Embodying friction: a meeting point of dance and science education

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ABSTRACT

This study highlights how the investigatory and creative dimensions of contemporary dance can transform the concept of friction into an embodied object of teaching and learning. Within the field of science education, dance has been used to develop frameworks of embodied learning, allowing learners to engage experientially with scientific concepts. This study investigates friction as a bodily concept, aiming to generate fundamental kinetic patterns that can serve both as learning objects and as material for choreographic composition. To this end, a choreographer and a science educator collaboratively explored the conceptual dimensions of friction through dynamic bodily interaction, self-observation, and reflective processes. Data were collected through video recordings and field notes and analyzed using multimodal analysis. Through their collaborative exploration, the researchers produced a set of foundational kinetic structures corresponding to distinct aspects of friction, including: (i) static friction *(e.g., gripping the ground with hands or feet), (ii)* limiting friction *(e.g., various bodily holds), (iii)* sliding friction *(e.g., gradual changes in motion due to pulling forces on a body lying on the floor), (iv)* coefficient of sliding friction *(e.g., sliding on the floor with fabric versus direct body-floor contact), (v)* electromagnetic nature of friction *(e.g., exploring non-contact interactions among atomic electrons through varying body dynamics and velocities), (vi)* a frictionless world *(e.g., envisioning scenarios involving uncontrollable sliding or the inability to walk or reach a destination).*

KEYWORDS

Embodied learning, dance-science interdisciplinary approach, informal education, friction

RÉSUMÉ

Cette étude met en lumière comment les dimensions investigatrices et créatives de la danse contemporaine peuvent transformer le concept de friction en un objet d'enseignement et d'apprentissage incarné. Dans le domaine de l'éducation scientifique, la danse a été utilisée pour développer des cadres d'apprentissage kinesthésique, permettant aux apprenants d'appréhender expérientiellement des concepts scientifiques. Nous étudions ici la friction comme concept corporel, visant à générer des motifs cinétiques fondamentaux qui servent à la fois d'outils pédagogiques et de matériaux pour la composition chorégraphique. Pour ce faire, une chorégraphe et une didacticienne des sciences ont collaboré pour explorer les dimensions conceptuelles de la friction à travers des interactions corporelles dynamiques, des pratiques d'auto-observation et des processus réflexifs. Les données, recueillies par enregistrements vidéo et carnets de terrain, ont été analysées via une analyse multimodale. Cette collaboration a produit des structures cinétiques fondamentales correspondant à différents aspects de la *friction, notamment: (i)Friction statique (ex.: ancrage des mains ou pieds au sol) (ii)Friction limite (ex.: diverses prises corporelles) (iii)Friction glissante (ex.: modifications graduelles du mouvement par traction d'un corps au sol) (iv) Coefficient de frottement (ex.: glissades sur tissue vs contact direct peau-sol) (v)Nature électromagnétique de la friction (ex.: interactions non-contact évoquant les électrons atomiques, par variations dynamiques et vitesses corporelles) (vi) Un monde sans friction (ex.: scénarios de glissades incontrôlables ou d'impossibilité de marcher).*

MOTS CLÉS
Apprentissage incarné, approche interdisciplinaire danse-science, éducation informelle, friction

