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| RESEARCH ARTICLE

On the Cognitive Traps in Physics and Its Teaching Strategies: An Analysis Based on Conceptual Metaphor Theory

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| ABSTRACT
Conceptual metaphor is the core tool of physical thinking, but it may become the source of misunderstanding in learning although it has helped students understand abstract concepts. Based on the conceptual metaphor theory, this paper systematically discusses the metaphor trap in physics learning and its teaching strategies. The findings are as follows: (1) Metaphorical language of concepts such as force, current, heat and wave-particle duality leads to systematic mistakes such as consumption misunderstanding, path selection misunderstanding, storage misunderstanding and tunneling misunderstanding; (2) These misunderstandings stem from the interactive cycle of grammatical structure in language, ontological dislocation in cognition and lack of metaphorical consciousness in teaching; (3) To break this cycle, we need to cultivate metaphorical awareness, coordinate the use of multiple metaphors, carry out "removing metaphor" training, and integrate historical reflection and other teaching strategies. This study provides a theoretical basis and practical path for physics teachers to identify and deal with cognitive obstacles caused by language.

| KEYWORDS

Conceptual metaphor; physics learning; cognitive trap; ontology dislocation; teaching strategy

| ARTICLE INFORMATION

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Introduction

In physics study, students often have some intractable misunderstandings. When learning mechanics, students often think that "an object can only move when it has force" and "it will stop when the force is used up"; When learning electricity, students think that the current will be "consumed" in the circuit and will "choose" the path with less resistance; When learning thermodynamics, students think that heat can be "stored" and "flowed"; When learning quantum mechanics, students believe that particles will "lose energy" when they pass through the barrier. These misunderstandings are universal (McKagan & Wieman, 2005), intractable (Brookes & Etkina, 2007) and cross-disciplinary, which are classic problems in physics education and research.

It is worth noting that although these misunderstandings are distributed in different fields, they show common characteristics, i.e. students tend to understand abstract physical concepts as concrete "things"— force is a consumable entity, current is a flowable entity, heat is a storable entity, and particles are colliding objects. This cognitive tendency of "materializing" abstract concepts implies that these misunderstandings may have a common deep root.

What are the roots of these cognitive traps? A noteworthy but often overlooked direction is language. When teachers say "current flows", "particles pass through the barrier" and "heat flows from a high-temperature object to a low-temperature object", students often take these metaphorical languages literally— understanding "flow" as the motion of matter, "passing through" as the physical passing, and "flow direction" as the transfer of fluid. These literal interpretations form a cognitive model that is inconsistent with scientific consensus and become the language source of learning disabilities.

Lakoff and Johnson(1980) claims that metaphor is not a rhetorical device, but a basic structure of human thinking. Conceptual metaphor projects the empirical structure of specific source domain to abstract target domain through "cross-domain mapping", which enables us to understand and talk about abstract concepts. Physics, as a highly abstract discipline, its conceptual system can't be separated from the construction of metaphor. From "force" to "field" and from "wave" to "particle", physicists inevitably borrow the metaphorical language of daily experience (Corni, Fuchs & Savino, 2019; Pulaczewska, 1999）。

However, while metaphor helps to understand, it may also constitute a cognitive trap. Lakoff and Johnson(1980) clearly pointed out that every metaphor is selective—it highlights some aspects while inevitably obscuring others. This feature means that every metaphor that helps us understand may also shows the limitation of understanding.

This limitation is greatly shown in physics learning. Brookes and Etkina(2007) found that students understand "particles passing through the barrier" as the physical interaction between two objects, and think that particles "lose energy"— this is the literal interpretation of metaphorical language. Cetin(2016) found that students describe physics with negative metaphors such as "physics is a maze", which constitute a cognitive framework that hinders learning. Chi, Slotta and de Leeuw(1994) point out that students often mistake the concept of "process" for "matter", and this "ontological misplacement" is the cognitive root of many scientific misunderstandings.

