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# Thermodance: a dance-based modeling approach to enhance scientific conceptual understanding and outreach

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**Abstract:** The Thermodance project combines dance and scientific pedagogy to (i) develop modeling approaches based on the participants body movement and interaction, (ii) practice scientific intuition by putting the participants into movement (principles of embodied cognition), (iii) produce immersive outreach activities to engage the public through dance, and (iv) co-create choreographies inspired from the developed body-based models and their underlying scientific concepts. Since 2022, several courses and workshops have been held with students and participants from a wide range of backgrounds. Each occurrence concluded with an open performance during which the audience was invited to actively participate, manipulate, feel and embody scientific concepts through dance. Participants showed great engagement in scientific practice, and self-reported improvements in conceptual comprehension and scientific curiosity. Through this practice, scientists, students, and the general public are invited to focus on feeling, sensations and intuition, offering an alternative and accessible approach to advanced scientific concepts.

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*Keywords:* dance ; physical modeling ; scientific outreach ; embodied cognition ; pedagogic innovation

## 1. INTRODUCTION

Engineering students are trained and selected based on their strong mathematical abilities. In fact, the prevailing scientific teaching approach is to present material in a mathematical format. Consequently, a significant portion of students' efforts and attention is devoted to mastering mathematical formalism, often at the expense of understanding the underlying scientific concepts. Similarly, the general public's perception of science is largely rooted in the belief that mathematics is at the core of scientific practice. The association "science = mathematics" can be a deterrent for some young students who struggle with mathematical representations. While mathematical formalism undoubtedly plays a crucial role in scientific exploration, we argue that a conceptual understanding of many advanced scientific concepts can be developed through less technical, more human-centered approaches.

The Thermodance project pursues a scientific goal: to foster students' physical intuition by harnessing the power of dance to put the body in motion. Grounded in research on embodied cognition (Shapiro and Stolz, 2019; Sevдалис and Keller, 2011), our approach seeks to (a) liberate physical concepts from traditional mathematical formalism, enabling students to represent and manipulate them in a more tangible way; (b) cultivate a bodily intelligence that connects with oneself, space, and others, thereby refocusing learning on personal perceptions and intuitions; and (c) enhance long-term retention of scientific

concepts by integrating declarative (lists of words, facts, concepts...), procedural memory (motor processes), and emotional memory.

Meanwhile, the project's artistic ambition is to develop a novel form of choreographic writing rooted in the lexical realm of scientific concepts. By distilling a poetics from these concepts, we aim to create a non-textual, non-mathematical language that allows us to explore, represent, and experience physical principles in a new way. The artistic co-creation process culminates in public performances, where science is presented to a broader audience in an accessible, inclusive, and engaging artistic form.

The Thermodance project has far-reaching implications for addressing various societal issues surrounding the image of science, from both the public's and students' perspectives. Firstly, it integrates artistic practice into scientific learning, humanizing the image of scientists and repositioning the emotional and creative aspects at the core of scientific inquiry. This enables students to develop a more nuanced, empathetic understanding of physical concepts, empowering them to engage diverse audiences through multiple communication channels. Secondly, the project invites the general public to participate in scientific exploration through an innovative, immersive experience, where choreography embodies physical principles. By presenting science in a format associated with art, creativity, and culture, it transcends the technical barriers that often intimidate non-experts, making it more accessible and

engaging. Lastly, the project contributes to changing society's image of student culture in science and engineering schools, and thus help create a more inclusive environment for students from diverse backgrounds to thrive in scientific studies.

This paper summarizes our experience conducting the ThermoDance project in different contexts over the past three years:

- Fall 2022: 4 workshops of 3h involving 12 students in their 1st year of engineering studies (equivalent 3rd year of bachelor). The goal was primarily a pedagogic one.
- Winter 2022/2023: 5 workshops of 3h involving three of the students from the pedagogic session. The primary goal was an artistic one, resulting in a public representation.
- Spring 2023: a 2h workshop to a dozen of higher education teachers, at the thematic day 'Le futur désirable des jeunes chimistes 2023 : Le temps du CARE' at Sorbonne Université.
- Fall 2023: 5 workshops of 3h, to 10 students of all backgrounds and levels. The main goals were both pedagogic and to create a danced conference for scientific mediation.
- Fall 2023 and 2024: 18h course over a week, involving 15 students in their last year of engineering studies, registered in CentraleSupélec's Research Track. The main goal was to create outreach activities to engage the public about scientific research topics.