THEORETICAL FRAMEWORK

Embodied cognition posits that cognitive processes are not detached from the body and the environment but instead emerge from their dynamic interaction (Gallese, 2000). According to this perspective, concepts are shaped through bodily experience and practical engagement with the world (Garbarini & Adenzato, 2004; Stolz, 2015). Recent studies in cognitive science, education, and neuroscience (Anderson, 2018; Foglia & Wilson, 2021; Macrine & Fugate, 2022) confirm that movement and sensory stimulation directly influence cognitive processes, thereby revealing the intricate relationship between bodily actions and mental representations. Essentially, the embodied view of cognition rests on the premise that mental representations are materially grounded in sensory and motor experiences (Lakoff & Johnson, 1999). Nonetheless, contemporary research (Dobler et al., 2024) has highlighted that while many cognitive functions are deeply embodied, higher-order levels of abstract thought may operate through more symbolic mechanisms. Still, findings from neuroscience and cognitive psychology suggest that even abstract concepts may retain underlying embodied references (Borghi et al., 2018; Mazzuca et al., 2021). In the field of education, the embodied nature of learning has been implicitly acknowledged for decades. Dewey (1938) argued that knowledge emerges through learners' bodily actions, while Vygotsky emphasized that the body- through physical activities such as gestures, tool use, or labor -serves as the primary medium through which cultural tools and social interactions mediate cognitive development (Glick, 2012). For Piaget (1977), "to know is to act upon reality"; in other words, thought originates in physical actions that later become internalized as abstract operations. Furthermore, the impact of embodied learning has been systematically explored in recent years across science education, mathematics, and STEM/robotics contexts (Chachlioutaki & Pantidos, 2023; Mira et al., 2024; Roth & Welzel, 2001; Weisberg & Newcombe, 2017; Zhang et al., 2024). In the field of science education, alongside cognitive and sociocultural perspectives on learning, trans- and interdisciplinary approaches have emerged that foreground the arts as vital partners in the conceptualization of scientific ideas (Pantidos et al., 2014; Turka et al., 2017). Within this horizon, embodiment redefines learning as an embodied, sensorial, and lived experience, where artistic practice intertwines with scientific inquiry, weaving together new pathways for the creation and negotiation of meaning (Pantidos et al., 2008; Webster et al., 2022).

In science education, multimodal approaches play a significant role in conceptual development, with each semiotic mode (e.g., gestures, images) offering distinct modalities for meaning-making (Chachlioutaki & Pantidos, 2024). Within such frameworks, the human body functions as a critical agent, linking modalities and enhancing conceptual understanding (Hwang & Roth, 2011; Kress et al., 2001). Research has shown that gestures contribute significantly to the conceptualization of scientific ideas, especially at early stages of learning when verbal language may be limited (Roth & Lawless, 2002). Moreover, physical action facilitates the transition from concrete experience to abstract understanding (Hadzigeorgiou et al., 2009), by enhancing kinesthetic memory and perception (Kontra et al., 2012). For instance, college students who physically engaged with concepts such as torque and angular momentum performed significantly better than those who observed passively (Kontra et al., 2015). Similarly, preschool children in hands-on conditions retained their improvements more effectively than those exposed to simulations (Zacharia et al., 2012). Other studies have shown that embodied enactments of phenomena such as shadows or earthquakes lead to substantial conceptual gains (Chachlioutaki et al., 2016; Herakleioti & Pantidos, 2016).

Cognition, in its embodied form, operates largely as a metaphorical process. In science education, metaphors have traditionally been viewed as an effective pedagogical tool for conveying complex scientific concepts. However, theoretical approaches by Lakoff and Johnson (1980, 1999) argue that metaphors are not merely rhetorical devices, but fundamental cognitive mechanisms that shape human reasoning. For these scholars, metaphors go beyond linking two conceptual domains (source and target); they are rooted in bodily experience. From this viewpoint, the understanding of abstract concepts is grounded in basic bodily experiences and sensorimotor actions - a claim that aligns with the broader framework of experientialism.

Niebert et al., (2012), in a study of 199 instructional metaphors used in science classrooms, found that the most effective ones are those whose source domains connect with learners' everyday, embodied experiences. This underscores the importance of linking scientific concepts to bodily actions, without assuming that all bodily experiences necessarily provide productive metaphorical grounding.