The above research shows that conceptual metaphor plays a dual role in physics learning, i.e. it is both a tool for understanding and a source of misunderstanding. However, the existing studies have paid more attention to the positive functions of metaphor while its negative effects have not been systematically studied.

Based on this, this study focuses on the core question: What is the internal relationship between cognitive traps and conceptual metaphor in physics? How do teachers deal with these traps through teaching? Specifically, it includes three sub-questions: (1) What are the specific manifestations of metaphor traps in physics learning? (2) What are the causes of these traps? (3) How do teachers identify and respond to the traps?

The theoretical significance of this study lies in extending the conceptual metaphor theory from "how to construct knowledge" to "how to restrict knowledge"; The practical significance lies in providing physics teachers with teaching strategies to identify cognitive traps and deal with metaphorical obstacles.

1. Theoretical basis and analytical framework

Lakoff & Johnson(1980: 4) put forward that metaphor is not just a rhetorical device of language, but a basic structure of human thinking: "Our daily conceptual system is basically metaphorical in terms of its thinking and action" . The operating mechanism of conceptual metaphor is "cross-domain mapping": the empirical structure of a familiar and concrete "source domain" is projected to a strange and abstract "target domain", so that the latter can be understood and talked about.

Johnson(1987) further put forward the concept of "image schema", which provided the basis of physical experience for metaphor. Image schema comes from the repeated interaction between human beings and the physical world, including "container" schema, "path" schema, "verticality" schema, "force" schema and so on. Corni, Fuchs and Savino(2019) pointed out that all branches of macro physics share the same image schema structure.

Lakoff and Johnson(1980) clearly pointed out that every metaphor is selective — it highlights some aspects of the target domain while inevitably obscuring others. Taking "argument is war" as an example, it highlights antagonism and obscures cooperation.

This feature is equally significant in physical metaphors. Pulaczewska(1999) pointed out that the metaphor of "current" originated from fluid, which effectively helps to understand the directional motion of charge, but it may also obscure the fundamental difference between electric field and water flow. Lancor(2014) found that "energy" needs multiple (even contradictory) metaphors to be fully understood because each metaphor highlights some features while obscuring others.

Lakoff and Johnson(1980) called another kind of metaphor "ontological metaphor". They regarded abstract concepts as entities and substances, which enabled us to refer to, quantify and discuss these concepts.

Brookes and Etkina(2007) introduced this idea into the research of physics education, pointing out that grammatical structure reflects ontological classification, i.e. grammatical "participant" (noun) corresponds to "matter" and grammatical "process" (verb) corresponds to "event or process". When the grammatical structure is consistent with the scientific consensus, language is "literal"; When the two conflict, language is metaphorical. For example, "heat" in "heat flow" is a noun (matter), but in modern thermodynamics, "heat" is a process, and this expression constitutes a grammatical metaphor.

The research of Chi, Slotta and de Leeuw(1994) supported this view. They found that students often mistakenly classify the concept of "process" into the category of "matter"— heat treatment as a storable thing, electric current as a consumable thing, and force as a possessive thing. This "ontological dislocation" is the cognitive root of many scientific misunderstandings.

Based on the above theory, this study puts forward a three-layer analysis framework of metaphor trap.

The first layer is language, the grammatical structure of metaphor, aiming to examine how concepts are expressed in language, i.e. which are coded as nouns (matters)? What are coded as verbs (events)? When the grammatical structure is inconsistent with the scientific consensus, language itself may become the source of misunderstanding.

The second layer is cognition, the ontological commitment of metaphor, aiming to investigate what ontological categories metaphor classifies concepts into, materiality metaphor, personification metaphor or spatialization metaphor. When the ontological commitment of metaphor conflicts with scientific consensus, students may have ontological dislocation.

The third layer is teaching, the lack of metaphorical consciousness, aiming to investigate whether metaphor exists clearly in teaching, discuss its limitations, provide multiple metaphors and guide "de-metaphor". When there is a lack of reflection on metaphor in teaching, students are more likely to take metaphorical language literally.

