* allows the **dying away** p-prim to be evoked in situations where the initial condition may be a person’s emotional state that gradually fades—such as the joy or motivation at the start of a new project that gradually diminishes over time. However, the meaning of the term *initial condition* is left to the reader’s interpretation. For instance, in the context of physics or mathematics, this term may be interpreted as the state of a system at time $t = 0$, from which its temporal evolution is measured. Although the term can be interpreted in ways that extend to other contexts, the *locus* lies in the thing, state, or entity that undergoes change (fades), and not in the cause or interaction that generates it (such as an external force).

The labels and descriptions of p-prim, conceptual resources, or epistemological resources found in the literature are the result of the abstraction of analyzed language—often natural and intuitive language—within a data corpus provided by the researchers in such a way that these descriptions can help the PER community identify them in their own studies [1,29]. The labels for these cognitive resources are generally tentative and do not define their essence. What is of utmost importance is the description of these cognitive resources, as they contain all relevant information about their characteristics, attributes, and participating entities, which can be associated with specific scenarios or events [1,5,38].

IV. COGNITIVE LINGUISTICS

Throughout history, humanity has developed various forms of communication, using signals, gestures, symbols, and sounds [39]. As the human species evolved and expanded across the planet, its forms of communication also transformed, becoming rooted in collectively constructed cultural and social structures. In every intentional act of communication between two individuals, a message is transmitted using a code that must be known and meaningful to both parties [40]. This code is composed of linguistic signs that follow a certain structure; in other words, they are organized according to specific rules. Moreover, this code must be meaningful and significant to both parties in order for effective communication to occur.

Cognitive linguistics studies how language relates to mental processes and human experience. It is concerned with the connections between linguistic signs, cognition, and interaction with the environment, aiming to explain how we generate and understand meanings [41]. Cognitive linguistics integrates various elements from other fields of knowledge. On the one hand, it draws from communicative processes that involve forms of natural language and its structure; on the other hand, it incorporates cognitive processes that occur in the human mind, such as the processing of environmental information through the senses [42]. The wide range of disciplines that contribute to cognitive linguistics makes it a theoretical framework

that is not limited to linguistic theories alone but rather a flexible approach from which the cognitive processes involved in the generation and understanding of language structures are studied [43].

Natural language forms—such as speech and writing—develop in social and cultural contexts and acquire meaning when associations between words and sentences are established.

Cognitive semantics studies how people represent knowledge and construct meaning, based on the principle that these processes are shaped by their experience with the world [41]. Words, whether individually or grouped, can be organized into linguistic or conceptual categories according to the characteristics they share. These categories allow us to structure our knowledge about the world [44]. For example, the word *mammal*, as a category to which certain species belong, provides information about their type of diet, modes of reproduction, and anatomical and physiological features, among others. In other words, these categories are groupings of entities or elements encoded in the human mind.

According to Lakoff [44] and Evans and Green [41], knowledge is organized in mental conceptual structures that are expressed through language. These structures are composed of linguistic concepts or lexical units with meaning, which, when activated, serve as access points to broader knowledge networks.

Linguistic meaning occupies a central role in cognitive linguistics. From the perspective of cognitive semantics, language allows us to infer information about the human conceptual system [41,43,45]. Linguistic meaning is perspectival, meaning that it depends on the speaker's point of view. For example, a given situation can be described in different ways depending on its spatial orientation (e.g., in front of, behind, or on top of) [43]. Talmy [46] shows how language encodes spatial relations through conceptual schemas. Linguistic meaning is neither fixed nor absolute; it is influenced by the orientation and manner in which the speaker conceptualizes and communicates their experiences. Thus, when we speak, we not only describe the environment but also activate prior cognitive structures that shape its interpretation.

Embodied cognition, a thesis on which cognitive semantics is based, holds that the human body and experience are fundamental to the construction of meaning. According to this thesis, linguistic concepts can be modified depending on how experiences are encoded, implying that knowledge structures are also flexible [47].

In general terms, humans have the capacity to express ideas through linguistic units that follow a semantic structure. Linguistic meaning is constructed within a dynamic conceptual network, in which words activate different domains of knowledge [45]. These units, when contrasted with an individual's background knowledge, are conceptualized and assigned meaning. Language is closely

linked to cognitive development and the formation of conceptual categories. That is, linguistic meaning can also change as people acquire new experiences with their environment, extending conceptual categories to other domains [41]. This adaptive capacity reflects the dynamic nature of linguistic meaning.

Finally, meaning also has an **encyclopedic** nature, since words function as access points to broad and complex knowledge structures [41,43]. This characteristic is related to the role of human beings in their environment and to the way in which language reflects their social and cultural experience. Thus, language not only describes the world but also frames it, activating cognitive structures that guide its interpretation [10,44].

V. FRAME SEMANTICS: A COGNITIVE LINGUISTICS APPROACH

When we talk about *framing*, it is necessary to clarify the theoretical perspective from which we use the term. This concept has a diffuse origin, and some authors have contributed to refining the term and tracing its historical antecedents [48,49], locating its roots in fields such as sociology—with extensions into communication and media studies—as well as in cognitive linguistics [50], which originated in cognitive psychology, and also in social semiotics [51].

In this line, Sullivan [48] has provided valuable historical insights regarding the concept of framing. According to Sullivan, from a cognitive standpoint, the term *framing* refers to the interpretation of experiences and the processing and understanding of information perceived through sensory interaction with the world. *Framing* occurs through the activation of *cognitive frames*, which are cognitive structures that include events or situations that unfold in a characteristic sequence, their participants, processes, and properties of physical objects, among other elements [50]. These *cognitive frames* are evoked within individuals' knowledge systems by particular stimuli or features and influence—or even determine—individuals' behavior or expectations [48,49].

When considering how framing—from a cognitive perspective—structures experience, a useful example can be found in the different procedures involved in *gas station* services. In many places, drivers may choose between a full-service station and a self-service station, each of which activates a distinct sequence of actions and role expectations. In a full-service station, the driver remains inside the vehicle while an attendant approaches, greets the driver, and asks for the desired amount and type of fuel. The attendant then pumps the fuel and may offer additional services such as washing the windshield or checking tire pressure. Once the tank is full, the attendant removes the nozzle, secures the gas cap, and receives payment; the driver may also provide a tip before leaving the station. In contrast, at a self-service station, there is no

attendant, and the driver performs each step personally: after parking, the driver exits the vehicle, selects the amount and type of fuel at the payment terminal, and completes the transaction. The driver then pumps the fuel, replaces the gas cap, and returns the nozzle to its place. Any additional tasks—such as cleaning the windshield or checking tire pressure—are also carried out by the driver. Only after completing these steps does the driver return to the vehicle and exit the station. This contrast illustrates how framing imposes distinct sequences, roles, and expectations on what is ostensibly the same general activity.

In general terms, the situation of supplying fuel can be structured as involving a supplier who provides fuel to a recipient in order to fill their gas tank. This kind of cognitive frame can also be evoked by words such as *supply*, *fuel*, *refuel*, etc. In the context of frame semantics, these words serve as access points to the conceptual structures that Fillmore called *semantic frames*.

From the perspective of cognitive linguistics—and specifically cognitive semantics—language is understood as reflecting broader conceptual structures, such as image schemas [44] and experiential frames [10], which organize how we conceptualize certain events. **Frame semantics** is a research program proposed by Charles Fillmore [10,11], grounded in encyclopedic knowledge and in the conceptual frames activated by words. These frames are cognitive structures that organize experience and allow us to interpret events or situations, such as a commercial transaction, a car accident, or a trip.

Frame semantics does not function as a large dictionary in which each word has a fixed associated meaning. Rather, words are interpreted in relation to the context in which they appear in order to yield a meaningful interpretation. For example, a *snack* is understood as a light meal eaten between breakfast and lunch or between lunch and dinner. This word makes sense in cultures where there is more than one daily meal; however, in other cultures or ethnic groups that do not follow a structured or ordered pattern of daily eating, the concept of a snack may be meaningless.

