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Aikido and Basic Physics: The Application of Aikido as a Strategy to Improve the Understanding of Physics Concepts in Basic and Higher Education

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Abstract
This article proposes an innovative interdisciplinary analysis that explores conceptual correspondences between the principles of Aikido, a Japanese martial art developed by Morihei Ueshiba, and the fundamentals of basic physics, particularly the laws of conservation, force, and mass. Through a comparative methodology, we demonstrate how the concepts of energetic flow (Ki), dynamic balance, centralization, and circular movement in Aikido offer valuable pedagogical analogies for comprehending complex physical principles such as energy conservation, angular momentum, fundamental constants, and Noether's symmetries. The results suggest that this integrative approach not only enriches the teaching of physics for students at various levels but also provides a conceptual framework that facilitates the transition between intuitive-embodied and abstract-mathematical knowledge. We conclude that incorporating martial arts-based metaphors, particularly Aikido, represents a promising pedagogical strategy for teaching theoretical physics, potentially increasing engagement and deep conceptual understanding in educational contexts.

Keywords: Aikido, Physics, Conservation Laws, Physics Teaching, Interdisciplinarity, Basic Education, Higher Education

1. Introduction

Theoretical physics, with its high degree of mathematical abstraction, often poses significant challenges for students and even for the scientifically literate public (Angell *et al.*, 2004) [1]. Simultaneously, there is a growing interest in incorporating embodied and experiential approaches in science teaching (Niebert *et al.*, 2012) [13]. In this context, martial arts, particularly those that emphasize principles of harmony and dynamic balance, emerge as potential sources of pedagogical analogies for fundamental physical concepts.

Aikido, developed by Japanese master Morihei Ueshiba (1883-1969) in the first half of the 20th century, distinguishes itself from other martial arts by its emphasis on harmonizing with the opponent's energy rather than directly opposing it. Its fundamental principles include the efficient use of energy (Ki), circular movements, centralization, and maintaining dynamic balance (Ueshiba, 2007) [21]. Notably, these principles present conceptual parallels with the fundamentals of basic physics, particularly the laws of conservation and equilibrium.

This article systematically investigates these correspondences, proposing an integrative model that utilizes Aikido principles as a conceptual framework for understanding and teaching fundamental physical concepts. Our central hypothesis is that the embodied experience of Aikido principles can serve as a cognitive bridge to understanding abstract physical concepts, facilitating the transition between intuitive-experiential knowledge and formal-mathematical comprehension.

2. Theoretical Framework

2.1 Aikido

Aikido is a modern Japanese martial art developed by Morihei Ueshiba, also known as O Sensei, during the 20th century. It emerged from a combination of various traditional Japanese martial art techniques, including Daito-ryu Aikijujutsu, kenjutsu (the art of the sword), and jojutsu (the art of the staff), among others.

The history of Aikido is deeply tied to the life of Morihei Ueshiba. He began his martial arts journey as a dedicated practitioner of different styles, seeking to refine his understanding of combat techniques and the underlying philosophy. However, over time, Ueshiba became more interested in finding a way to use martial arts not only to defeat opponents but also to promote peace and harmony.

In 1925, Morihei Ueshiba founded the "Ueshiba Juku" dojo in Tokyo, where he began teaching his own techniques, which eventually became known as Aikido. Over the following years, he continued to develop and refine his art, gaining a devoted following and expanding his influence.

After World War II, Morihei Ueshiba and Aikido gained even greater recognition and popularity. He established the "Aikikai Hombu" dojo in Tokyo, which became the official center of Aikido and a training institution for students worldwide.

A distinctive characteristic of Aikido is its emphasis on nonviolence and peaceful conflict resolution. Instead of stressing direct confrontation and aggression, Aikido teaches self-defense techniques based on harmonizing with the opponent's movement and efficiently utilizing energy.

Today, Aikido is practiced worldwide by millions of people from diverse cultural backgrounds and is recognized not only as an effective martial art but also as a path for personal development, spirituality, and inner peace. Morihei Ueshiba's legacy continues to live on through the many Aikido practitioners and masters who pass on his teachings and values to future generations.

2.2 Physics Applied to Aikido

Physics applied to Aikido provides a fascinating perspective on how fundamental physical principles are employed in a martial art that emphasizes harmony and nonviolence. In Aikido, practitioners aim to effectively control and redirect the opponent's energy using techniques that incorporate essential physics concepts.