Despite this rich theoretical foundation, the relationship between embodied metaphor and pedagogical practice remains unexplored. While there is evidence that grounding scientific concepts in the physical environment can enhance learning, there is still a lack of concrete pedagogical models for implementing this in educational settings. For this reason, the present study turns to dance, a discipline whose epistemology centers on the human body, encompassing artistic, pedagogical, and psychological dimensions. Dance, by its very nature, is a form of embodied investigation and conceptualization. The human body moves through space, constantly searching for the creation of bodily forms, altering rhythm and momentum across different body parts (Coates & Demers, 2019). Furthermore, dance is a cognitive art, in which the body serves as a tool for inquiry, conceptualization, and reflection within choreographic composition and improvisation (Buttingsrud, 2021; Midgelow, 2015; Welch, 2022). In recent years, science education has begun to explore learning environments in which the dancing body becomes a means of inquiry for conceptualizing scientific phenomena such as particles, states of matter, microbes, or chemical elements (e.g., Buono & Burnidge, 2022; Nikolopoulos & Pardalaki, 2022; Solomon et al., 2022). In this context, the present study investigates how the concept of friction in physics can be re-conceptualized and embodied through choreographic composition. The conceptualization of friction through dance emerged within the design of the educational project *Dancing with Physics: Together Apart*, which aimed to connect dance with physical science and the social dimension of coexistence. For the implementation of this project, the embodiment of friction was explored on two levels: (a) the investigation of friction in bodily terms, leading to the generation of fundamental kinetic patterns that could serve both as learning objects and as material for choreographic development, and (b) the teaching of these movement patterns to a group of dancers for the creation of a performance. The present study focuses on the first level, presenting the inquiry process through which foundational kinetic structures were developed, embodying the concept of friction in choreographic terms.

METHODOLOGY

A choreographer and a science educator jointly investigated the conceptual aspects of friction through dynamic embodied interaction, self-observation, and reflective analysis. Therefore, the present study adopts a *self-study-inspired*, *practice-as-research* (PaR) methodology (Nelson, 2022; Vanassche & Kelchtermans, 2015) to investigate how interdisciplinary collaboration between a choreographer and a physicist can generate new understandings of scientific concepts through movement. While self-study traditionally centers on teacher education, we adapted its core elements -systematic self-reflection, iterative cycles of inquiry, and critical dialogue- to an artistic-scientific context (Hamilton & Pinnegar, 2013). Data were collected through video recordings, field notes, and occasional written reflections by the researchers. Both content analysis and multimodal analysis were applied (Chachlioutaki et al., 2016). After each session, the video recordings and field notes from the previous meeting were jointly reviewed to identify critical incidents emerging from the embodied interactions (Halquist & Musanti, 2010; Tripp, 1993), while acknowledging our disciplinary biases: the choreographer prioritizing bodily awareness and kinesthetic meaning-making, and the physicist emphasizing quantification and conceptual precision. The study unfolded across three phases:

Phase 1

The initial phase focused on the kinesthetic experiences generated through the embodied interaction between the two researchers. Rather than relying on their pre-existing conceptualizations of friction -whether from lived experience or scientific knowledge- the researchers initiated a movement-based inquiry. They engaged in bodily experiments involving pulling, bracing, sliding, pushing, and resisting, emphasizing the dynamics of bodily interaction with each other and the floor. The inquiry began with one body seated on the floor and the other standing, slowly pulling the seated one by the arm. This simple kinetic configuration became the departure point for deeper embodied explorations of friction. From the outset, the roles of the two participants were distinct: although the science educator had an informed understanding of friction, he refrained from directly intervening conceptually, instead co-constructing a bodily framework for improvisation with the choreographer. These actions were gradually categorized into the following clusters:

(a) One body seated on the floor while the other attempts to pull it by arms or legs. The roles were alternated with attention to mass differences between the bodies. Questions emerged such as: *What is required to move a body with greater mass? How should I shift my weight while pulling? Does lowering my center of gravity help?* We also explored pulling speed: *How slowly must I pull to allow the seated body to gradually release from the floor's grip?* Once the seated body began moving, new questions arose: *How does its velocity change after the initial breakaway? Does contact area (larger or smaller) affect sliding resistance? How does floor texture influence motion?*

(b) Pushing the seated body from various points. *Is it easier to push or pull a seated or lying body? Why?*

(c) Pulling the seated body by the arms while the standing partner accelerates and releases at the endpoint, allowing the seated body to slide independently.