In frame semantics, words or lexical units are not defined in isolation but in relation to a broader system of encyclopedic knowledge and conceptual relations. Understanding the verb *buy*, for instance, requires *evoking* a semantic frame that includes roles such as BUYER, GOODS, SELLER, and MONEY, among others. In this way, frame semantics emphasizes the perspectival and experiential nature of language, as the meaning of expressions is derived from how speakers conceptualize familiar situations [50,52].

A semantic frame can represent an event, a state, an attribute, a relation, or an entity [53] and is described in such a way that it includes its context-specific semantic

roles, called “frame elements,” and each semantic frame is evoked by a word or lexical unit. These lexical units are defined as an association between a word and its meaning, in relation to the Semantic Frame to which it is linked [50].

VI. FRAMENET

The computational implementation of the frame semantics research program is FrameNet [13]. In FrameNet, a “Frame” (semantic frame) is a knowledge structure that involves a set of participants and specific semantic roles, known as FEs, and includes a set of predicates that make use of these roles. Each frame is evoked by a word or LU. A frame is defined in terms of its frame elements, which are categorized into core FEs and noncore FEs. That is, each frame has elements that are essential and others that are circumstantial and may or may not appear. More importantly, each frame is associated with a group of words that are understood within the context of that frame [50].

As an example, lexical units such as *bubble*, *cascade*, *drip*, *percolate*, *pump*, *spray*, *spurt*, and *stream* are verbs defined in relation to a body of information concerning the movement of a fluid. In FrameNet, these LUs belong to the Frame `Fluidic_motion` (the underscore is required when defining a frame with two or more words). In this frame, a **fluid** moves from a **source** to a **goal** along a **path** or within an **area**.

A. Origins and scope of FrameNet

FrameNet is a computational lexical database, initially developed by researchers at the University of California, Berkeley [54]. Nowadays, the webtool is maintained by a research group at the Federal University of Juiz de Fora [55]. FrameNet is a web-based tool that enables the annotation of text corpora using the available semantic frames (and their corresponding lexical units that evoke them) contained in the database. In other words, the main goal of FrameNet is to aid in the annotation process of sentences using the definition of frames to show how the FEs fit syntactically with the word that evokes each frame [56]. The 1200 existing semantic frames with their corresponding frame elements and over 17 000 lexical units (at the time of the compilation of the version used [14]) do not represent the entire universe of human knowledge, nor do they provide an exhaustive catalog of all possible conceptual structures of human reasoning. Rather, these (semantic) frames were inductively constructed through a large-scale empirical analysis of English corpora, following the methodological principles of the Frame Semantics project [13,50]. The creation of each semantic frame emerges from recurring patterns found in linguistic usage: when a set of lexical units consistently evokes a shared conceptual scenario with a stable

configuration of participants and relations, a semantic frame is proposed. This process explains both the size of the database and the uneven distribution of frames across semantic domains. Some domains—such as commercial transactions, motion events, and social interactions—are represented by numerous frames, whereas others, including specialized scientific domains, are less comprehensively captured.

The FrameNet database has grown over time in response to changes in language and the creation of new semantic frames that extend the FrameNet database toward specific domains such as tourism in Brazil, sports, etc. [53].

The association between a given text passage and a frame is carried out through a process called *annotation*. This annotation process consists of identifying lexical units within a text corpus that serve as targets to evoke a frame. Through semantic and syntactic analysis, the frame elements present in the text that define each frame are identified, and the meaning of the passage is interpreted using the set of frame elements [57]. These annotations are performed using the FrameNet Brasil webtool [6].

B. Corpus annotation with FrameNet

In FrameNet, each *frame* is described in terms of a set of semantic roles, or *frame elements*, which may be:

- **Core elements:** essential roles that define the *frame*.
- **Peripheral elements:** complementary or contextual roles that expand the understanding of the *frame*.

Figure 1 shows the robbery *frame*, its definition, core and noncore elements, its relations with other *frames*, and the lexical units that evoke it.

We will use the example sentence “The thief robbed the store of cash by threatening the clerk violently” to illustrate the annotation process in detail.

Annotation constitutes the operational core of the methodology based on *Frame Semantics* [57]. In an annotation process, systematic relations are established between LUs and the *frames* they evoke, as well as the *frame elements* that participate in each instance. Each lexical unit in the data set is analyzed to determine whether it evokes a *frame* according to the FrameNet taxonomy or through frames adapted to specific contexts. This step includes:

- Assigning the **lexical unit** to the most appropriate *frame*, considering both the context and the lexical meaning. The lexical units contained in the FrameNet database appear highlighted in bold in the phrase to be annotated. Figure 2 shows all LUs detected by FrameNet, but given the context of the situation, only one of them represents the event of a robbery: the word “**robbed**,” which functions as the *target* of this *frame*.
- Recording possible **alternative** or polysemous **frames**, if the LU may evoke different frames. Once

the word (lexical unit) that serves as the *target* is selected, FrameNet displays two LU’s associated with the *frame* robbery evoked by the word “robbed.” In this case, as shown in Fig. 3, we select the verb “rob” as the most appropriate LU that fits with the robbery *frame*.

1. Labeling of frame elements

Frame elements represent the semantic roles involved in the situation described by the *frame*. During annotation, the following steps must be carried out:

- Distinguishing between **core elements**—roles essential for the definition of the *frame*—and **peripheral elements**—contextual information that enriches the frame.
- Assigning elements to their corresponding linguistic expressions, ensuring accuracy in the delimitation of textual boundaries.

In this example, Fig. 4 shows how, once the *frame* is selected, the elements or roles that belong to the robbery *frame* can be associated. To do this, the span of words corresponding to each element is selected. For instance, *the thief* corresponds to the element **perpetrator**, defined as the person who takes the **goods** from a **victim**. Then, *the store* is associated with source, which refers to the original location of the goods before they change location. It is not associated with **victim**, since this element is defined as the *person* or group of persons who possess the goods before they are taken by the perpetrator. The elements mentioned above are the *core* elements.

This process continues until all corresponding elements have been associated. Figure 5 displays the example sentence with all annotated elements, including *noncore* elements such as **means** and **manner**.

2. Noninstantiated frame elements

In a semantic annotation based on *frame semantics*, it is possible that not all elements of a *frame* appear explicitly. In many cases, certain frame elements are implicit but can be inferred from the linguistic or situational context. *FrameNet* accounts for these cases with the concept of *null instantiation*, which distinguishes three types: *Indefinite null instantiation* (INI), when the missing element cannot be identified; *definite null instantiation* (DNI), when the element can be recovered from the immediate context; and *constructional null instantiation* (CNI), when the omission is due to grammatical or constructional constraints of the language [13,58]. In the annotation scheme, such elements are recorded with their respective labels (INI, DNI, or CNI), accompanied, when necessary, by justificatory notes that clarify the semantic inference made by the annotator.

Robbery
[#91]

Definition

These are words describing situations in which a **Perpetrator** wrongs a **Victim** by taking something (**Goods**) from them. In some cases, the **Source** location from which the **Goods** were taken is used to metonymically refer to the **Victim**. The robbery can be done in a particular **Manner** (for example, forcefully) and via a specific **Means** (for example, by threatening the **Victim**). Half of the team held up the tellers while the others were stationed to report the arrival of police. As opposed to Theft, Robbery focuses on the harm to the **Victim** and on the **Source** location from which the **Goods** have been removed, rather than the **Goods** themselves.

Core Frame Elements

FE Core:

Perpetrator The **Perpetrator** is the person (or other agent) that takes the **Goods** away by force or threats. Leslie robbed Kim of her watch.

Source Source is the initial location of the goods, before they change location. Leslie and Kim robbed a bank This FE is realized in compound nouns as follows: bank robbery

Victim The **Victim** is the person (or other sentient being or group) that owns the **Goods** before they are taken away by the **Perpetrator**. Leslie robbed Kim of her watch.

