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EMBODIED COGNITION AND THE SHIFT FROM OBJECT-LIKE TO EVENT-LIKE REASONING IN MECHANICAL WAVES LEARNING: A CONCEPTUAL REVIEW WITH CRITICAL REALISM

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ABSTRACT

Physics learning in the classroom often merely focuses on writing equations and substituting numbers into formulas, while the bodily experience of how it feels for a wave to propagate is rarely truly experienced by learners. This condition is actually a legacy of the old classical cognitivism, which strictly separates the mind from the body, whereas Embodied Cognition (EC) research precisely shows the opposite: that conceptual understanding is deeply rooted in physical experiences, gestures, and interactions with the surrounding environment. This article weaves Kersting's four dimensions of EC- physical, phenomenological, ecological, and interactionist sense- with Wittmann's framework of shifting from object-like to event-like reasoning on the topic of mechanical waves, with critical realism as an epistemological bridge explaining how cognitive mechanisms that are not directly observable can be traced through the tracks of students' gestures and body language. Through a narrative-thematic literature review of publications themed around embodied cognition, grounded cognition, and physics conceptual reasoning, this study shows that the four dimensions of EC are intertwined in a single learning event, and that bodily experience provides the process mechanism for the reasoning shift, while Wittmann's framework becomes the conceptual marker to recognize whether that shift has actually occurred. This weaving offers a conceptual map for the design of mechanical wave learning activities that involve the bodies of learners, while simultaneously opening an empirical validation agenda through qualitative studies that trace students' gestures and reasoning in depth.

Keywords: *Embodied Cognition, Object-like reasoning, Event-like reasoning, Mechanical Waves.*

ABSTRAK

Pembelajaran fisika di kelas sering kali hanya berfokus pada penulisan persamaan dan substitusi angka ke dalam rumus, sementara pengalaman tubuh tentang bagaimana rasanya sebuah gelombang merambat nyaris tidak pernah benar-benar dialami peserta didik. Kondisi ini mewarisi kognitivisme klasik yang memisahkan pikiran dari tubuh, padahal riset *Embodied Cognition* (EC) menunjukkan bahwa pemahaman konseptual justru berakar pada pengalaman fisik, gestur, dan interaksi dengan lingkungan. Artikel ini merajut empat dimensi EC dari Kersting, physical, *phenomenological, ecological,* dan *interactionist sense,* dengan kerangka pergeseran penalaran *object-like* ke *event-like* dari Wittmann pada topik gelombang mekanik, dengan critical realism sebagai jembatan epistemologis yang menjelaskan bagaimana mekanisme kognitif yang tidak teramati langsung dapat ditelusuri lewat jejak gestur dan bahasa tubuh siswa. Melalui tinjauan literatur naratif-tematik atas publikasi bertema *embodied cognition, grounded cognition,* dan penalaran konseptual fisika, kajian ini menunjukkan bahwa keempat dimensi EC saling berjalin dalam satu peristiwa belajar, dan bahwa pengalaman tubuh menyediakan mekanisme proses bagi pergeseran penalaran, sementara kerangka Wittmann menjadi penanda konseptual untuk mengenali apakah pergeseran itu benar-benar terjadi. Rajutan ini menawarkan peta konseptual bagi desain aktivitas pembelajaran gelombang mekanik yang melibatkan tubuh peserta didik, sekaligus membuka agenda validasi empiris lewat studi kualitatif yang menelusuri gestur dan penalaran siswa secara mendalam.

Kata Kunci: *Embodied Cognition, Object-Like Reasoning, Event-Like Reasoning,* Gelombang Mekanik.

A. Introduction

In a typical physics class, the teacher writes the wave equation on the whiteboard, students take notes, and then practice problems are solved simply by inserting numbers into the formula. This process runs smoothly from an administrative standpoint, and test scores might be good, but something is often missed. The understanding of how it feels for a wave to propagate, how energy transfers without moving the medium's particles, is rarely physically experienced by the learners. Physics, in practice, is often taught as a collection of self-standing symbols (Ponczek, 2009), detached from the sensory experiences that actually serve as the root of the emergence of these concepts.