In what follows, we first lay the fundamental methodology and give examples of exercises conducted during the workshops. We then illustrate how this approach has been applied for pedagogic innovation, participative scientific outreach, and artistic creation.

## 2. GENERAL METHODOLOGY OF DANCE-BASED MODELING

Here we present the general approach followed in the courses and workshops. Depending on the finality of the activity, this can serve as the basis for pedagogic work, outreach activity creation, and/or artistic co-creation, as detailed in the next sections. Building upon extensive discussions between scientists and choreographers, progressive exercises inspired from the practice of theater and dance were developed, with the aim to connect the participants perception, movements, expression, and interactions, to scientific concepts. A typical session is organized based on the following sequence

### 2.1 Warm-up by progressive introduction of dance elements

The general profile of participants were scientific students, mostly engineers, with little to no experience in dance. One of the first goal was therefore to make the participants feel comfortable moving their body through space, making them aware of their posture and able to interact with each other by defining respectful contact practices. Progressive warm-up exercises were introduced, giving some basic dance vocabulary as well as elements of improvisation (see list of example exercises in Appendix). An important aspect is that all exercises are performed over adapted

music background. This gives a common reference pulse and mind-set to the participants, makes the activity more ludic, and gives them the opportunity to start expressing movement variations inspired by the musics. An example of exercise sequence during the first workshop can be the following:

- (1) Basic warm up exercises while introducing the workshop, the instructors and the participants.
- (2) Balancing the stage (Exercise A.1) to progressively put the participants in movement and waken their awareness of their surrounding.
- (3) Writing in space (Exercise A.3) to activate the different parts of the body, try different orientations and regions in space, introduce some elements of constrained improvisation.
- (4) Equilibrium exercises two by two, where the participants balance each others weight either holding each others forearm, reposing back to back, or shoulder against shoulder. In addition to creating a confidence bond between participants, it helps recognize acceptable zones of contact.

This sequence is of course adaptable depending on the duration of the workshop, involvement of participants, and preferences of the instructors.

### 2.2 Body based scientific modeling

Next, the objective is to transition from exercises to a first body-based scientific model. One of the basic concept that can be quickly illustrated is the one of 'ideal gases':

- (1) The starting point is the stage balancing exercise (Exercise A.1), with the particularity that participants must walk in straight trajectories. This requires that they gently bounce back on the room limits and on other participants when their path intersects. Background music can be helpful to maintain the group's homogeneous pace in beat with the tempo.
- (2) To get a feeling of the number of rebounds against the walls, participants are asked to clap their hands when they bounce against a wall.
- (3) Participants are asked to increase the pace. This can be done by changing the music to a higher beat per minute (or by setting the speed level if variation 2 of Exercise A.1 was previously performed). The pace is then changed again to slow, fast, medium...
- (4) The exercise is stopped, and the participants are asked to explain what they saw, what this might have represented, what they felt.

Through guided facilitation, participants are led to realize that they have collectively modeled a gas, with each individual representing a particle. The facilitators help them understand that the overall clapping noise intensity is a measure of particle bouncing frequency, which is related to the thermodynamic concept of gas pressure. By varying the walking pace, they effectively manipulate the particle agitation, analogous to changing the gas temperature (with a musical thermostat!). As they observe how increased pace (temperature) correlates with higher noise levels (pressure), they can intuitively connect their experience to a qualitative representation of the ideal gas



Fig. 1. Photographs of the public restitution of the workshop mediation through artistic practice, held in CentraleSupélec in November 2024. Here the fundamentals of ferromagnetism and how temperature affects magnetic dipole orientation is illustrated. The public is invited to embody a magnetic dipole and indicate a random orientation with their body (top picture). Then, at given time intervals, they are asked to update their orientation according to their closest neighbors' average orientation. After few time steps, all participants are aligned (bottom picture), illustrating how short range interactions induce a long range order. This basic principle is then extended to incrementally add orientation perturbators, representing rising material temperature, up to a point where no macroscopic order is observable. This workshop introduces a discussion about the nature of Curie temperature in ferromagnetic materials.

law, where pressure is proportional to temperature (under conditions of constant volume and material quantity)

### 2.3 Model refinement and scientific exploration

At this point, it is important to explicit the limitations of this basic model. For instance, the model accounts for particle interactions (humans are not ideal), so the resulting gas is not ideal. This can be used to formulate further questions: what type of gas can it be if it is not ideal? How can the model be modified to account for this? What underlying hypothesis were made? Can we revisit these hypotheses in the setting of our body-based model? As an example, during one of our workshops, such discussion led us to build a model of van der Waals gas, where each participant/particle had an exclusion volume as well as a preferred inter-particle distance. Feedbacks from the participants highlighted that they could 'feel' that compared to ideal gases, the pressure and accessible volume to the particles were modified, in agreement with van der Waals equation.