One key principle of physics applied to Aikido is the conservation of momentum and energy. During the execution of techniques such as Irimi Nage, Kaiten Nage, and Kokyu Nage, practitioners leverage the opponent's momentum and energy to perform projections and immobilizations. These techniques clearly demonstrate how the opponent's kinetic energy can be efficiently transferred and redirected instead of merely dissipated or directly opposed.

Additionally, the intelligent use of the center of gravity and balance is essential in Aikido. When executing techniques, practitioners maintain a low and stable center of gravity, ensuring a solid base to resist the opponent's attacks and maintain control of the situation. This reflects fundamental physics principles, where an object with a low center of gravity is more difficult to displace.

Another important aspect of physics applied to Aikido is the understanding of angular momentum and energy transfer. In techniques involving rotations, such as Kaiten Nage, practitioners use angular momentum to amplify rotational movement and effectively project the opponent. This demonstrates how physical principles related to rotational motion can be practically applied in combat situations.

Beyond bodily techniques, the use of traditional weapons in Aikido, such as the Bokken (wooden sword) and Jo (staff), also provides valuable insights into physical principles. Practicing with these weapons teaches practitioners to strategically manipulate and control kinetic energy, demonstrating how these concepts can be applied in various combat contexts.

In summary, physics applied to Aikido offers a unique perspective on the practical and effective use of fundamental physical principles in a martial art that values harmony, nonviolence, and conflict control. By understanding and applying these principles, Aikido practitioners can enhance their technical skills and deepen their understanding of the world around them.

2.3 Embodied Approaches in Science Education

The theory of embodied cognition posits that cognitive processes are deeply rooted in the body's interactions with the environment (Lakoff & Johnson, 1999) [10]. In the educational context, this perspective suggests that understanding abstract concepts can be facilitated through concrete physical experiences and body-based metaphors (Wilson, 2002) [23].

Research in science education has demonstrated the effectiveness of embodied approaches to teaching physical concepts. Scherr *et al.* (2013) [15] documented how activities involving bodily movements can enhance the understanding of mechanics concepts. Niebert *et al.* (2012) [13] analyzed how body-based metaphors facilitate the comprehension of abstract scientific concepts.

This work combined the experience of a physics teacher, who is currently a shodan (1st Dan black belt) in Aikido, with colleagues in training and teaching at different education levels—higher education for engineering students and basic education for high school students, yielding positive results in both contexts.

2.4 Fundamental Principles of Aikido

Aikido is founded on specific philosophical and biomechanical principles that distinguish it from other martial arts. Key principles highlighted include:

- **Ki (vital energy):** A central concept representing the energy flow that permeates all things. In Aikido, practitioners learn to sense, direct, and harmonize with this flow (Saotome, 1993) [14].
- **Hara (centralization):** Refers to maintaining awareness and control of the body's physical and energetic center, located approximately three fingers below the navel (Stevens, 1997) [20].
- **Circular Movement:** Utilizing circular trajectories to redirect the opponent's force rather than opposing it directly (Westbrook & Ratti, 2001) [22].
- **Dynamic Balance:** Maintaining stability while in motion, continuously adapting to changes in external forces (Shioda, 1991) [17].

2.5 Fundamentals of Physics

The conceptual pillars of basic physics analyzed in this study include Energy, Torque, Center of Mass, Levers, and Circular Motion.

Martial arts offer an excellent opportunity to analyze and apply physics. Aikido, in particular, is filled with levers, rotations, and projections. The physical concepts applicable to Aikido can also be applied in engineering and across the foundation of Newtonian mechanics, widely studied by students in Basic Education.

Throughout this article, we explore the most relevant physical concepts for students and the techniques applied to achieve this objective.

3. Methodology

This study employs a qualitative comparative methodology, identifying and analyzing conceptual correspondences between Aikido principles and the fundamentals of modern physics. The analysis was structured into three phases: Identification of Principles**,** Comparative Analysis**,** and Development of the Integrative Model.

3.1 Identification of Principles

A systematic review of the literature on the fundamental principles of Aikido and the core concepts of Basic Physics.

3.2 Comparative Analysis

Establishing conceptual correspondences between the identified principles, focusing on structural and functional analogies.