This situation does not occur without reason. The tradition of science education in many countries, including Indonesia, inherits the view of classical cognitivism which positions the mind as an abstract information processor, focusing on teacher-centered instruction that prioritizes the process of transferring understanding and rote memorization (Pandey & Singh, 2025). It is like a computer model that processes symbols without caring about the body that runs them (Rambusch, 2004). Cognitive research is beginning to change this assumption. Embodied Cognition (EC) views cognitive processes as rooted in bodily experience, where movement also influences how a person understands concepts and interacts with their environment (Gashaj et al., 2024). The formation of conceptual structures in the human mind toward even the most abstract phenomena does not emerge from a vacuum, but is born from human bodily experiences as well, whether from touch, gestures, movements, or directly felt muscle pulls (Lakoff & Johnson, 1999). The human mind is highly complex and intelligent, as if everything is centered in the brain, when in reality it also requires the movement of bodily experience to help process its conceptual understanding (Gashaj et al., 2024; Sammu & Segun, 2025; Van der Schyff et al., 2022), between motor and cognitive development, especially in brain areas such as the prefrontal cortex and cerebellum which are involved in both motor skills and cognitive functions (Godwins, 2023). Even intricate and complex concepts ultimately become easier to understand and return to simplicity through the movements or actions of the bodily activities themselves as well as the utilization of the environment (Glenberg, 2010; Kersting et al., 2021; Van der Schyff et al., 2022).

The use of EC in education, which combines psychological and scientific terms, namely didactics, is starting to become popular and develop in the European educational research world. Scientific educational experimental models have been pioneered, introducing empirical methods into educational experiments and driving the evolution of educational experiments toward a more scientific and standardized framework (Guo et al., 2023). In studies of physics education application, EC serves as an appropriate, flexible container and a aligned framework for topics like waves, motion, force, and fields that demand spatial and dynamic understanding that is difficult to capture only through text or formulas. The study by Kersting et al. (2021) developed EC in science education with a four-dimensional framework, namely physical sense, phenomenological sense, ecological sense, and interactionist sense, to examine how bodily involvement is manifested in physics learning activities. On the other hand, Wittmann (2002) raises the lens of another framework that is no less relevant, namely how students' reasoning shifts from viewing waves as if they are objects moving from one point to another following their direction of propagation, similar to a roller coaster schema (object-like), toward the understanding that waves are actually a series of sequential oscillation events at each point of the medium (event-like).

This article does not report field data, but aims to be purely conceptual, reweaving the two theoretical frameworks above with the epistemological footing of critical realism, so that a sufficiently solid theoretical map is available before being used to read empirical phenomena in the field on another occasion. There are two problem formulations to be answered. First, how the four dimensions of EC and the shift from object-like to event-like can be integrated into one coherent reading framework. The second point that needs to be explored concerns the theoretical implications of this combined framework for the design of physics instruction, especially the material on mechanical waves.

B. Study Approach

As an idea article, this study does not take the route of empirical data collection, but rather a narrative-thematic literature review (Lam & Sodhi, 2025), which emphasizes discussions based on literature reviews rather than field data collection, with a focus on defining a reflective narrative, outlining its characteristics, and selecting sources using several criteria (Alam et al., 2025). Reference publications come from indexed journals discussing embodied cognition, grounded cognition, gestures in learning, or conceptual reasoning in physics and mathematics, published in the range from 2000 to 2024, with an emphasis on the last decade. Classic sources like Lakoff and Johnson are still included due to their position as the theoretical foundation that continues to be referenced to this day, even though they are more than twenty years old.

This narrative review technique synthesizes prior publications to reveal underlying patterns, distinctive themes, and blind spots in the existing knowledge base, providing a comprehensive perspective on the issues under review (Lam & Sodhi, 2025; Paudel, 2025). The source search process was conducted in three stages. The first stage, comprehensive reading, is a thorough reading of each source to capture the core arguments and theoretical positions of their frameworks (Okoli, 2015). The second stage, thematic grouping, groups themes based on the proximity of ideas, for example, the literature group on EC dimensions, the group on object-like and event-like reasoning, and the group on critical realist epistemology (Perlman et al., 2025). The third stage, argumentative synthesis, is the weaving of these three groups of themes into a mutually supporting discussion flow, rather than a sequential summary without connection (Wakefield, 2015; Wolfswinkel et al., 2013).

This conceptual-theoretical literature review does not use a statistical meta-analysis approach or a systematic review with the PRISMA protocol. The choice of the narrative-thematic model is based on the nature of the topic which demands the weaving of philosophical and conceptual ideas, rather than the aggregation of quantitative findings. Such an approach is commonly used in idea articles or review articles in science education journals, especially when the goal is to build new theoretical frameworks from existing ones.

C. Theoretical Review and Conceptual Foundation

From Symbolic Cognition to Embodied Cognition

Cognitive science was once dominated by the metaphor of the mind as a computer (Abraham, 2016; Eliasmith, 2003; Kelty-Stephen et al., 2022). Confronting the old philosophy that separated the mind from the physical body, Embodied Cognition boldly shows that concepts and reasoning are by no means abstract entities floating on their own (Lakoff & Johnson, 1999). This view is dissected through three main theses. First, Conceptualization, here showing how the anatomy and physical limitations of the human body play a role in, and even dictate, the way we construct a concept. Second, Replacement, a kind of rebellion against old computational symbolism, was replaced by a dynamic system model that is more flexible, more alive.