FE Core set(s):
{Victim,Source}

Non-Core Frame Elements

Co-participant Co-participant denotes a person that participates in a coordinated way in robbery event as the primary protagonist, the **Perpetrator**.

Explanation The state of affairs that the **Perpetrator** has in mind which leads to the decision to commit the robbery. Listen, I just mug people 'cause I got mouths to feed -- nothing personal.

Frequency The number of times a robbery event occurs. An Agoura Jills cigar store was robbed twice last week

Goods The **Goods** are anything (including labor, time, or legal rights) that can be taken away. Leslie robbed John of his watch.

Manner The **Manner** describes the way in which the Robbery took place. He was known for committing violent muggings on schoolchildren

Means The **Means** indicates the means by which the Robbery takes place. John mugged his victim by holding a toy gun to his head.

Place The **Place** is where the Robbery occurs. They robbed a bank in North Berkeley.

Purpose The action that the **Perpetrator** is trying to accomplish by the robbery. They used to rob folks just to see the expression on their faces.

Time The **Time** indicates when the Robbery occurs. They ROBBED a bank in North Berkeley last May.

Relations

Inherits:

[Committing_crime](#)

Uses

[Theft](#)

Lexical Units

[hold-up.v](#)
[hold-up.n](#)
[mug.v](#)
[mugger.n](#)
[mugging.n](#)
[ransack.v](#)
[rifle.v](#)
[rob-blind.v](#)
[rob.v](#)
[robber.n](#)
[robbery.n](#)
[stick-up.v](#)
[stick-up.n](#)

FIG. 1. Screenshot from the FrameNet web tool. The robbery frame is shown. The colored words represent the core and noncore elements that constitute this frame. The bottom row displays a set of lexical units that evoke this frame.

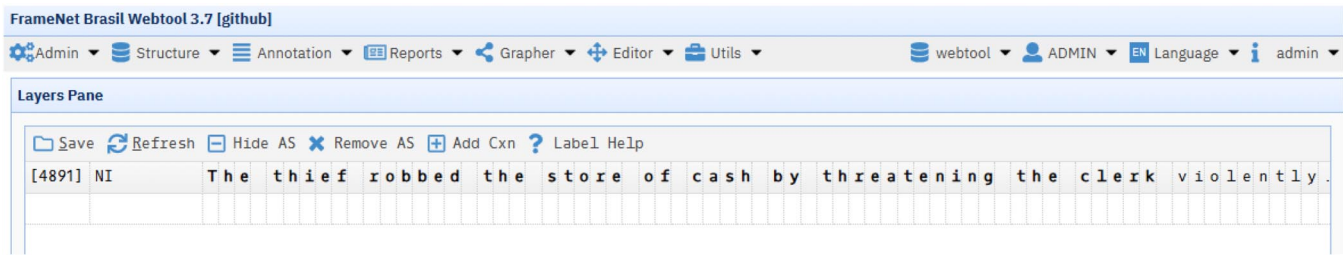


FIG. 2. Screenshot of the FrameNet interface showing a sentence used as the text corpus for annotation.

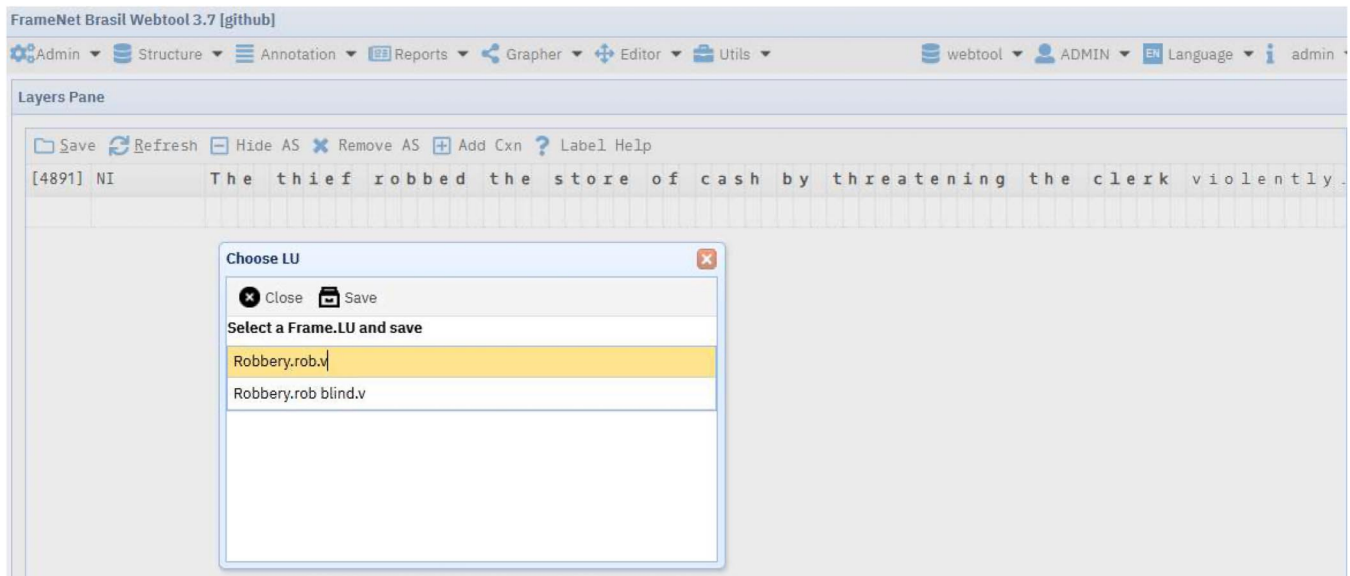


FIG. 3. Screenshot of the FrameNet interface showing the possible LUs that evoke the robbery *frame*. The verb “rob” is highlighted in yellow, as it is the one that evokes this *frame*.

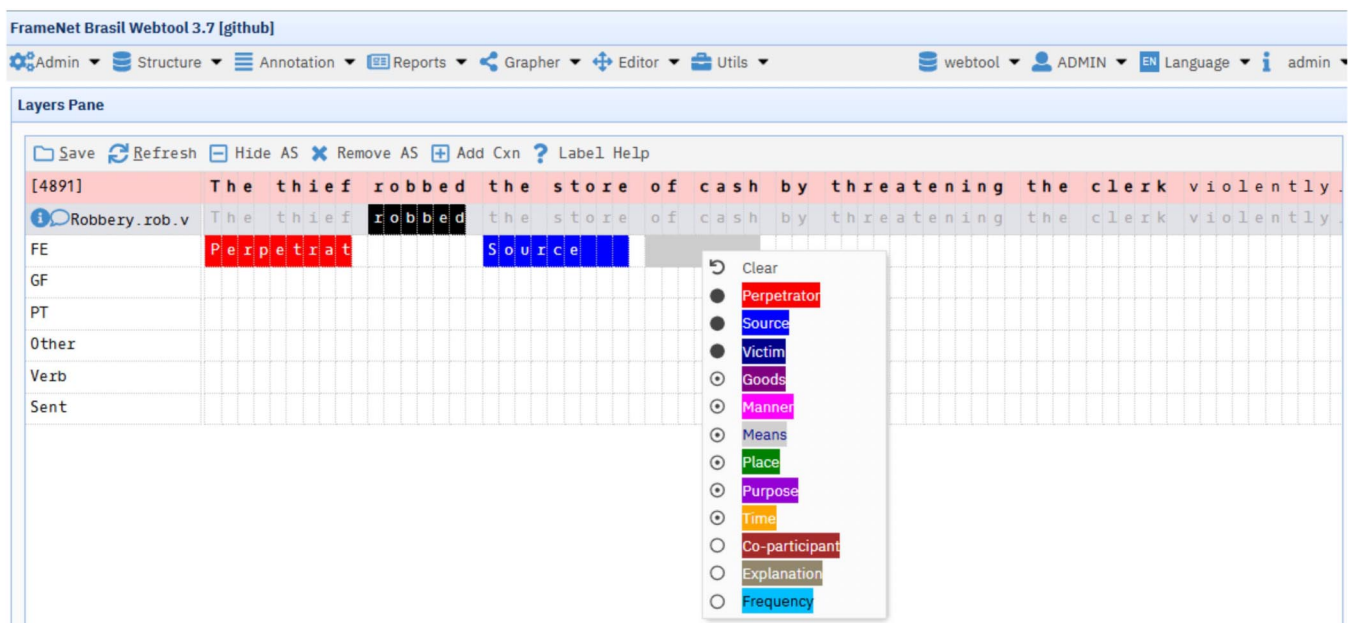


FIG. 4. Screenshot of the FrameNet interface. The elements that are part of the Robbery *frame* and can be associated with specific parts of the text are shown.