These three layers are interrelated and strengthened. The grammatical structure of language provides the possibility of misunderstanding (language layer), students literally use metaphorical language according to their daily cognition (cognitive layer), and the lack of reflection in teaching makes misunderstanding last (teaching layer). This circular mechanism explains the universality and stubbornness of metaphor trap.

2. A Case Study of Metaphor Trap in Physics Learning

This part systematically investigates the metaphor traps in learning the four core concepts of "force", "current", "heat" and "wave-particle duality" in physics by using the three-layer analysis framework (language layer, cognitive layer and teaching layer) , and reveals their specific manifestations and formation mechanisms.

2.1 Concept of "Force": Misunderstanding for Experience Metaphor and Consumption

"Force" is one of the most basic physical concepts of human beings, and its source domain is the physical experience of muscle exerting force — pushing, pulling and resisting (Pulaczewska, 1999). This experience is projected into the physical world through metaphor. Expressions such as "gravitational attraction", "repulsive effect" and "inertial resistance" all personify the object as a subject with "will". Although Newtonian mechanics abstracts "force" as $F=ma$, the metaphor of force in language is still active.

The metaphorical analysis of senior high school students in Cetin (2016) shows that students often understand "force" as an entity that can be "owned" or "consumed". Typical misunderstandings include "An object can only move when it has force", "When the force is used up, it will stop" and "A moving object has force, but a stationary object has no force". These misunderstandings directly transfer the "force" or "strength" in daily language to physical concepts.

The following is the three-layer frame analysis.

On the language layer, in expressions such as "gravitational attraction" and "resistance action", "force", as a grammatical subject, is coded as an entity that can "act". This grammatical structure strengthens the substantive and anthropomorphic characteristics of force.

On the cognition layer, students often classify "force" into the ontological category of "matter" (which can be owned and consumed), rather than the category of "interaction". This ontological misplacement is the cognitive root of misunderstanding.

On the teaching layer, the language of "force" is often used directly in teaching without reflection, and students are not clearly told that "force" is an interaction rather than an entity, and they are not guided to distinguish "force" in physics from that in daily language.

2.2 Concept of "Current": Misunderstanding for Fluid Metaphor and Path Selection

"Current" comes from the metaphor that "water is fluid". Physicists describe the motion of charges as "fluid", such as "current flow", "charge storage" and "current in circuit". The source domain is the flow of water — water flows in the pipeline, from high to low, and it will be diverted when it meets branches.

Students may have the following misunderstandings in the research of Brookes and Etkina(2007) caused by fluid metaphor: (1) Misunderstanding for consumption. Students may think that current will be "consumed" in the circuit, which violates the law of conservation of charge; (2) Misunderstanding for path selection. In parallel circuit, it is thought that current will "select" the path with less resistance, ignoring the decisive role of potential difference; (3) Misunderstanding for speed. Students may equate "current speed" with the actual drift speed of electrons, ignoring the difference between electric field propagation and the motion of charges.

The following is the three-layer frame analysis.

On the language layer, "current flow" encodes "current" as grammatical subject (matter) and "flow" as process, which completely reproduces the grammatical structure of language describing "fluid", suggesting that current is an entity similar to water.

On the cognition layer, students classify "current" into the ontological category of "matter" and think that current is an entity that can be "consumed" and "selected", rather than the directional moving process of charge.

On the teaching layer, the expression "Electric current is like water flow" is often used as teaching analogy, but the application scope and limitations of analogy are often not clearly stated, which leads to students' excessive extension of fluid metaphor.

2.3 Concept of "heat": Misunderstanding for Fluid Metaphor and Storage

Caloric theory in 18th century regarded "heat" as a kind of conserved fluid— "thermal mass". Although caloric theory has been abandoned, its language heritage remains in expressions like "heat flow", "heat capacity" and "heat absorption"—these terms are all heat-treated as entities (Brookes & Etkina, 2007).