Importantly, once such body-based model is established and its limits identified, it is then possible to experiment with it. Participants are often quick to suggest to modify the amount of particles in the system, decrease the volume, mix particles of different temperatures... An interesting follow-up experiment on the ideal gas model is when a piston divides the space between a hot and a cold gas compartment. Some participants then model the piston

forming a barrier in the middle of the space, while the rest of the participants are gas particles on either side of the piston. On one side the gas is hot (participants have a fast pace) while on the other side the gas is cold (slow pace). Particles will therefore bounce on the piston at different rate on each side. The participant/piston should not resist the pushes, taking a step in the direction they are pushed every time someone bounces against them. It becomes clear as the experiment unfolds that the hot gas expands while the cold one compresses, as the piston stabilizes at an equilibrium position. Such experiments introduce concepts of work (felt by the piston), thermodynamic equilibrium, heat transfer, entropy..

Many scientific concepts can be approached following the above methodology. Different directions can be given to the activity depending on the finality of the workshop.

## 3. APPLICATIONS AND DISCUSSION

### 3.1 Teaching and modeling through body movement

Here we discuss the pedagogic potential of 'model by dancing' approach to scientific education that offers the Thermodance project. During the fall semester of 2022, a dozen of students (first year of engineering school, equivalent to 3rd year of bachelor) volunteered to participate in 4×3h workshops. All students were enrolled in either course Thermodynamics or Physics of Transfers. During this phase, we went back over the fundamental concepts

seen in class, and set up an approach to modeling these principles through body movement. The topics studied included ideal and non-ideal gases, phase transitions of pure and binary mixtures, heat transfer, laminar to turbulent flow transition, and hydrodynamic boundary layers.

Various dance-based models were co-created with the students, the teacher, and the choreographers. This gave students a means to explore and experiment with scientific concepts without the need for the technicality of either mathematical formalism or experimental apparatus. The limitations of the dance-based models were emphasized and discussed, highlighting the scientific methodology inherent to any modeling approach: hypothesis and model formulation, testing, observation, evaluation of the hypothesis and limitations of the model, adjusting hypothesis and model and so on. Although some models did not satisfactorily represent a physical concept, discussing the reasons and trying to overpass them turned out to be a good exercise.

We propose that the Thermodance project offers pedagogic benefits that complement the advantages of active learning and student-centered approaches (Freeman et al., 2014; Smith et al., 2013). Specifically, our dance-based modeling method has two key advantages. Firstly, it enables science students with tendencies to overly focus on mathematical formalism, to take a step back and refocus on the underlying scientific concepts and mechanisms. Secondly, it provides an alternative pathway for students who struggle with the technical mathematical framework typically used to teach science, allowing them to engage with concepts through observation, action, and sensory experience, and subsequently, to better understand their mathematical formulation. This could, for instance, help biology student majors to collaborate with physicists and mathematicians, and vice versa.

### 3.2 Scientific mediation through artistic practice

The embodiment of scientific concepts through the codes of dance presents a favorable environment to engage a non-scientific public on scientific topics while transmitting an image of scientific practice in contact with society.

We developed a 18-hours workshop entitled "Scientific mediation through artistic practice" based on the Thermodance project. The workshop format was 18 hours in a single week, involving fifteen students in their last year of engineering school (equivalent Masters) specializing in academic research. Two instances of this workshop were held in November 2023 and 2024.

The learning objectives were that at the end of the course the participants would be able to propose a scientific modeling approach through movement, develop modes of scientific mediation that engage with a non-scientific public, link the practice of scientific mediation with artistic practices, and co-construct short participatory performances as a team, addressing current research themes. Throughout the course, each group of participants created a dance-based activity to engage a public over scientific concept. Importantly, the public should actively participate in the activity, embodying part of the concept through their movement.



Fig. 2. Photograph of the rehearsal for the danced conference held in Scene de la Recherche at ENS Paris Saclay in February 2023. This choreography is inspired from phase transition physics, where sticks represent the bounds between particles/dancers allowing them to move fluidly while keeping strong interactions between each others.