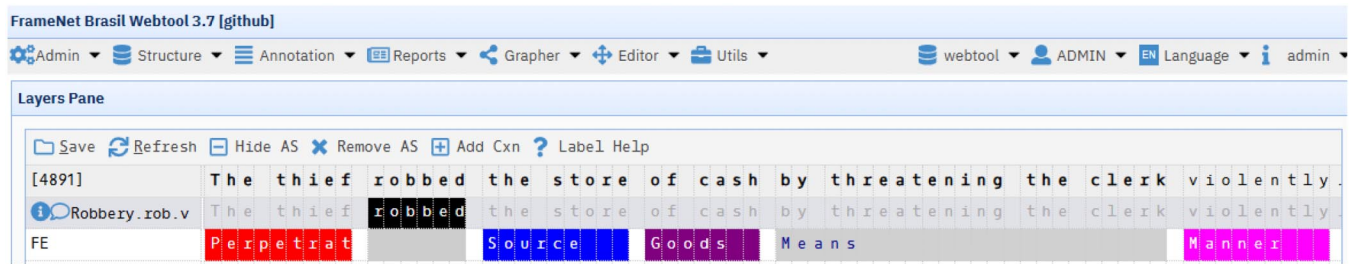


FIG. 5. Example sentence fully annotated with the corresponding *core* and *noncore* elements.

VII. A FRAME SEMANTICS APPROACH TO INTUITIVE IDEAS: OUR PROPOSAL

P-prims are cognitive structures that serve as interpretive and explanatory frameworks through which meaning is given to experiences with the environment [1]. It is essential for researchers to know and be able to recognize when these cognitive structures appear encoded in language, since the language students use reflects their reasoning about the physical phenomena and processes that take place in the world [59].

Descriptions of p-prims have undergone slight changes among different authors, including elements that enrich or expand the context in which each p-prim is evoked. In this regard, the question that motivates our proposal is: Is it possible to provide a semantic structure to p-prims such that they can be schematized in a way that allows for more precise identification of their context of application based on their constituent elements?

The language used by students to express their intuitive ideas may be colloquial and even lack proper use of terms or concepts, as these intuitive ideas in physics originate from interpretations of experience and the context in which they emerge. Since Piaget's work on children's intuitive ideas about the concepts of speed, velocity, and displacement [60], it may be difficult for researchers to provide descriptions that accurately reflect these ideas. In this sense, the principle of redescription [1] (p. 127); [5] (p. 4), which underlies our work, grants a certain degree of flexibility when reschematizing existing p-prims or cognitive resources, allowing new findings or descriptions to be adjusted, refined, and concretized to strengthen the theory.

Understanding how cognitive resources such as p-prims are schematized based on their fundamental elements or components is essential for researchers to recognize them. In this work, we aim to provide a syntactic structure to the description of p-prims, which would make them more identifiable and understandable in relation to their context of activation. Our research program consists of redescribing p-prims through a schematization based on the formalism of Frame Semantics [10,11], defining their respective Frame Elements (core and noncore) and the Lexical Units that evoke them. In this paper, we present part of our

research program, focused on the redescrptions of a selected set of *p-prims* used as case studies to illustrate and explain our proposal.

We will define the components of each p-prim (frame elements, in the terminology of frame semantics) using the FrameNet webtool, where each p-prim schematized by diSessa [1] is uploaded as a text corpus. The annotation process for each schematization is carried out as follows: Step 1: A p-prim is selected from a line of text, which is opened in annotation mode.

Step 2: A lexical unit (word) within the line of text is identified as representative of the meaning of the p-prim. If necessary, the initial description of the p-prim is rewritten to include a lexical unit that serves as a target.

Step 3: By right-clicking, the web tool provides a list of frames evoked by the selected lexical unit.

Step 4: After careful analysis of each proposed frame, we select the one(s) that best match(es) the p-prim's description.

Step 5: The frame elements (core or noncore) are then matched to words in the line of text.

Step 6: Based on the frame elements and the frame associated with each p-prim schematization, we rewrite the p-prim in terms of frame elements.

A. Case study 1: The force as a mover p-prim

As a first example of our proposed schematization, we will carry out the annotation process for the p-prim **force as a mover**. Figure 6 shows the interface of the FrameNet Brasil webtool [14], where the annotation process is performed. Below the toolbar, we find the text passage to be annotated (step 1), which in this case is a rewritten version of the original *force as a mover* p-prim. As indicated in step 2, the original description was rewritten to include a word that serves as a target that; on the one hand, is contained in the FrameNet database, and on the other, preserves the original meaning of the description. Specifically, the original description:

A directed impetus acts in a burst on an object. Result is displacement and/or speed in the same direction.

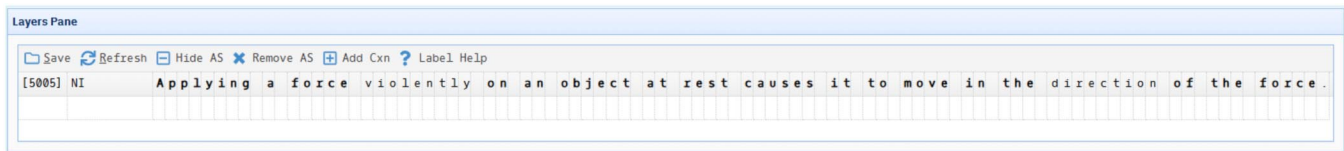


FIG. 6. Interface of the FrameNet Brasil webtool. The original description of the p-prim *Force as a mover* has been rewritten, including the word “move” instead of *displacement and/or speed*. Then the rewritten sentence is annotated.

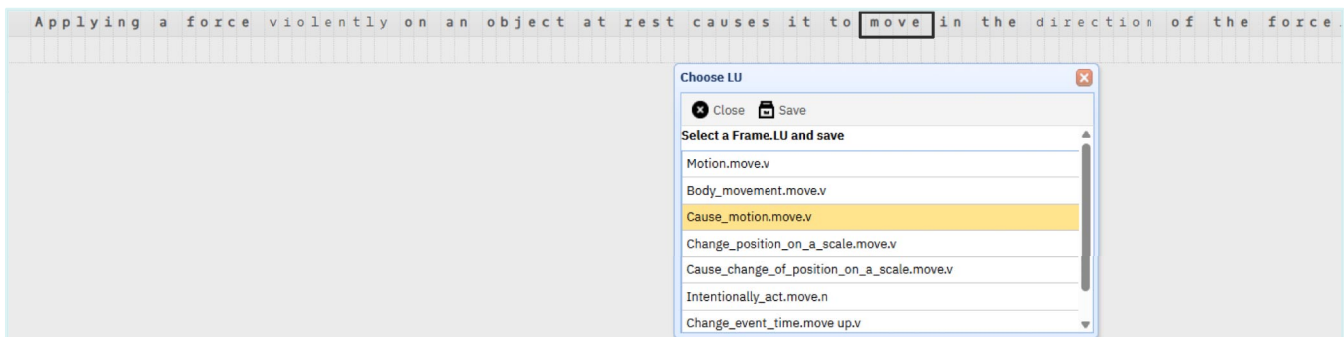


FIG. 7. Interface of the FrameNet Brasil webtool showing the Frames that are evoked by the Lexical Unit “move.”

has been rewritten as:

*Applying a force violently on an object at rest causes it to **move** in the direction of the force.*

In this new version of the p-prim’s description, we included the word **move**, which will later serve as the target. This is because the word “displacement” is not listed in the FrameNet database and the word “speed” is associated with frames related to the duration of an event (Taking_time) or with the description of an object’s velocity (Speed_description).