(d) Pushing or pulling a standing body by acting on different points, e.g., attempting to induce sliding by pushing the ankles of a grounded body. *How can I initiate sliding while the body remains upright? What positional adjustments are necessary?*

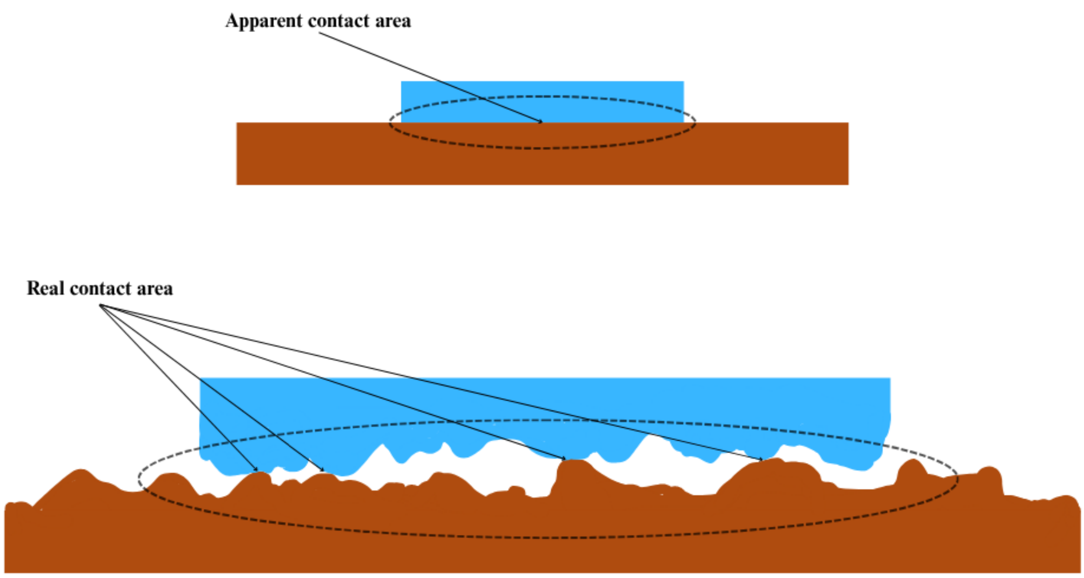
(e) Two bodies leaning on each other, out of vertical alignment, using palms, forearms, shoulders. *How do my feet anchor to support me? How do the surfaces in contact interact? Can I slide from this contact point? Can I push the other body into motion?*

(f) One body in a "spider-like" posture with hands and feet on the ground; the other attempts to shift or release it through pulling or pushing.
(g) Experimentation with modes of locomotion. *What happens to my feet while walking? How do I push the ground to move through space? What if I slip or jump?*
(h) Focus on points of contact—body-to-body or body-to-ground. *How can I draw the viewer's attention to what happens at the contact point?* Movements were slowed dramatically to highlight the moment of release and subsequent slide (e.g., between two hands).

Phase 2
In this phase, the researchers studied how friction is conceptualized in science education material and interactive simulations. Examples include *PhET Interactive Simulations* (https://phet.colorado.edu/sims/html/friction/latest/friction_all.html) and textbooks such as Hewitt (2002) and Halliday et al. (2013).

Phase 3
Finally, the researchers revisited the audiovisual material generated in Phase 1, aiming to conceptually enrich the eight initial kinetic patterns with scientific understandings from Phase 2. Their objective was to identify the embedded conceptual dimensions of friction already present in their movement and to transform or further develop them accordingly. For instance, while studying scientific illustrations depicting the interaction between two surfaces in contact (e.g., Figure 1), they examined how the interlocking of microscopic bumps and hollows initially resists motion (static friction). They then explored, through movement, how this resistance gradually gives way -first at the limit of static friction, and eventually transitioning to sliding friction- as the interlocking diminishes.