The first day of the course was based on the approach described in Section 2. During the first day (6 hours), participants were walked through a series of exercises to make them comfortable moving in space, using basic codes of dance, and interacting with each others. They were then guided to experience some scientific concepts through dance-based modeling, such as ideal gases, phases transitions, and attractive-repulsive interactions of particles. This gave them examples of how to involve a group in a conceptual scientific model, and how to guide the discussion on the limits of the model, and possible improvement. Subsequently, the participants were asked to reflect individually on an advanced scientific concept related to their research interest, before sharing it in small groups. The 2nd day of the course, after warm up exercises, the different emerging topics were discussed with the whole class and groups of four to five students were constituted on each topic.

The rest of the week was then dedicated to a mix of dance inspired exercises (see Appendix) and group work on the topics. The instructors guided the groups to test ideas, suggested techniques or exercises to draw inspiration from, and helped account for mediation concepts. The resulting activities covered a relatively large range of topics including quantum entanglement, tumor cell targeting by immunotherapy, auroras borealis, the central limit theorem, Curie temperature in ferromagnetic materials (see Figure 1), and neutron interactions with matter in nuclear reactors.

Public engagement was excellent in both instances, with feedback explicitly mentioning a better understanding of scientific concepts (self-evaluated). Unfortunately, the homogeneous profile of the public (mostly engineering students in various specialties) did not allow to investigate the effectiveness of the scientific mediation further.

### 3.3 Artistic creation

While the danced-based models require body movement and interactions inspired from the practice of dance, their

finality is scientific or pedagogic. This necessitates being rigorous with the use certain terminologies to communicate concepts. In contrast, artistic creation is largely based on idea associations, ambiguous meanings, and conceptual extrapolations. This is why, during winter 2022/2023, we dedicated 5 workshops of 3h to co-create artistic performances inspired from the danced-based models developed in the previous session. The goal was to remove some of the constraints that scientific rigor imposes, and extrapolate the developed material into choreographies. The result was presented in a 40min danced-conference in the theater Scène de Recherche at ENS Paris-Saclay.

We followed different creative processes. One of them was a reflection on the contrast mentioned above between the rigorous, non-ambiguous mathematics formalism, and the countless nuances of their interpretation into scientific concepts. To illustrate this idea, we went back on one of the most well-known physical equation: the ideal gas law

$$PV = nRT$$

where  $P$  is the gas pressure,  $V$  is the volume occupied by the gas,  $n$  is the number of moles of gas in the volume,  $R$  the perfect gas constant, and  $T$  the temperature. First, each participant wrote a short sentence describing the meaning of this equation according to them. Then, they were asked to create a short choreography that textually transcribed their sentence. The result differed strongly from one another, illustrating how from an unambiguous equation that is universally accepted, interpretation and ways to experience it vary widely from person to person. These choreographies were the basis for a tableau of the public danced-conference.

Another example of choreographic creative process was to draw inspiration from a danced-based model of phase transition. In that model, different types of bounds between particles/participants were explored, and among them, wood sticks held in equilibrium between the participants hands. This inspired a choreography exploring the freedom of movement of the individuals and of the group when all participants are interconnected via such links (see Figure 2). The result gave an impression of constrained fluidity, evocative of a dynamic drop of liquid. The choreography was performed in public over the recorded voice of a lecture on phase transition.

#### 4. CONCLUSION

We introduced a novel scientific modeling approach that leverages dance and theater practices to foster conceptual understanding and scientific intuition. Following an overview of our methodology, we demonstrated its application across three domains: pedagogic innovation, scientific outreach, and artistic creation. Through a series of exercises, we guided participants in developing choreographic propositions that embodied scientific concepts, thereby facilitating a shift from internalized understanding to external, dynamic expression. This process enabled the concepts to be observed, heard, and experienced in a tangible, living flow.

Although we did not conduct quantitative assessments, the feedback from participants and the public was over-

whelmingly positive, with self-reported improvements in conceptual comprehension and scientific curiosity.

The Thermodance approach exhibits promising potential to engage diverse audiences. It can be adapted for middle school and high school students, inspiring individuals with artistic inclinations to pursue scientific careers. Additionally, it can facilitate interdisciplinary collaboration between physicists, biologists, and social scientists. Furthermore, our approach can be tailored to address global health issues in academia by integrating artistic and creative practices rooted in science. In this vein, a current initiative inspired from Thermodance and addressed to PhD candidates is underway at Université Paris-Cité (Heuzé et al., 2025).