Third, and this is the most daring, the Constitution radically claims that cognitive components do not simply reside in the head, but literally extend to the environment through functional coupling or what is known as the Parity Principle. Even so, it is natural that a claim as bold as this remains a subject of fierce debate until now (Shapiro & Spaulding, 2025). Wilson (2002) summarizes this shift through six views of embodied cognition that have now become standard references, ranging from cognition being situated, time-pressured, to the idea that the environment becomes part of the cognitive system itself, not just a passive background.

From the standpoint of physics education, this way of looking actually becomes a highly progressive and effective teaching implication as an alternative to teaching physics concepts. If cognition is indeed rooted in the body, then learning that ignores the movements and physical experiences of learners essentially cuts off the natural path to understanding, rather than accelerating it as has been commonly assumed.

Four Dimensions of Embodied Cognition in Physics Learning

Kersting and colleagues offer a more operational framework for reading EC in the context of physics, divided into four dimensions. Fundamentally, 'embodiment' is understood as the experience that emerges from our body's existence in interacting with the material and socio-cultural world, while 'embodied cognition' refers to the processes of thinking, knowing, and communicating that rely heavily on physical bodily features outside the brain (Kersting et al., 2021).

Based on the framework byKersting et al. (2021) the four-dimensional perspective, which is continuous with one another, does not stand alone. Physical sense, which views the body solely as a biological physical structure that serves as the basis for cognitive mechanisms; cognition is influenced and habituated by the body's condition, and the structures of the perceptual and motor systems play a fundamental role in cognitive functions such as concept definitions and rational inferences. Second, Sense of Phenomenological Embodiment, highlighting the subjective experience of learners when experiencing phenomena through their own bodies, rooted in phenomenology, emphasizing the body as a structure of lived experience and the centrality of the first-person perspective. The body is not just a physical structure, but also a part of the human experiential world, a kind of feeling of 'experiencing' waves, rather than just knowing them cognitively. Third, Sense of Ecological Embodiment: the key concept is 'affordances', the action possibilities offered by the environment; this perspective opens up space for reframing science learning in terms of affordances and actions, with the role of situational tools and digital affordances becoming increasingly relevant in educational technology Lastly, Sense of Interactionist Embodiment, which highlights how meaning is constructed through social interaction, gestures, and shared language with others in the learning space.

The four dimensions of embodiment can even emerge together, more than one or all four at once, in a single event or activity. A student moving their arm to mimic wave propagation is exercising the physical dimension, while also potentially experiencing the phenomenological dimension through the sensation of muscle fatigue or the rhythm of the movement they feel themselves. If the movement is performed while holding a rope or standing in a line with their friends, the ecological and interactionist dimensions become active at the same time. This four-dimensional framework, in other words, is not a separate checklist, but rather a layered lens for reading the same learning event from different angles.

In addition, this paradigm provides a critical foundation for re-evaluating the effectiveness of conventional physics instruction. Many laboratory activities claimed to be 'hands-on' turn out to touch the physical dimension only superficially, limited to pressing buttons or recording numbers, without truly activating either the phenomenological or interactionist dimensions. Genuine bodily involvement demands more than just physical contact with equipment; it demands experiences that are meaningful and socially connected.

The Shift from Object-Like Reasoning to Event-Like Reasoning

Wittmann (2002) raises another issue that is no less fundamental, namely how students perceive the wave object itself. This issue states that many students tend to view waves as if they are objects moving from one point to another along their direction of propagation. This is also discussed in several previous studies focusing on students’ flawed perspectives that become limitations in understanding wave concepts, namely viewing them as moving like objects and particles shifting horizontally or disturbances occurring in the medium (Barniol & Zavala, 2017; Haerunnisa et al., 2022; Hrepic et al., 2010; Rangkuti & Karam, 2022; Wittmann, 2002; Wittmann et al., 1999). This way of looking is called object-like reasoning.

The problem is that mechanical waves are actually not a transfer of matter, but a series of sequential oscillation events at each point of the medium, with vibrating particles moving vertically (Hrepic et al., 2010; Rangkuti & Karam, 2022; Tongchai et al., 2011) around their equilibrium points, something more accurately understood as event-like reasoning.

The shift from object-like to event-like is not merely a correction of concepts, but a profound epistemic change regarding how physical reality is understood (Ferrero & Sánchez-Gómez, 2015). The contribution of EC becomes a rational path in facilitating this shift in thinking paradigms. When students are asked to move their bodies to mimic a single point of a medium oscillating up and down in place, without changing positions, while the wave pattern is actually seen propagating through sequential movements among the students, this kind of bodily experience provides a direct path to event-like understanding, far more direct than verbal explanations or static diagrams in textbooks.