The research of Chi, Slotta and de Leeuw(1994) found that students often misunderstand "heat" as a matter rather than a process. They often think that heat can be "stored" in objects, "flowed" between objects and "lost" from the system. When learning the second law of thermodynamics, this may lead to a misunderstanding for the principle of entropy increase, i.e. students regard "heat" as an entity that will "consume" rather than a change in energy distribution.

The following is the three-layer frame analysis.

On the language layer, terms such as "heat flow" and "heat capacity" encode "heat" as a grammatical participant (noun), giving it the ontological status of "matter". This grammatical structure is different from the conceptual system of modern thermodynamics.

On the cognition layer, students are more likely to classify heat as "matter" ontology, and think that heat is an entity that can be "stored", "flowed" and "lost", rather than a process of energy transfer.

On the teaching layer, terms such as "heat flow" are often used in teaching without tracing their historical roots. Students are not clearly informed that these terms are the linguistic heritage of caloric theory, and students are not guided to understand that the essence of heat is a process rather than an entity.

2.4 Concept of "wave-particle duality": Misunderstanding for Classical Metaphor and Tunneling

The core insight of quantum mechanics is that microscopic entities have the properties of both waves and particles, but both concepts of "wave" and "particle" are derived from macroscopic experience and are projected into the quantum field through metaphor. In the description of tunneling phenomenon, physicists often use the expression "particles passing through the barrier", in which "passing through" borrows the spatial motion metaphor of classical physics.

Brookes and Etkina(2007) revealed the so-called "exhaustion misunderstanding". All the six students interviewed by Morgan, Wittmann and Thompson(2003) think that particles "lose energy" during tunneling. Research by McKagan and Wieman(2005) showed that more than 50% of engineering students and more than 40% of physics students still hold this misunderstanding after completing modern physics courses. Students misunderstand the potential energy diagram as a "physical object" with which particles "interact" instead of understanding it as the energy state of particles themselves.

The following is the three-layer frame analysis.

On the language layer, "particle passing through barrier" encodes "particle" and "barrier" as two grammatical participants (two independent entities), which interact by "passing through"(the process). This grammatical structure "canonizes" the quantum process.

On the cognitive layer, students literally interpret this expression as a physical interaction between two objects — one object passes through the other, which inevitably consumes energy. They misunderstand the barrier as an "external object" rather than the potential energy state of the particle itself.

On the teaching layer, Brookes and Etkina(2007) found that students still insist that the potential barrier is an "external object interacting with particles" even if the potential energy diagram is clearly marked in class and textbook to represent the energy state of particles themselves. This shows that the metaphorical structure of language may have more cognitive influence than explicit graphic explanations, and there is a lack of reflective discussion on metaphorical language in teaching.

To sum up, based on the three-layer analytical framework, we can find the metaphor traps in understanding four core concepts, as shown in the following table.

Concept	Metaphorical language	Students' misunderstanding	Language problem	Cognitive problem	Teaching problem
Force	"Gravitational attraction"	Misunderstanding for consumption	Force as grammatical subject	Matter ontology	No reflection is given to daily language
Electric Current	"current flow"	Misunderstanding for path selection	Current as a flowing entity	Matter ontology	The limitation of analogy is unclear.
Heat	"heat flow"	Misunderstanding for storage	Heat as a grammar participant	Matter ontology	The historical roots have not been traced back.
Wave-Particle Duality	"particle passing through"	Misunderstanding for tunneling	Particle and barrier double entity	Classical causal framework	Metaphor is not reflected.

The four types of metaphor traps fall into the same pattern, i.e. the metaphorical structure of language provides students with the potential for misunderstanding, and the ontological dislocation of cognition turns this possibility into actual misunderstanding, and the lack of metaphorical awareness in teaching makes the misunderstanding continue and strengthen. This model provides a basis for the subsequent teaching strategies.

3. Cause Analysis of the Metaphor Traps

The causes of these metaphor traps in physics learning can fall into three categories(language, cognition and teaching), which may reveal their internal mechanisms.