3.3 Development of the Integrative Model

Development of a pedagogical framework that uses the identified correspondences as a foundation for teaching physical concepts. The validity of the proposed correspondences was evaluated based on criteria of conceptual coherence, pedagogical relevance, and explanatory potential, as established by Gentner (1983) [7] for the evaluation of scientific analogies.

4. Results and Discussion

4.1 Ki and Energy Conservation

The concept of *Ki* in Aikido has significant correspondences with the principle of energy conservation in physics. In Aikido, *Ki* is conceived as energy that flows, transforms, but never disappears-it only changes form or direction. This conception closely aligns with the first law of thermodynamics, which states that energy cannot be created or destroyed, only transformed.

When an Aikido practitioner executes a technique like **irimi-nage** ("entering throw"), they do not block the attacker's force but move with it, redirecting it in a circular motion. This principle of non-opposition and redirection perfectly illustrates energy conservation: the attacker's kinetic energy is not negated (which would violate conservation) but transformed and redirected.

This correspondence offers a powerful embodied analogy for teaching the principle of energy conservation. Students can physically experience how energy transforms but remains conserved, creating a concrete basis for understanding this abstract concept.

4.2 Hara and Fundamental Constants

The concept of *Hara* (center) in Aikido can be analogically related to fundamental constants in physics. Just as the *Hara* represents an invariant reference point from which all effective movements originate, fundamental constants represent invariant values that define the basic characteristics of the universe.

In Aikido, the practitioner must maintain awareness of their *Hara* regardless of the complexity of movement or intensity of the attack.

This analogy facilitates the understanding of the role of fundamental constants as "anchor points" in a universe of continuous change. Just as an Aikidoka always returns to the awareness of their center during practice, physicists always return to fundamental constants in the formulation and application of physical laws.

4.3 Circular Motion and Angular Momentum

The principle of circular motion in Aikido directly corresponds to the concept of angular momentum and its conservation in physics. In Aikido, circular movements are used to redirect the opponent's force with minimal effort, leveraging principles of levers and momentum.

Techniques like **tenkan** (pivoting movement) clearly demonstrate the conservation of angular momentum. When the practitioner rotates around a fixed point (usually one foot planted on the ground) while maintaining contact with the attacker, they essentially create a two-body system that conserves its total angular momentum.

This correspondence allows for an intuitive understanding of angular momentum conservation through embodied experience. Students can literally feel how angular momentum transfers and remains conserved during rotational movements, creating a concrete foundation for the abstract mathematical concept.

4.4 Ma-ai and Space-Time Relations

The concept of *ma-ai* (appropriate spatial and temporal distance) in Aikido presents interesting parallels with physics. In Aikido, *ma-ai* is not merely a physical distance but a dynamic space-time relationship between practitioners that determines the optimal moment for action.

This conception resonates with the idea that space and time are not separate entities but interconnected aspects of a single structure. The ideal *ma-ai* is relative to the specific situation, the practitioners involved, and the technique being employed.

The embodied experience of *ma-ai* in Aikido provides a base for understanding the interconnectedness of space and time in physics.

4.5 Symmetries and Balance

Aikido's principles of balance offer valuable analogies for the concept of symmetry in physics. In Aikido, balance is not a static condition but a dynamic state constantly adjusted in response to external forces. Similarly, symmetries in physics are not merely geometric properties but fundamental invariances of physical laws under certain transformations.

When an Aikido practitioner maintains their balance while moving, they demonstrate a form of invariance—their stability is maintained despite changes in position or orientation. This invariance under transformation precisely defines symmetry in physics.

Noether's theorem, which establishes the connection between symmetries and conservation laws, finds an embodied analogy in Aikido practice. Just as each symmetry in physics corresponds to a conserved quantity (e.g., temporal symmetry corresponds to energy conservation), each principle of balance in Aikido corresponds to an effective technique.

4.6 Integrative Model for Physics Teaching

Based on the identified correspondences, we propose an **integrative model** for teaching fundamental physical concepts using Aikido principles as the conceptual framework. This model operates on three levels:

1. **Experiential Level:** Introducing physical concepts through exercises based on Aikido principles, allowing students to physically experience the principles before their mathematical formalization.
2. **Analogical Level:** Explicitly establishing correspondences between the experienced principles and formal physical concepts, using embodied experiences as a foundation for building mental models.
3. **Formal Level:** Introducing the mathematical formulation of physical concepts, anchored in the previously established experiences and analogies.