Figure 7 shows the *frames* evoked by the lexical unit *move*, which functions as the *target* (step 3).

After a careful analysis of the frames suggested by the *webtool*, the *Cause_motion* frame was selected, as it best fits the description of the *p-prim force as a mover* (step 4). Once the frame is evoked, clicking below each bold word displays a list of all the frame elements (core and noncore) that constitute the frame, as shown in Fig. 8.

During the annotation process, a frame Element is associated with a word (or group of words) within the body of text (Step 5). Frame Elements marked with a filled black circle correspond to core elements, while those

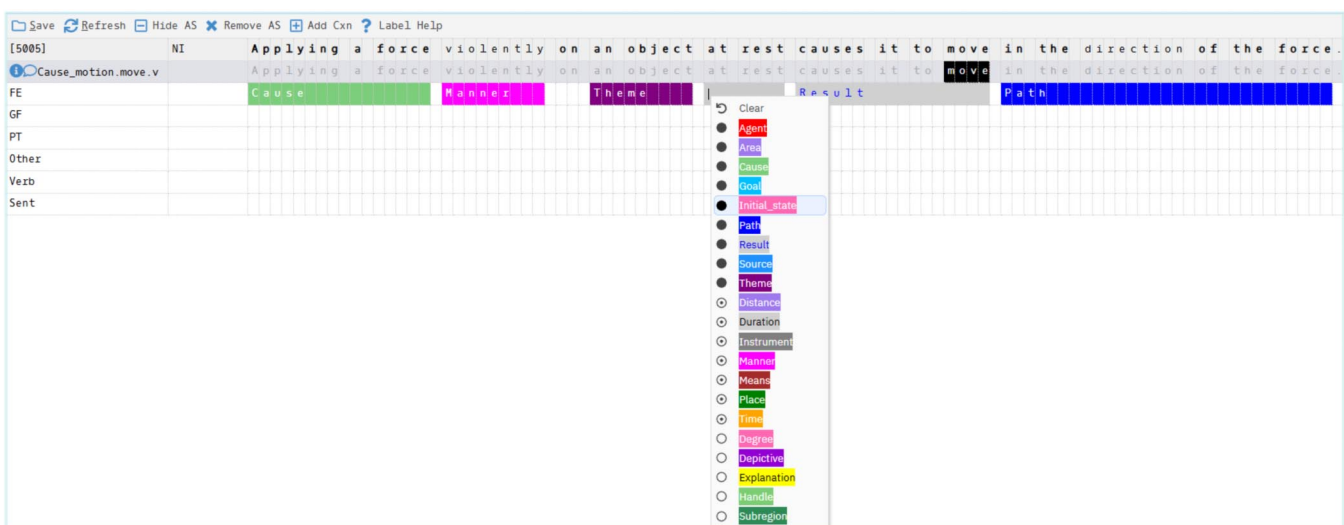


FIG. 8. Interface of the FrameNet Brasil webtool displaying a list of available frame elements for the *Cause_motion* frame.

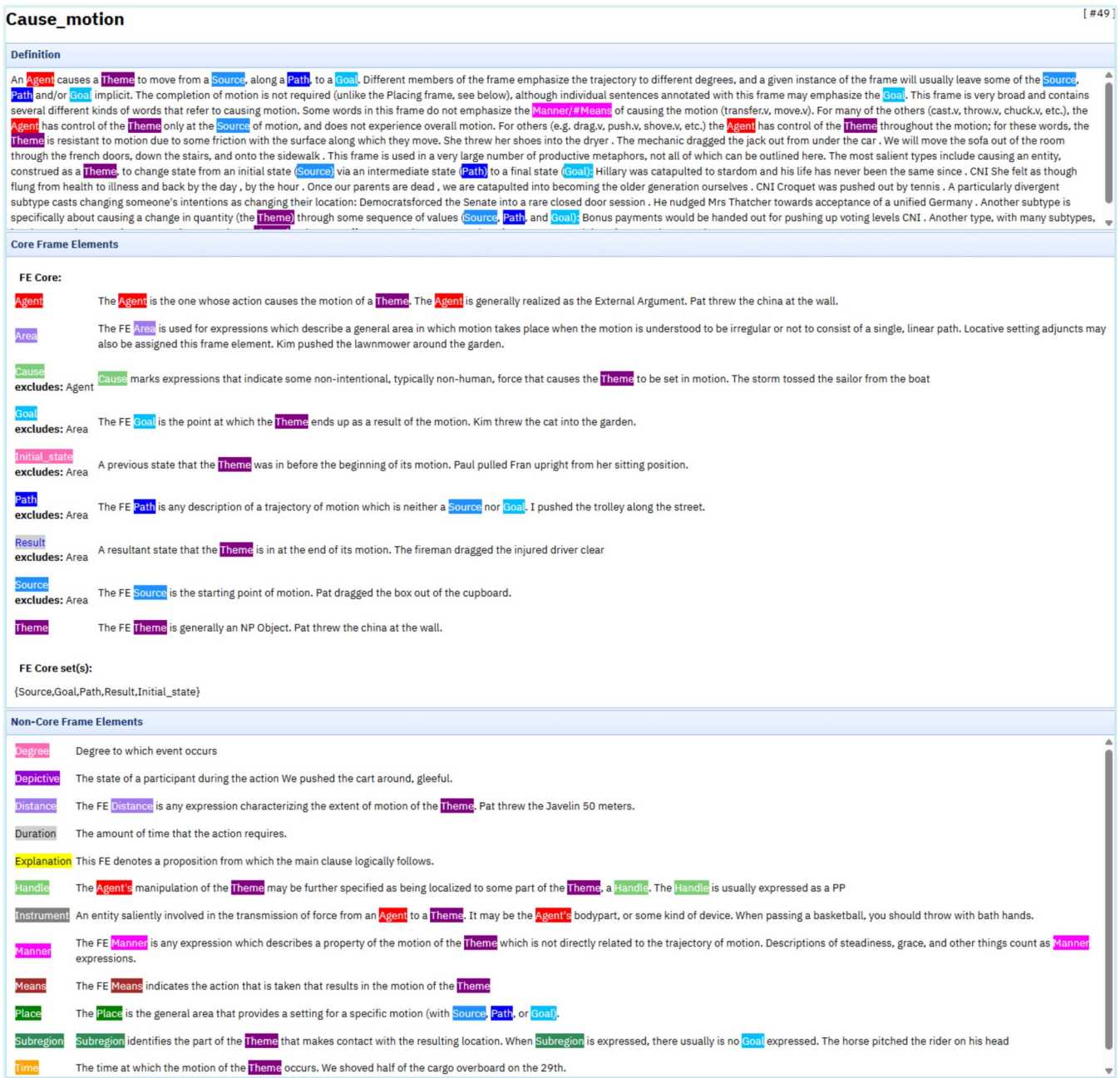


FIG. 9. Interface of the FrameNet Brasil webtool showing the definition of the frame Cause_motion, and the definitions of its core and noncore frame elements.

marked with a circle containing a central black dot correspond to noncore or peripheral elements, elements that are not necessarily required to appear in the sentence being annotated (see Fig. 8). The definition of the frame Cause_motion and its Frame Elements, which serves as

a reference to redescribe the p-prim **Force as a mover**, is shown in Fig. 9.

Our proposed schematization of the p-prim **Force as a mover**, based on the elements identified in the annotation process, is described (Step 6) as follows:

An Agent or a Cause acting in a certain Direction causes a Theme to initiate its motion along a Path.