At this point, the two theoretical frameworks discussed earlier support each other. The physical and phenomenological dimensions of EC provide the mechanism for how that reasoning shift can occur experientially, while Wittmann’s object-like to event-like framework provides the conceptual markers to recognize whether the shift is actually occurring or not. The relationship between these two frameworks is indeed complementary; the EC framework is more process-oriented, while Wittmann's framework is oriented toward the expected conceptual outcomes.

Critical Realism as an Epistemological Foundation

A follow-up question that can be explored more deeply is how far this EC claim can actually be accounted for from an epistemological standpoint. Cognitive mechanisms like reasoning shifts cannot be observed directly with the naked eye; they can only be traced through visible traces, gestures, speech, facial expressions, or body movement patterns (Goldin-Meadow & Wagner Cook, 2012; Vinciarelli et al., 2019). This is where critical realism, as formulated by Maxwell (2012), offers the right footing.

Critical realism stands between two extreme poles: naive positivism, which assumes everything must be directly observable to be considered real, and radical constructivism, which tends to negate the existence of an independent reality altogether (Losch, 2009; Smith, 2023; Tynan, 2023; Willis, 2023). The critical realist position acknowledges the existence of truly real cognitive mechanisms (Smith, 2023), such as the shifting process from object-like to event-like in students' minds, even though the mechanism itself cannot be observed directly (Bhaskar, 2010; Joseph, 2014). What can be observed is only its manifestation through behavior and body language, while the underlying mechanism must be inferred through retroductive reasoning from those manifestations toward their causal structures (Dufour, 2010; Giese & Schnapp, 2021).

This kind of epistemological footing is highly crucial for EC studies, because without it, claims about 'bodily experience shaping understanding' easily fall into speculative claims without a solid methodological foundation. Critical realism gives space for researchers to acknowledge the limitations of observation, while remaining confident that something real is happening behind those seemingly simple student body movements (Dufour, 2010; Giese & Schnapp, 2021).

Unifying the three frameworks above, the four dimensions of EC, the shift from object-like to event-like, and critical realism epistemology, yields a sufficiently complete conceptual map to read mechanical wave learning more deeply. The propositions offered by this article can be summarized as follows: the four dimensions of EC function as the process mechanism, the provider of the experiential pathway that makes the reasoning shift possible, while Wittmann's framework functions as the outcome marker, determining whether the shift is actually occurring conceptually. Critical realism binds the two through the claim that the mechanism between the process and outcome, although not directly observable, remains real and can be traced through the traces of gestures and body language.

In other words, the proposed model does not just line up three theories in parallel, but positions each in a different functional role within a single explanatory chain: process, marker, and epistemological bridge. This map is open to being tested and refined through field data in subsequent studies.

Theoretical and Practical Implications

The first implication concerns the design of learning activities. Activities designed should ideally not stop at physical movement alone, but be directed to trigger meaningful phenomenological experiences and social interactions, because that is where the reasoning shift is most likely to occur.

The second implication concerns the role of teachers. Physics teachers need to be trained to read students' gestures and body movements not merely as fun additional activities (Scherr, 2008), but as real traces of ongoing cognitive processes, traces that can be read through the retroductive lens of critical realism (Dufour, 2010; Giese & Schnapp, 2021; Goldin-Meadow & Wagner Cook, 2012). The ability to read such traces is not yet a major part of the pre-service physics teacher education curriculum in Indonesia, even though its potential is significant for diagnosing misconceptions earlier.

Limitations and Future Research Directions

This article deliberately stops at the conceptual level, not entering the realm of field testing, because the related empirical data is being prepared for a separate publication that focuses more deeply on discussing field findings. The theoretical framework woven here is expected to serve as a roadmap that facilitates the reading of that data later, not as a substitute for empirical validation itself.

For future research, empirical validation of this combined framework is an urgent agenda, especially through qualitative studies that trace students' gestures and reasoning in depth in the context of mechanical wave learning.

D. Conclusion

This study weaves three theoretical frameworks the dimensions of Embodied Cognition, the shift from object-like to event-like reasoning, and the epistemology of critical realism into a single conceptual map to read physics learning that is closer to the bodies and experiences of learners. This weaving confirms that bodily involvement in learning physics is not just a methodological ornament, but an epistemic path that has a strong theoretical foundation, especially for topics that demand spatial-temporal understanding like mechanical waves.

The primary contribution of this article lies in the integration of frameworks that previously tended to be discussed separately in the literature: the descriptive phenomenological dimensions of the EC framework on one hand, and Wittmann's conceptual reasoning framework, which is more oriented toward learning outcomes on the other. Critical realism acts as an epistemological bridge explaining why and how the two frameworks can be legitimately linked methodologically, even though the object discussed, namely the cognitive mechanism, can never be directly observed. For physics teachers in the field, this study at least offers a strong enough theoretical reason to start designing learning activities that truly involve the bodies of learners, rather than merely adding variety to teaching methods.

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