This model aligns with Kolb's experiential learning theory (1984) [9] and constructivist approaches that emphasize the importance of connecting new knowledge to existing conceptual structures (Ausubel, 2000) [2].

5. Pedagogical Applications

5.1 Integrative Exercises

We propose a series of integrative exercises incorporating Aikido principles for teaching specific physical concepts:

1. **Energy Conservation:** Redirection exercises where students experiment with how the energy of a movement can be transferred and transformed without being "destroyed."
2. **Angular Momentum:** Circular motion exercises where students observe how angular velocity increases as the distance to the rotation center decreases (similar to the effect of a figure skater pulling their arms closer).
3. **Symmetries and Conservation Laws:** Exercises demonstrating how certain properties remain invariant during specific transformations, illustrating the connection between symmetry and conservation.

5.2 Case Studies

We present two preliminary case studies where this approach was implemented—one at the higher education level and the other in basic education (high school).

5.2.1 Introductory Physics Course for Undergraduate Students

The incorporation of Aikido-based exercises was instrumental in introducing classical mechanics concepts, resulting in better conceptual retention and increased student engagement. These exercises were conducted by Sensei and Applied Physics to Engineering professor Huemerson Maceti at the Hermínio Ometto Foundation University Center – FHO.

Some of the topics addressed in class include the following examples, illustrated in the figures below:

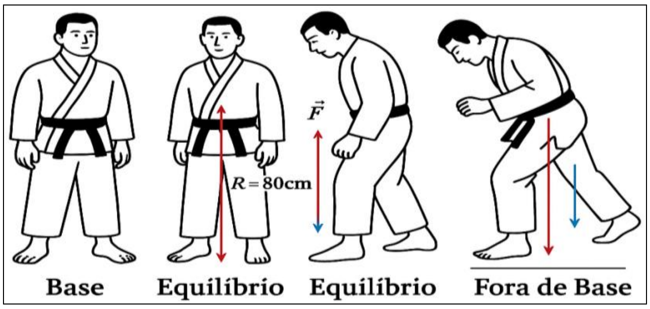


Fig 1: Center of Mass and Equilibrium

Students explored the concept of equilibrium, focusing on the relationship between the base of support and the center of gravity, as well as potential imbalances. The discussion extended to engineering problems (e.g., statics).

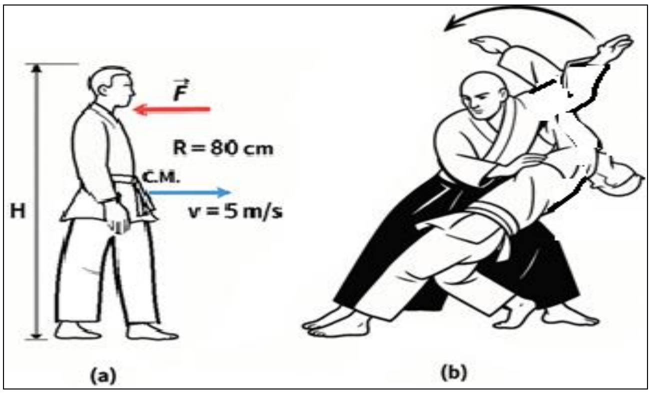


Fig 2: Torque and Angular Momentum

This activity related a person's body dimensions to the position of the Center of Mass (C.M.), the velocity of the person, and the point where a force (*F*) is applied (e.g., neck), creating Torque or Moment of Force. This approach enabled students to engage not only with torque concepts but also with angular momentum and its implications, extending the learning to rotational motion in engineering.