3.1 Grammatical Structure and Literal interpretation of Metaphor in Language

Brookes and Etkina(2007) pointed out that the grammatical structure of language has a profound influence on meaning construction, drawing on the functional grammar theory (Halliday, 1985). Metaphorical expressions in physicists' discourses often adopt specific grammatical forms, which may lead students to literal interpretation.

Take "particle passing through barrier" as an example, its grammatical structure is: particle (subject)+passing through (process)+barrier (object). This structure "canonizes" the quantum process — implying that two independent entities interact through spatial motion. When students hear this expression, they naturally understand it as a physical interaction between objects.

Similarly, "current flow" encodes "current" as a flowing entity and "in circuit" as a space container, which strengthens the material interpretation of fluid metaphor.

Pulaczewska(1999) pointed out that with the frequent use of metaphor, its metaphoricity was gradually grammaticalized while the original vivid metaphor became natural and unconscious. When teachers say "current flows", they seldom realize that "flow" is a metaphor; When the textbook wrote "Heat flows from a high-temperature object to a low-temperature object", it was seldom realized that this was a linguistic relic of caloric theory. The more commonly used metaphor is, the easier its metaphoricity is to be forgotten, and literal interpretation becomes the default way of understanding.

Lancor(2014) pointed out that many concepts in physics rely on a single dominant metaphor (for example, both "current" and "heat" depend on fluid metaphor). The solidification of this single metaphor strengthens the specific understanding path and obscures other perspectives. When students are exposed to only one metaphor, they are more likely to regard it as the whole of the concept, rather than part of the perspective, which is the exact linguistic root of the metaphor trap.

3.2 Cognitive Level: Ontological Dislocation and Concept Transfer in Cognition

Chi, Slotta and de Leeuw(1994) proposed that human beings divide things into different ontological categories, which constitute the basic framework for understanding the world. They divided scientific concepts into three categories:

Matter: an entity with mass, which can be stored, moved and consumed.

Process: an event or change that occurs in time and does not occupy space.

Psychological state: thought, emotion and consciousness.

Each category has its own attributes and reasoning patterns. Matter can be "owned" and "stored", but process cannot.

Chi and others found that students often mistake the concept of "process" into the category of "matter", and this "ontological misplacement" is the cognitive root of many scientific misunderstandings.

In thermodynamics, "heat" is a process of energy transfer, but students think that heat can be "stored" and "flowed".

In Electricity, "current" is a directional motion of charges, but students think that current will be "consumed" and "chosen" path.

In mechanics: "force" is interactive, but students think that force can be "owned" and "exhausted".

The root of ontological dislocation lies in that physical language encodes the concept of process as a noun, and nouns mainly refer to material objects in children's early language experience. When students hear "heat", "current" and "force", they naturally understand it as material existence.

Vosniadou(1994) pointed out that students had formed "naive theories" through their daily experience before entering the science class. These theories are based on metaphors and conflict with scientific concepts. In daily experience, "motion is maintained with force" , "force is what objects have" and "heat is what objects contain". These everyday concepts will not disappear automatically, but will continue to affect understanding as a cognitive framework.

3.3 Lack of Metaphorical Awareness in Physics Teaching

Corni, Fuchs and Savino(2019) pointed out that physics teachers are often in an "unconscious" state when using metaphorical language for they regard metaphorical language as a natural and direct scientific language. This unconscious usage leads to the fact that teachers will not actively tell students that language is metaphorical, discuss the scope and limitations of metaphor, or guide students to reflect on the masking effect of metaphor.

The analysis of mainstream physics textbooks by Brookes and Etkina(2007) shows that textbooks usually adopt the following ways to deal with metaphorical language: default use (direct use without explanation), introduction of analogy (analogy without definite limitation), and historical omission (using terms without tracing back to the source). Those inevitably lead to the conflict between metaphorical language and scientific consensus, but the textbook does not provide cognitive tools to solve it.

At present, there are few systematic strategies to deal with metaphor traps in physics teaching with lack of metacognitive training, lack of multiple metaphorical perspectives, lack of historical reflection, and lack of "de-metaphorical" guidance. Lancor(2014) pointed out that understanding complex concepts requires the coordinated use of multiple metaphors, but teaching often sticks to a single metaphor, which leads to students' one-sided understanding.