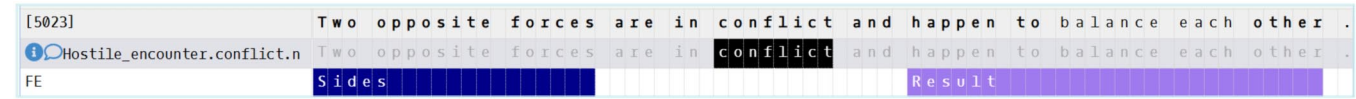


FIG. 10. Interface of the FrameNet Brasil webtool showing the annotation of the p-prim *Dynamic balance* from the Frame *Hostile_encounter*.

The words in bold represent the core elements, that is, the elements that are essential to define the p-prim, following the syntactic structure of a *frame*, and are defined as follows:

- **Agent:** The agent is a volitive entity whose action sets in motion the theme.
- **Cause:** It marks expressions that indicate some nonintentional, typically nonhuman action that causes the theme to be set in motion (excludes the agent).
- **Theme:** The object or entity that starts moving as a result of the action of the agent or the cause.
- **Direction:** It indicates the direction in which the action of the agent or the cause is exerted on the Theme.
- **Path:** It is any description of a trajectory of motion of the theme. Usually follows the direction of the agent's action or the cause.

In situations where the p-prim **force as a mover** is evoked, there may also appear circumstantial or context-dependent elements, which do not necessarily affect the definition of the p-prim. These elements, in the language of Frame Semantics, are known as noncore Frame Elements, and for the situation in which this p-prim is framed, we define them as follows (using *italics*):

- **Instrument:** An entity saliently involved in the transmission of the action from an Agent to a Theme. It may be the Agent's body part, or some kind of device.
- **Distance:** It is any expression characterizing the extent of motion of the Theme.
- **Manner:** It is any expression which describes a property of the motion of the Theme which is not directly related to the trajectory of motion. Descriptions of steadiness, grace, and other qualities count as Manner expressions.

In the following sections, we apply an analogous procedure to redefine the p-prims presented in Sec. III. With this proposal, we aim to contribute to the strengthening of the KiP framework by providing p-prims with an explicit syntactic structure that facilitates the identification of their core and peripheral elements, as well as the specific circumstances under which the p-prims are evoked.

B. Case study 2: The dynamic balance p-prim

The p-prim **Dynamic balance** is situated within a context in which two opposing forces are in conflict but *balance* each other out. We have slightly modified the original description:

A pair of forces or directed influences are in conflict and happen to balance each other,

as follows:

Two opposite forces are in conflict and happen to balance each other,

making explicit that this is a situation involving two forces acting in opposite directions. Following the procedure described above, the word *conflict* (highlighted with a black background) evokes the frame *Hostile_encounter*, as shown in Fig. 10. The definition of the *Hostile_encounter* frame and its Frame Elements that serve as a reference to redescribe the p-prim **Dynamic balance** are shown in Fig. 11.

Based on the annotation of the modified description, we can schematize the p-prim **Dynamic balance** as follows:

Opposing actions (**Side_1** and **Side_2**, collectively referred to as **Sides**) engage in a **Conflict** that results in a **Balanced_result**. The *degree* to which the actions oppose each other may fluctuate over time or remain stable.

This new description of the p-prim **Dynamic balance** identifies the two elements that are in conflict and the specific outcome, which is represented by a balance between these two opposing actions.

The core elements of this p-prim are:

- **Side_1:** The first participant in the Conflict, initiating or sustaining an action that is directly opposed by Side_2. It includes forces, groups, individuals, etc.

Hostile_encounter

[#86]

Definition

This frame consists of words that describe a hostile encounter between opposing forces (**Side_1** and **Side_2**, collectively conceptualizable as **Sides**) over a disputed **Issue** and/or in order to reach a specific **Purpose**. He still wants to fight Mike Tyson in about 8 months. Dennis Andries's European cruiserweight title clash against Akim Tafer of France in Beausoleil last February has been voted as the EBU's fight of the year.

Core Frame Elements

FE Core:

Issue	An unresolved question over which the two sides of a hostile encounter are in disagreement. They had a dust-up over who was prettier . Quite often it takes the form of a covert question of various sorts. So in an example like: They fought over the right to own land. among many other possibilities, the covert question might be more explicitly phrased as follows: They fought over what the right to own land means.
Purpose	The desired result of the outcome of the hostile encounter for the Side_1 or for all the Sides collectively. It may either directly refer to the state of affairs that is desired, e.g. He dueled with his former second to defend the honour of the man he had killed . or it the state of affairs may be implicit in an (abstract or concrete) entity that they desire, e.g. Rival Democratic presidential candidates Mr Bill Clinton and Mr Jerry Brown taunted each other at the weekend as mudslinging in the battle for votes in tomorrow's crucial New York primary reached a new low.
Sides	The jointly expressed sides in a hostile encounter. They fought over the right to own land.
Side_1	requires: Side_2 One of two participants in a hostile encounter. While the U.S.'s battle with terrorist-harboring nations is far off ... excludes: Sides
Side_2	requires: Side_1 One of two participants in a hostile encounter, usually the second mentioned. While the U.S.'s battle with terrorist-harboring nations is far off ... excludes: Sides

FE Core set(s):
{Issue,Purpose}

Non-Core Frame Elements

Degree	The Degree to which an event occurs.
Depictive	A Depictive phrase describing the actor of an action.
Duration	The amount of time for which a state holds or a process is ongoing.
Explanation	The Explanation for which an event occurs.
Instrument	The Instrument with which an intentional act is performed.
Internal_cause	The body movement may be prompted by either some outside phenomenon or occurrence, or by an Internal Cause, the Agent's mental or emotional state. Internal Cause is expressed in a PP complement.
Manner	Any expression which describes a property of the hostile encounter. Descriptions of the intensity count as Manner expressions. After Brundle's Jaguar took off like a scalded cat, it was Mass who hunted it down, an soon engaged it in a lurid battle.
Means	Means describes the way in which a side engages in a hostile encounter. President Corazon Aquino of the Philippines is bracing herself for a legal battle over her decision to allow the remains of the former president, Ferdinand Marcos, to be returned home from Hawaii for burial.
Particular_iteration	Expressions marked with this extra-thematic FE modify a non-iterative use of the target, and indicate that it is conceived as embedded within an iterated series of similar events or states.
Place	The location at which the hostile encounter takes place. Following the battle of Naseby in 1645 ...
Result	The Result of an event.
Time	The Time at which the hostile encounter occurs. Following the battle of Naseby in 1645 he died.

FIG. 11. Interface of the FrameNet Brasil webtool showing the Frame *Hostile_encounter* and its core and noncore frame elements.

- **Side_2**: The second participant in the Conflict, whose action opposes or responds to that of Side_1. It includes forces, groups, individuals, etc.
- **Sides**: The two entities (individuals, groups, forces, etc.) that engage in mutually opposing actions within the Conflict. Each Side initiates or sustains actions that counter the intentions or effects of the other.
- **Conflict**: The dynamic event or interaction in which both Sides engage opposing actions. It serves as the central scenario.
- **Balanced_result**: The resulting situation of the encounter where both Sides balance each other.

Whereas the peripheral or noncore elements are:

- *Purpose*: The reason why one of the Sides seeks to counterbalance the action of the other.
- *Duration*: The temporal span over which the Conflict and opposing actions unfold.
- *Degree*: The intensity or strength with which the Sides oppose each other. It may refer to how forceful, strategic, or persistent each Side's actions are.

- *Place*: The location—physical, social, or abstract—where the Conflict takes place.
- *Time*: The time at which the Conflict occurs.
- *Instrument*: The means, tools, methods, or resources employed by a Side to carry out its opposing action within the Conflict.

C. Case study 3: The overcoming p-prim

The schematic description provided by diSessa for this p-prim is relatively clear regarding the elements involved in a situation where two forces are present and one of them overcomes the other:

One force or influence overpowers another.