FIGURE 1

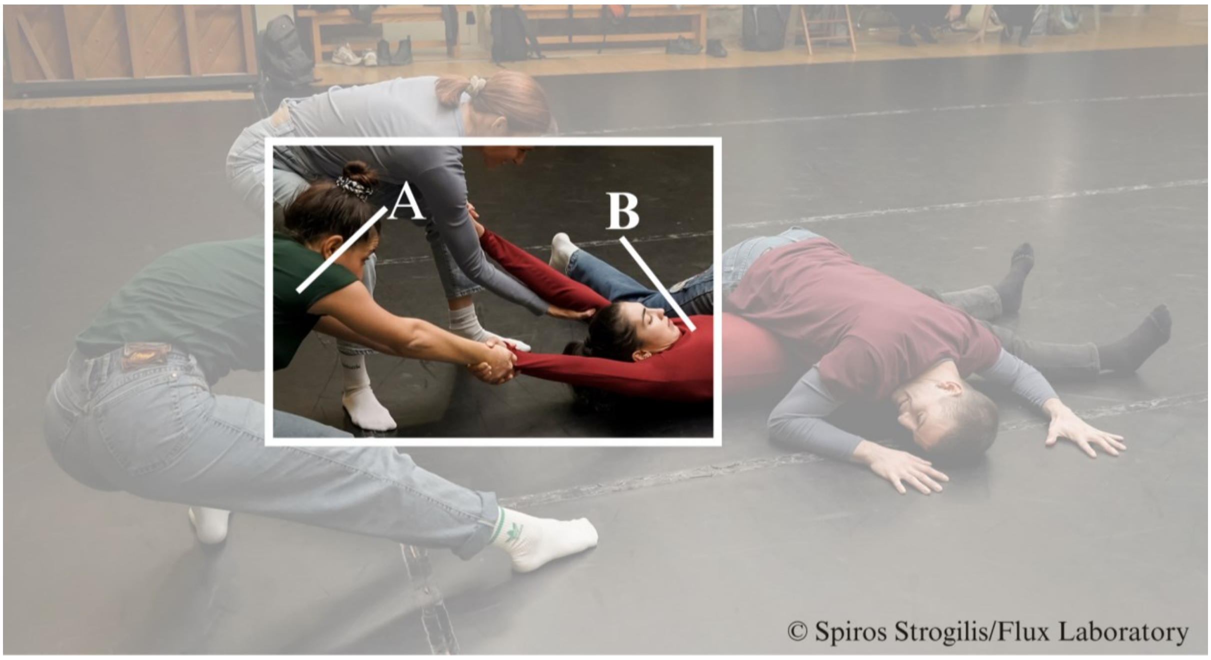


Asperities and troughs of two surfaces in contact

With this scientific understanding in mind, the researchers revisited Action (a) from Phase 1, in which a standing body slowly pulled a seated body across the floor. They decided to slow down the act of pulling as much as possible. The goal was to allow the pulled body to become fully attuned to the subtle experience of resistance and release during the pull. Specifically, attention was directed to how the arm -structurally through its ligaments and muscles, and in relation to the rest of the body, which was anchored to the ground through the contact surfaces- initially resisted the force and was gradually stretched to its limits. This extension eventually led to the progressive disengagement of the whole body from the floor, followed by a controlled sliding motion through space. Another objective was to guide the gaze of a future audience toward the *precise moment of resistance* at the body-floor contact point -just before the sliding begins- as well as toward the subtle tensions that persist throughout the act of sliding. These embodied tensions became central to the researchers' choreographic inquiry.

Figure 2 captures this reinterpreted version of Action (a), as it was ultimately embodied by the dancers during the performance development phase. As noted earlier, following Phase 3, the researchers introduced the movement structures to a group of dancers and collaboratively developed a stage performance within the framework of the *Dancing with Physics: Together Apart* program. In this choreographed scene, two bodies pull a third body that lies prone and immobilized by the additional weight of a fourth body resting on top. Beyond observing the full-body posture and muscle engagement of Dancer A, particular attention is drawn to her arms: fully extended, they are pulling on one of Dancer B's arms, forming a tenuous grip that appears to be held at the limit of physical capacity. This exact moment of gripping serves as a choreographic metaphor for a dimension of friction, and it was emphasized during the performance as a meaning-bearing gesture. Similarly, the hyperextension in Dancer B's arms evokes a state of tension that visually suggests either the moment just before sliding begins or a moment of extremely slow sliding in progress.