3.4 Correlation Mechanism of Three-layer Causes

The causes of language, cognition and teaching are interrelated and strengthened layer by layer, forming a "strengthening cycle of metaphor trap";

On the language layer, the grammatical structure of metaphor encodes the concept of process as a material entity, which provides potential for students to misunderstand.

On the cognitive level, students literally translate metaphorical language according to the daily cognitive framework, forming ontological dislocation.

On the teaching layer, there is a lack of reflective discussion on metaphor in teaching, and misunderstandings are not recognized and corrected, which can be sustained and strengthened.

As a result, a cyclic reinforcement has come into being. Students' misunderstanding is manifested as wrong answers, and teachers explain mistakes from the perspective of concept rather than language, and continue to use the same metaphorical language to strengthen the original cognitive path.

This circular mechanism explains why metaphor trap is universal and intractable — it is not an accidental learning difficulty, but a systematic phenomenon rooted in the interaction of language, cognition and teaching.

4. Teaching Strategies

The analysis above shows that metaphor traps are rooted in the interactive cycle of language, cognition and teaching. Breaking this cycle requires systematic teaching intervention. We here put forward teaching strategies from five dimensions, each of which is aimed at the causes of a specific layer and provides practical suggestions for classroom teaching.

4.1 Cultivating Metaphor Awareness: Making Metaphor Visible

One of the causes of metaphor traps lies in the invisibility of metaphor. When teachers say "current flows" and "particles pass through the barrier", few people realize that these expressions are metaphorical. Brookes and Etkina(2007) point out that making metaphors "visible" is the first step to help students avoid literal interpretation.

Therefore, teachers are suggested to clearly mark the metaphorical language, for example, "Note that' current flow' is a metaphor. We use 'flow' to describe the motion of charge, but the current doesn't really flow like water. "

In addition, teachers should guide students to identify daily metaphors. For example, they can design classroom activities, ask students to collect daily metaphors such as "wasting time" and "depressed mood", and discuss their sources and implied meanings.

Furthermore, teachers can use "metaphorical revelation" to ask questions. For example, when students say "the strength is exhausted", the teacher can ask: "Where does the word "exhausted "come from? If you understand 'force' as interaction rather than something that can be 'used up', how would you describe it? "

Research by Corni, Fuchs and Savino(2019) shows that teachers who have been trained in metaphor awareness can more keenly capture metaphorical understanding in students' language and consciously guide students to reflect on metaphorical language.

4.2 Coordinated Use of Multiple Metaphors

Lancor(2014) pointed out that a single metaphor must be selective because it highlights some aspects while obscuring others. Understanding complex physical concepts requires the coordinated use of multiple metaphors. Taking "energy" as an example, we need six complementary metaphors: measurable entity (conservation), changeable form (transformation), mobile (transfer), portable (materiality), lost from the system (dissipation) and storable (localization).

Therefore, teachers are suggested to consciously present multiple metaphors. For example, when explaining energy, the teacher should use metaphors such as "energy is money", "energy is fluid" and "energy is resource" to discuss the applicable situations of different metaphors.

Then teachers are advised to organize a discussion about the metaphor, for example, "If we understand current as 'water flow', what do we see? What do you see when you understand it as 'crowd flow'? What phenomena are suitable for explanation? "

Teachers may further encourage their students to draw a metaphor map for the core concepts, and mark the prominent and hidden aspects of each metaphor.

Amin's (2009) analysis of Feynman's Lectures on Physics showed that Feynman's flexible use of multiple metaphors is itself an example of effective teaching.

4.3 "Removing Metaphor" Training: from metaphor to mathematical form

Dieks(2021) suggests that physicists can "transcend" the metaphorical level of language and directly understand the mathematical structure through professional training. This ability should be the goal of physics education. "Removing metaphor" is not abandoning metaphor, but learning to switch between metaphor and mathematics. Metaphor provides intuitive images while mathematics provides accurate descriptions. Metaphor is the scaffolding while mathematics is the architecture.