Our proposal makes explicit the two elements in **Conflict**, resulting in a **Dominant** entity and, consequently, a **Subjugated** one, which are framed as follows:

A **Conflict** between two opposing **Sides** results in the **Dominant** overcoming the **Subjugated**.

The core elements of our proposal for the p-prim **Overcoming** are:

- **Conflict**: The event or situation in which the Sides are engaged.
- **Sides**: The opposing entities involved in the Conflict.
- **Dominant**: The Side that prevails in the Conflict, exerting greater influence, control, or force over the other.
- **Subjugated**: The Side that yields or is overcome in the Conflict, having its influence, control, or action suppressed by the Dominant.

The elements that may appear depending on the context or situation, that is, the peripheral elements, are:

- *Instrument*: The means or mechanism through which a Side acts during the Conflict. It may include tools, strategies, forces, or resources used to influence the outcome in favor of that Side.
- *Goal*: The desired outcome or objective that a Side seeks to achieve through the Conflict. It motivates the Side's actions.
- *Place*: The physical or conceptual location where the Conflict occurs. This can be a literal setting (e.g., a

battlefield or a courtroom) or a metaphorical one (e.g., a political arena or a cognitive space).

- *Duration*: The span of time over which the Conflict unfolds. It may be brief or prolonged and can affect the strategies and outcomes for both Sides.

D. Case study 4: The dying away p-prim

As previously discussed, the p-prim **dying away** is evoked in situations where a force gradually diminishes until it disappears. This p-prim has explanatory power in scenarios such as the upward launch of a coin, where students often assert that the launching force persists until the coin reaches the highest point of its trajectory or in cases where an object's motion gradually fades away. However, diSessa's description [1] refers explicitly to the motion of an object:

All motion, especially impulsively or violently caused, gradually dies away.

Our proposal takes as reference the frame *Ceasing_to_be* (see Fig. 12). Our redescription of the p-prim is as follows:

A scenario in which a **Dissipating_entity**—such as a force, influence, motion, or state—gradually diminishes in intensity over time. This dissipation may affect a **Theme**, resulting in a **Final_state** in which the original condition vanishes or stabilizes.

Ceasing_to_be [#933]	
Definition	
An Entity ceases to exist. Entire platoons have mysteriously vanished from battle, leaving enemy weapons to slice through empty air.	
Core Frame Elements	
FE Core:	
Entity	Concrete or abstract entity that does not exist after the event.
Non-Core Frame Elements	
Components	This FE identifies the components into which the Entity dissipates.
Degree	The completeness of the disappearance of the Entity .
Duration_of_final_state	This FE identifies the length of time before the Entity comes into existence again.
Explanation	This FE labels the Explanation of the destruction or disappearance of the Entity .
Manner	The way in which the Entity disappears.
Period_of_iterations	This FE identifies the Period_of_iterations during which habitual or iterative actions are performed.
Place	This is the Place where the new Entity ceases to exist.
Role	The aspect of the Entity which no longer exists.
Time	This FE identifies the Time when a new Entity ceases to be.

FIG. 12. Interface of the FrameNet Brasil web tool showing the definition of the Frame *Ceasing_to_be* and its core and noncore frame elements, evoked in the annotation of the *dying away* p-prim.

Whose core elements are:

- **Dissipating_entity**: The force, influence, motion, or state that diminishes gradually.
- **Theme**: The entity affected by the dissipation.
- **Final_state**: The state in which the original condition of the Theme has ceased or stabilized.

The peripheral elements are:

- **Cause**: The reason or mechanism triggering the dissipation of the *Dissipating_entity*.
- **Duration**: The temporal span over which the dissipation occurs.
- **Place**: The physical or contextual location where the dissipation takes place.
- **Manner**: The manner in which the dissipation occurs (e.g., slowly and suddenly).

VIII. EXAMPLES OF ANNOTATED SENTENCES ASSOCIATED TO SPECIFIC P-PRIMS

Our proposal is based on the theoretical framework of frame semantics, using as reference the frames (semantic frames) available in the FrameNet Brasil database [14], with the aim of providing a framework in which p-prims are defined by identifying their core and peripheral frame elements. In this way, we provide a syntactic structure to the description of p-prims found in the literature.

In order to make our proposal explicit, we will show a set of examples with sentences in which the

annotation process has been carried out manually, explicitly identifying their respective core and peripheral elements. These sentences have been previously grouped according to the p-prim to which they belong.

A. Force as a mover p-prim

• Sentence A.1:

The *child*_{Agent} pushed the *toy car*_{Theme} *forward*_{Direction} *along the hallway*_{Path}.

• Sentence A.2:

The *force applied*_{Cause} propels the *ball*_{Theme} *into the air*_{Path}.

• Sentence A.3:

*it*_{Theme} *falls to the ground*_{Path} because *gravity*_{Cause} *pulls it down*_{Direction}.

B. Dynamic balance p-prim

• Sentence B.1:

The *struggle*_{Conflict} between the *gravity*_{Side_1} and the *aerodynamic lift*_{Side_2} produced a *stableflight*_{Balanced_result} *for several hours*_{Duration}.

• Sentence B.2:

The *gravity pulling down*_{Side_1} and the *force pulling up*_{Side_2} are equal, so *it's like in equilibrium for a second*, so *it's not going anywhere*_{Balanced_result}.

• **Sentence B.3:**

A balance would be used *to keep the object in constant velocity upward*.**Balanced_result**

C. Overcoming p-prim

• **Sentence C.1:**

The *chess match***Conflict** between the *two grand-masters***Sides** ended with the *younger player***Dominant** defeating the *defending champion***Subjugated**.

• **Sentence C.2:**

On the ball *at point* **B_{Place}**, the *force of the throw***Dominant** has a magnitude big enough to overcome the *gravity***Subjugated** *trying to force the ball down***Goal**.

• **Sentence C.3:**

*The force needed to initially pick up the box from the ground***Dominant** is greater than the force needed to move the box to the top of the table. This is because you have to overcome *the force that keeps the box on the ground***Subjugated** and stationary.

D. Dying away p-prim

• **Sentence D.1:**

The *vibrations***Dissipating_entity** in the *metal plate***Theme** faded *due to friction***Cause** *until it was completely still***Final_state**.

• **Sentence D.2:**

The *echoes***Dissipating_entity** faded over several *seconds***Duration** in the *cave***Place** *until silence returned***Final_state**.

• **Sentence D.3:**

*It's [the ball]***Theme** going to slow down in a really small difference, so you can't even notice the *difference***Manner**, but eventually *it's going to stop***Final_state** *because of that little difference adding up***Cause**.

From the set of sentences presented above, some correspond to examples that we have generated in order to illustrate how core or peripheral elements are annotated. These are sentences A.1, B.1, C.1, D.1, and D.2. The other set of sentences corresponds to excerpts from interviews that we collected from the literature [61].

To illustrate instances of the p-prim *force as a mover*, we have selected short excerpts from Ref. [4]. Sentences A.2 and A.3 are situated within the context of the vertical launch of an object. In sentence A.2, the student refers to the initial launch of the object, whereas in sentence A.3, the student refers to the object's fall after it has reached the highest point of its trajectory.

In the examples associated with the p-prim *dynamic balance*, sentence B.2 was extracted from Ref. [36] (p. 691), in which a student (J) reasons about the vertical motion of an object, particularly about what occurs at the highest point of its trajectory. The core element **Conflict** is not instantiated explicitly; however, it is understood from the context of the situation and corresponds to a dynamic

in which two forces of equal magnitude and opposite directions act on the object (**Theme**).

Sentence B.3 is an excerpt from Ref. [4], in which a student reasons about the forces required to lift a heavy box from the floor and place it on a table. In particular, students are asked to compare the magnitude of the force needed to “detach” the box from the floor with the force required to maintain the box's motion toward the table. In this sentence, the core element **Balanced_result** is instantiated; however, the core elements **Sides** and **Conflict** are not instantiated explicitly. Nevertheless, the context provides them, since **Sides** refers to the upward-directed force (with the box already in motion) and the gravitational force, and **Conflict** corresponds to the situation of exerting an upward vertical force on the box in opposition to the gravitational force acting on it.