FIGURE 2



Dancers embodying action a)

The two researchers had deliberately aimed to avoid employing the scientific knowledge of friction as an explicit, declarative reference. Instead, their intention was to embed conceptual elements kinesthetically into the movement patterns generated during Phase 1. Their objective was to use these transformed movement patterns as a choreographic foundation, informing both the dramaturgical development and final performance composition within the *Dancing with Physics: Together Apart* program. Beyond the scientific conceptualization of friction, the researchers sought ways to allow the movement structures to address aspects of coexistence, which had been chosen as the social dimension metaphorically associated with the scientific concept of friction. For instance, in the aforementioned Action (a), the seated body was associated with the image of a person pinned to the ground -whether by emotional state, lived experience, or circumstance- while the upright figure's pulling motion represented a potential pathway out of this condition. As such, during the choreographic composition process, the transformed movement patterns from Phase 3 were not only enriched with conceptual elements related to physics but were also interwoven with the social metaphor of coexistence, generating a multi-layered interpretive structure.

As previously discussed, during Phase 1, the body generated kinesthetic experiences grounded in the sensory realities of the everyday world. How do we physically respond when someone pulls our arm? Do we resist? Do we surrender? Or do we repurpose the pull into a new body shape, a new spatial trajectory? This mode of inquiry, by definition, excluded any direct embodied engagement with the microscopic world, which remains invisible and inaccessible through ordinary sensory perception and interaction. As a result, in Phase 3, the microscopic dimension of friction -particularly its electromagnetic nature- was approached symbolically. The researchers studied scientific models and then translated particle interactions into bodily interactions, drawing analogies between the arrangement and motion of atomic particles and the arrangement and motion of their own bodies. In this phase, movement patterns were not generated intuitively through bodily exploration alone but emerged through a conscious translation of scientific content into movement. The researchers first studied the electromagnetic basis of friction, and only then engaged in choreographic experimentation to embody this knowledge through spatial relationships, resistance, and contact between bodies.

RESULTS

Through their interactions, the researchers produced foundational kinetic structures for conceptualizing friction about:

(i) static friction:

- Gripping the ground with hands or feet.
- A body trapped between the legs of a standing partner attempting to escape.

(ii) limiting friction:

- Varied bodily holds, extending beyond hand-to-hand contact to include different off-axis connections such as hand to knee or hands to shoulders or shoulder to shoulder.
- A body on the floor experiments with floor resistance, as it tries to move.

(iii) sliding friction:

- Giving acceleration to one body lying on the floor, by pulling it and then letting it slow down by itself until it stops.
- An upright body attempts to drag a grounded body from multiple contact points, generating guided displacement through space.

(iv) coefficient of sliding friction:

- Sliding on the floor with fabric versus direct body-floor contact.
- Sliding on the floor with different fabrics.

(v) electromagnetic nature of friction:

- Bodies moving in distinct patterns without physical contact, referencing the distance between particles.

- Bodies arranged in a configuration resembling that of particles -or rather, the asperities and troughs of two surfaces in contact- gradually sliding (with no contact) over one another.
- Bodies pulsating, at times more intensely and at others more gently, seeking to embody the oscillation of particles and its fluctuations during the phenomenon of friction.

(vi) a frictionless world:

- Imagining scenarios of uncontrollable sliding or the inability to walk or reach a destination. Every movement becomes perpetual motion, every surface an infinite slip ’n’ slide.

DISCUSSION

Dance, as perhaps the most representative system of bodily thinking and action, provides fertile ground for exploring applications of Conceptual Metaphor Theory (CMT) within educational contexts. According to Lakoff and Johnson (1980, 1987), concepts are fundamentally grounded in bodily experience and relate to everything the body does as a physical entity within the environment. This includes displacements through space toward a goal (e.g., walking from home to work), the perception of objects as having an inside, outside, and boundary (e.g., observing a glass of water), the application of forces (e.g., pushing a door open), vertical movement relative to gravity (e.g., going up or down stairs), or maintaining balance and stability (e.g., walking on an uneven surface). Lakoff and Johnson refer to these patterns as image schemas, which they view as fundamental mental structures derived from sensorimotor experience. Over time, such schemas can be extended metaphorically to support the understanding of abstract concepts. Thus, in science education, these image schemas may respectively underpin key concepts: projectile motion, systems, force, convection, and chemical equilibrium. From this perspective, the image schemas that serve as embodied cognitive elements in CMT are particularly tangible as kinesthetic experiences in the discipline of dance. While other physical domains such as physical education may also study bodily action, dance arguably functions in a distinctive way. As a system of embodied signs that generate spatial and temporal forms, dance inherently operates through and with image schemas (Welch, 2022). A dancer—whether in classical or contemporary form—engages in spatial displacements within a group, applies forces toward others or the floor, alternates between grounding and elevating the body through leaps, and strives for balance. These technical elements of natural embodied action, all occurring within an artistic-pedagogical framework, are not replicated in the same intensity or form within other disciplines. As such, the unique combination of artistic intentionality, embodied technique, and multimodal expression positions dance as a compelling field for applying CMT in the study of learning and conceptualization in science education.