Therefore, teachers are suggested to define the metaphor as the "scaffolding". for example, "This metaphor helps us to imagine, but the accurate description of physics is mathematical form. Just like building a house requires scaffolding, but the house itself is not scaffolding. "

Also, teachers are encouraged to design a "metaphor-mathematics" contrastive activity, i.e. they may ask students to "translate" metaphor expressions into mathematical expressions. For example, put "current flows" into the formula $I = \Delta Q/\Delta t$, the law of conservation of charge.

Gradually teachers should help students to dilute metaphor and strengthen mathematics, i,e, with the deepening of learning, students should reduce the dependence on metaphor and increase the discussion of mathematical forms. In highly abstract fields such as quantum mechanics, students must finally understand the direct meaning of wave function and state vector.

4.4 Historical Reflective Teaching

Pulaczewska(1999) indicated that many physical terms bear the historical heritage of abandoned theories. "Heat flux", "heat capacity" originated from caloric theory, and "current" originated from fluid metaphor. Tracing back to the historical roots is helpful for students to understand the metaphor in the terms and avoid literal interpretation.

Therefore, teachers may introduce the history of caloric theory when explaining "heat". In the 18th century, scientists regarded "heat" as a conserved fluid, and this theory has been replaced, but "heat flow" and "heat capacity" remain as a linguistic heritage.

Teachers may also have students to discuss about the topic "the retention of abandoned theories". "Why does the language of the overthrown theories still remain in today's textbooks? What implications does this have for understanding concepts? "

Finally, teachers may encourage students to compare historical theory with modern understanding. For example, ask students to compare the explanation of caloric theory and modern thermodynamic for the same phenomenon so as to understand the history and evolution of the metaphor.

The historical perspective can help students realize that today's scientific metaphor may also be surpassed by the future, thus cultivating a critical understanding of scientific knowledge is of great importance.

4.5 Comprehensive Application of Classroom Practice

Based on the case analysis above, different conceptual metaphor traps need targeted strategies, as shown in the following table.

Concept	Main Trap	Preference strategy
Force	Misunderstanding for consumption	Cultivating metaphor consciousness + Historical reflection
Electric current	Misunderstanding for path selection	Multiple metaphors + Removing metaphor
Heat	Misunderstanding for store	Historical reflection + Cultivating metaphorical consciousness
Wave-particle Duality	Misunderstanding for tunneling	Removing metaphor + multiple metaphors

A 4E Teaching Case: Taking "Current" as an Example

The first stage (Engagement): "'current flow' is a metaphor. It uses water flow to describe the motion of charge. But what's the difference between 'current' and 'water'? "

The second stage (Exploration): "In addition to 'water flow', we can also use 'crowd flow' to understand current. What do these two metaphors help us understand? "

The third stage (Elaboration): "Metaphor helps us to imagine, but the accurate description of physics is mathematical form. I = ΔQ/Δt is the definition of current, and the metaphor of 'flow' is not needed. "

The fourth stage (Evaluation): "What metaphors do we use today? What does each metaphor see? What's covered? What is the mathematical definition of current? "

Corni et al. (2019) pointed out that the implementation of the above strategies requires teachers to have "metaphorical awareness". The training of normal students should include conceptual metaphor theory, metaphor recognition training in physics language, metaphor teaching strategies for different concepts, classroom practice and reflection.

Conclusion

Conceptual metaphor is an indispensable tool for physics cognition. It makes abstract mathematical forms have intuitive meaning, and makes complex natural phenomena be understood and talked about. However, metaphor is revealing while hiding aspects of the concept. When students understand "current flow" as the motion of matter, and "particles passing through the barrier" as physical passing through, they are not "wrongly" understanding, but "literally" understanding the language we teach them.

It is an important task of physics education to help students understand the nature of metaphor, switch freely between metaphor and mathematics and enrich rather than solidify their understanding from multiple perspectives. That's what this study is expected to contribute to.

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