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#### Appendix A. SOME EXERCISES PERFORMED IN THE THERMODANCE WORKSHOPS

This non-exhaustive list of exercises illustrates some basic activities to quickly make participants comfortable moving in space, interact with each others, improvise, and start to relate some body movement activity to scientific context. The order in which the exercises are presented in the list is arbitrary. It has been observed that a tasteful choice of accompanying music is associated with better participant engagement.

### A.1 Stage balance

This exercise is mostly inspired from theater practice. Participants are asked to walk in the room to collectively occupy all the available space. This simple task activates the body, make the participants aware of the others and of the space surrounding them. It forces them to adjust their gaze to anticipate their and the others trajectories, improving their awareness of the surrounding. Multiple variations of this exercise can be performed:

Variation 1: At a given signal, all participants must freeze in space. Once the principle is understood, participants can choose individually to stop walking. As soon as one notice someone frozen, they freeze in turn. This exercise allows to practice body control, anticipation, and awareness of the surrounding.

Variation 2: The instructor defines different moving speeds that everyone has to follow, say from 1 slow-motion walking to 5 running. The participants are then instructed to switch from one speed level to another as a group. Attention is kept on maintaining group speed cohesion and fluid trajectories.

### A.2 Attraction/repulsion

This exercise builds on the stage balance activity and allows to introduce some scientific concepts such as dynamic systems, attractive/repulsive forces between particles...

The participants are walking in space following the stage balance exercise. Then they are asked to choose one person in the room while continuing walking and without saying it. They are then told that a given signal, they must try to be the furthest away in the room from the chosen person. Generally, the resulting dynamic is that participants spontaneously form a relatively of stable vortex.

Variation 1: A possible variations is to choose a person to be the closest to. This leads the participants to form a compact amalgam (some previous exercises to make participants comfortable being in contact with each others might be necessary).

Variation 2: One of the most interesting variation is to ask to choose two participants, and then instruct them that they must 'protect' the first person from the second by always positioning themselves in between the two. This leads to a continuously moving system with short-lived stable configuration.

It is important to properly debrief the activity, possibly asking some participants to step aside to watch the dynamics and comment on it afterwards.

### A.3 Writing in space

This exercise can be done with little prerequisite to introduce efficiently some elements of improvisation, body movement dissociation, and different plans of movements.

The basic idea is to imagine having a pen on one part of the body and to write something in space with it. It is advised to introduce the exercise progressively, and to ask to write very concrete words, sentences, or even equations.

For instance, the participants can be told that they have a pen on their elbow, and to write their name (or a word, an equation, or anything else concrete) in space with it. All levels of space should be proposed, up, down, sides, middle... Participants can write different sizes, and progressively move their whole body in space to write big letters more easily. Then the pen can switch successively to the top of the head, to the knee, to the hips, to the nose... Finally, they are given the freedom to switch when they want to any part of the body in a continuous movement.

### A.4 Quality of air/ground

In this exercise the participants must imagine evolving in a different environment, such as replacing air with water or honey, experiencing the gravity as if on the moon, having the legs in mud... For participants who are not comfortable yet with improvisation, the exercise can be performed on an basis of Exercise A.3. The participant should feel and make the observers feel like their movement is resisted by the appropriate texture. This exercise helps perceive the 'quality' of the surrounding. It also practices controlling individual parts of the body as well as slow motions. It can also help introduce some basic scientific concepts such as viscosity, inertia, the Reynolds number, gravity...

### A.5 Fall of objects

This exercise aims at improving observation and reflect on properties of matter. The principle is simple: the participants choose an object among for instance feathers, pieces of fabrics, sheets of paper, crushed sheets of paper, plastic bags, paper bags... Then they drop the object from shoulder height, and observe the way it falls and lands on the ground. They must then imitate the dynamic, trajectory, rhythm, and overall 'quality' of the object. Training on falling and ground work additionally benefits this exercise. Some discussion about basic scientific concepts can be introduced, such as gravity, aerodynamics, elasticity, viscoelasticity, mechanical behavior...

### A.6 Circle of improvisation

This exercise helps with basic improvisation, observational skills, and group cohesion. However it requires the participants to already be comfortable moving in space and around each other. It is therefore recommended to wait at least until the second workshop to proceed with this exercise.

The participants form a large circle with enough space between everyone so that everyone can see each other. Some energetic music is recommended. One participant is designated as the leader, and start dancing/improvising freely on the music, while all the others imitate its movements as close as possible. It is recommended to start with relatively easy and clearly readable movements. After some time, the leader gestures to another participant to become the leader, and so on until every participant has been the leader. It is important that each participant remains the leader long enough (about a minute).