In the examples of the p-prim *Overcoming*, sentence C.2 is an excerpt from Ref. [4], in which a student explains what happens during the upward trajectory of an object launched vertically upward. This case, in particular, reflects one of the most common ideas: that the force with which the object is launched continues acting on it during its ascent.

Sentence C.3 is also an excerpt from Ref. [4], in which a box is lifted from the ground and placed on a table. We have included the student's full response to provide context, and it is important to note that the element **Subjugated** corresponds to the force keeping the box on the ground, not the force that moves the box to the table. This clarification is necessary because the complete excerpt could mislead the reader into annotating the force that moves the box as the subjugated one. In this sense, between the force required to lift the box and the force that moves it toward the table, there is a kind of “transition” or “transformation” from one force to another, rather than a relationship of dominance or subjugation.

Finally, sentence D.3 is an excerpt from Ref. [21], in which a group of students discusses a situation in which a ball first moves downward along a ramp and then travels on an infinite, smooth horizontal surface. We have added the words *the ball* to provide context and make explicit what *It's* refers to. In this case, the **Dissipating_entity** element is not instantiated explicitly; however, the use of *slow down* refers to the motion or speed of the ball, from which we infer that the ball's motion is the core element **Dissipating_entity**.

IX. DISCUSSION AND CONCLUSIONS

Understanding the relationship between semantic frames and p-prims requires clarifying the distinct objectives of their respective research programs. FrameNet, as a computational lexical project, aims primarily to document how linguistic meaning is structured in relation to the conceptual knowledge that speakers routinely draw upon when using words. Semantic frames represent culturally

shared, linguistically evidenced conceptual scenarios, emphasizing the roles, relations, and typical event structures encoded in lexical patterns [57]. In contrast, p-prim theory—within the Knowledge in Pieces framework [1]—aims to characterize the fine-grained cognitive resources that novices employ when reasoning about physical phenomena. These resources are not necessarily linguistically expressed; they are cognitive primitives inferred from patterns of student reasoning. Their purpose is explanatory rather than descriptive: p-prims model how intuitive knowledge is organized, activated, and coordinated during sensemaking in physics.

Given that p-prims described in physics education research are conceptual resources grounded in intuitive experiential reasoning, it is important to note that FrameNet was not designed within the physics education field; instead, this computational lexical database serves as a resource for semantic role labeling in text corpora [62,63], and it can also be used for semantic role labeling in image recognition [6,64]. Thus, although many semantic frames relate to everyday physical interactions (e.g., Motion, Fluidic_motion, and Impact), they represent conceptual structures that emerged from general language use rather than from systematic analyses of novices' reasoning in physics. For this reason, the completeness of the FrameNet database with respect to conceptual resources relevant for reasoning about physical phenomena—particularly intuitive reasoning—cannot be assumed.

Because our study proposes linking each p-prim to a related semantic frame, it is necessary to consider whether all p-prims can be straightforwardly associated with semantic frames in the current FrameNet database. While many p-prims correspond to experiential patterns commonly encoded in natural language and thus have close conceptual analogs within FrameNet (e.g., *Force as a mover* and the Semantic Frames Motion or Cause_motion), this is not universally the case. Some p-prims involve abstract causal expectations or simplified intuitive principles whose representations in language are diffuse or fragmented. For example, p-prims related to *recoil* phenomena such as the motion after a released tension may underlie linguistic expressions but do not always correspond to a clearly defined semantic frame. Conversely, some semantic frames are not intended to describe intuitions about certain physical phenomena, as is the case of the semantic frame “Robbery” shown in Sec. VI.

Thus, the mapping between p-prims and frames should be understood as a methodological procedure rather than a strict one-to-one correspondence. The process involves identifying the semantic frame that best approximates the structure and roles implied by each p-prim, while recognizing that some intuitive knowledge elements may not be represented in FrameNet due to their domain specificity or lack of overt lexicalization. This motivates a careful

description of the criteria used to select semantic frames and highlights the need to extend the database when necessary. Aligning p-prims with semantic frames, therefore requires acknowledging that the two systems do not categorize experience in the same way. However, the comparison is theoretically productive: Semantic frames can provide structured representations that clarify the conceptual elements underlying p-prims, while p-prims highlight intuitive reasoning that may not always be fully reflected in linguistic usage. Recognizing these differences strengthens the analytical grounding of the proposed approach and clarifies the interpretive scope of the mapping between p-prims and frames. Moreover, this work introduces a two-way extension connecting frame semantics, grounded in cognitive linguistics, with physics education.

In relation to the sentences extracted from the literature and presented in Sec. VIII, the examples show how the semantic structure emerges from students' verbal expressions, and it is through this structure, assigned to the p-prims, that we can identify the core or peripheral elements manifested in their reasoning. With the semantic structure of the p-prims, the way we understand students' reasoning changes, since we can now approach it through the elements they highlight in a given situation and through which they make sense of it. In other words, we can determine which pieces of information they use in their reasoning. A more detailed description of the methods for identifying and interpreting students' reasoning, based on our proposal for the schematization of p-prims, will be included in a later work [65].

In this work, we propose a redescription of the *p-prims* through a reinterpretation and syntactic restructuring of each *p-prim* from the KiP framework [1], using tools and concepts derived from Frame Semantics [10,66]. The proposal is grounded in the principles of cognitive linguistics—particularly its encyclopedic and embodied conception of linguistic meaning—and offers a structured, linguistically informed framework based on frame semantics for articulating the semantic and conceptual components of p-prims.

Our proposal represents a significant methodological contribution by offering a new way to systematize the intuitive ideas that students manifest in educational contexts. The identification of cognitive structures through syntactic schemas based on frame semantics not only improves the description of these ideas but also clarifies their circumstances of application based on the analysis of students' natural language. The recognition of cognitive resources is carried out through the analysis of verbal expressions produced by students during the knowledge construction processes in different contexts and learning moments [20,21]. In this work, we discussed the redescriptions and schematizations of the *p-prims* **force as a mover**, **dynamic balance**, **overcoming**, and **dying away** [1]. Structuring *p-prims* through a formal approach

opens new paths for their identification, analysis, and application both in educational research and in the development of technological resources.

The study of the language used by students provides hints about their conceptual system and how it is organized. Methods employed for recognizing ideas, concepts, or misconceptions have evolved as new technologies have advanced. Recent progress in big data science, deep learning, ML, and their relationship with linguistic theories that have led to large language models (LLMs), as well as NLP techniques, have opened new ways to detect language elements that account for students' conceptual systems [9,59,67]. Our proposal offers a bridge between cognitive theory and NLP tools. The use of resources such as FrameNet [13] opens the possibility of building automated systems for the detection and analysis of *p-prims* from text corpora generated by transcriptions of interviews with students.

Furthermore, an extension is envisioned toward generating visual representations of *p-prims* that support both the teaching and the understanding of how students interpret physical phenomena. Describing *p-prims* in terms of their constituent elements—such as an agent, a cause, or a direction—makes it possible to design a visual representation (whether a static image or an animation) that

incorporates these elements, thereby depicting a given *p-prim* in a faithful manner. Although, to the best of our knowledge, there is no literature in PER where similar work has been conducted on the generation of this type of visual representation, related studies do exist in the field of linguistics, particularly those focusing on generating images or animations (2D or 3D) from natural language [68–71]. These resources have not only didactic value but also formative value, both in teacher education and in the development of AI-based educational tools [59].

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DATA AVAILABILITY

Some of the data that support the findings of this article are openly available [4,14]. Data of Refs. [21,36] that support the examples of annotated sentences are not publicly available because they are owned by a third party and the terms of use prevent public distribution. The data are available from the authors upon reasonable request.

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