The movement patterns generated as foundational structures for the creation of the performance conceptualized friction at multiple levels, depending on the imagined or observed interaction between two bodies in contact. Three levels were identified: (a) Macrolevel: movement structures corresponding to observable interactions, such as a dancer pulling another across the floor, (b) Mesolevel: structures imagining the interlocking textures of the two surfaces, as if viewed through magnification—e.g., various grips involving hands, feet, or limbs, (c) Microlevel: structures expressing the electromagnetic interactions between external electrons of two materials, enacted through dancers simulating particle-like movement and interaction.

From a methodological standpoint, a recurring critical incident in the collaboration was the shared decision that the concept of friction should not be treated in a declarative manner.

The movement structures produced were intended to reflect scientific meaning, but that meaning had to be embedded dramaturgically within an artistic product that emphasized the connection between dance, physics, everyday life, and human relationships. For this reason, in Phase 1, the science educator intentionally withheld all verbal or theoretical input about friction. The only frame introduced to the choreographer was to engage in bodily improvisations based on the principle of two bodies interacting—with each other and with the floor.

From a semiotic perspective, this study can be understood as an attempt to transform or reconceptualize the scientific knowledge of friction by inserting bodily codes into the traditional coding system of the physical sciences. Conventional scientific discourse, especially in educational materials, is heavily mediated through mathematical formalism, terminology, symbolic representations, and abstract inscriptions-codes that are often inaccessible to non-experts. In contrast, this study produced embodied movement structures that conceptualize, in bodily/choreographic terms, aspects such as static friction, the limiting value of static friction, sliding friction, the coefficient of friction, and even a hypothetical frictionless world. These embodied codifications are semiotically distinct from classical scientific inscriptions but nevertheless proved viable as epistemological representations—at least within the research context of this study. The researchers aim to further explore the pedagogical potential of bodily codes, and especially of dance, in engaging learners with scientific concepts through design-based educational research. Furthermore, the codification of friction through the body exemplifies a form of expressive pluralism - that is, the creation of meaning through an alternative semiotic system. As Givry and Roth (2006) argue, this kind of semiotic multiplicity is a marker of conceptual development. Multiplicity does not imply redundancy but reflects the capacity of human cognition to express transformation. Bodies, text, inscriptions (e.g., diagrams, graphs) may refer to the same conceptual object, but the ability to articulate different modalities of a spatial entity -such as a sliding body- is an indicator of advanced spatial intelligence (Goodchild & Janelle, 2010; Hegarty, 2010). More broadly, the ability to transfer knowledge across modalities has been investigated in both biological organisms and artificial systems as a pathway toward improved performance (Orabona et al., 2009; Yildirim & Jacobs, 2013).

This study demonstrates that the investigatory and creative dimensions of contemporary dance can transform the concept of friction into an object of embodied teaching and learning. Such a transformation allows scientific concepts to penetrate informal and non-formal learning environments, while also holding promise for reforming methodologies in formal education settings.

AKNOWLEDGEMENTS

The artistic and educational program *Dancing with Physics: Together Apart* was realized under the aegis and with the financial support of the Hellenic Ministry of Culture and the support of Flux Laboratory Athens. We wish to thank the dancers Anna Anousaki, Petros Nikolidis, Xenia Stathouli and Anastasia Valsamaki for their valuable collaboration.

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