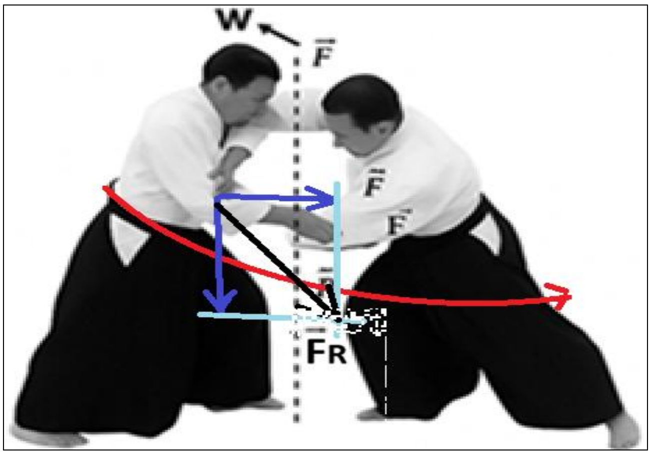


Fig 3: Centripetal Force and Resulting Forces

In this example, students analyzed the application of centripetal force and weight during a rotational technique. The represented technique (likened to a helical motion) combines the rotation of the opponent while pushing them downward, enhancing the resulting forces acting on them.

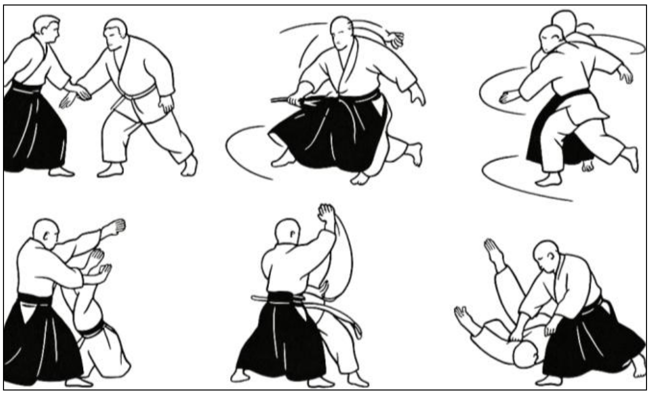


Fig 4: Irimi Nage Technique

During the Irimi Nage technique, a practitioner enters the opponent's space and performs a projection. Students in the first year of engineering were asked to explain how momentum and energy conservation apply to this technique and how the practitioner utilizes the opponent's movement to execute the projection.

Expected answer: In Irimi Nage, momentum and energy conservation are applied when the practitioner moves into the opponent's space. By redirecting the opponent's motion, the practitioner utilizes the momentum and energy of the attack to execute the projection. This is achieved by synchronizing with the opponent's movement and applying a directed force amplified by the attacker's momentum and energy.

Fig 5: Kokyu Nage Technique

In this technique, students explored the physical concepts of center of gravity and balance.

Proposed discussion: How does controlling the center of gravity influence the effectiveness of this technique? How does proper breathing contribute to balance and stability during the execution of Kokyu Nage?

Expected answer: In Kokyu Nage, controlling the center of gravity is essential for technique effectiveness. Maintaining a low and stable center of gravity allows the practitioner to resist the opponent's attacks and remain balanced throughout the technique. Correct breathing contributes to balance and stability, enabling the practitioner to use their energy efficiently.

5.2.2 "Physics and Aikido" Workshop for High School Students

The use of Aikido demonstrations to explain physics concepts to the general public, with positive feedback regarding the accessibility and clarity of explanations, proved very effective for high school students. The event was held at **Colégio Puríssimo Coração de Maria** in Rio Claro/SP, with the participation of students and senseis from "Aiki Kaizen Rio Claro" alongside physics teachers and students from the school.

The activity began with a vector lesson, including geometric constructions using rulers, compasses, protractors, and set squares, from which geometric and trigonometric properties were derived, as illustrated in Fig 6.

Fig 6: Introductory Geometry Class: Applying Vectors in Martial Arts

After the initial geometric analysis, students were introduced to some physics topics applied to martial arts, such as Energy, Linear Momentum, Center of Mass, and Moment of Force. Subsequently, the students participated in a practical demonstration, as shown in Figs. 7, 8, and 9.

Fig 7: Demonstration of Physical Concepts in Aikido

Fig 8: Demonstration of Physical Concepts in Aikido

Fig 9: Demonstration of Physical Concepts in Aikido

In **Fig 10**, we can see the space used for the workshop, which included mats, a projector, and a turntable for illustrating Angular Momentum.

In **Fig 11**, students experimented with the effect of Angular Momentum on a turntable while holding weights. They extended and retracted the weights (by stretching and bending their arms), experiencing firsthand the principles of angular momentum conservation.

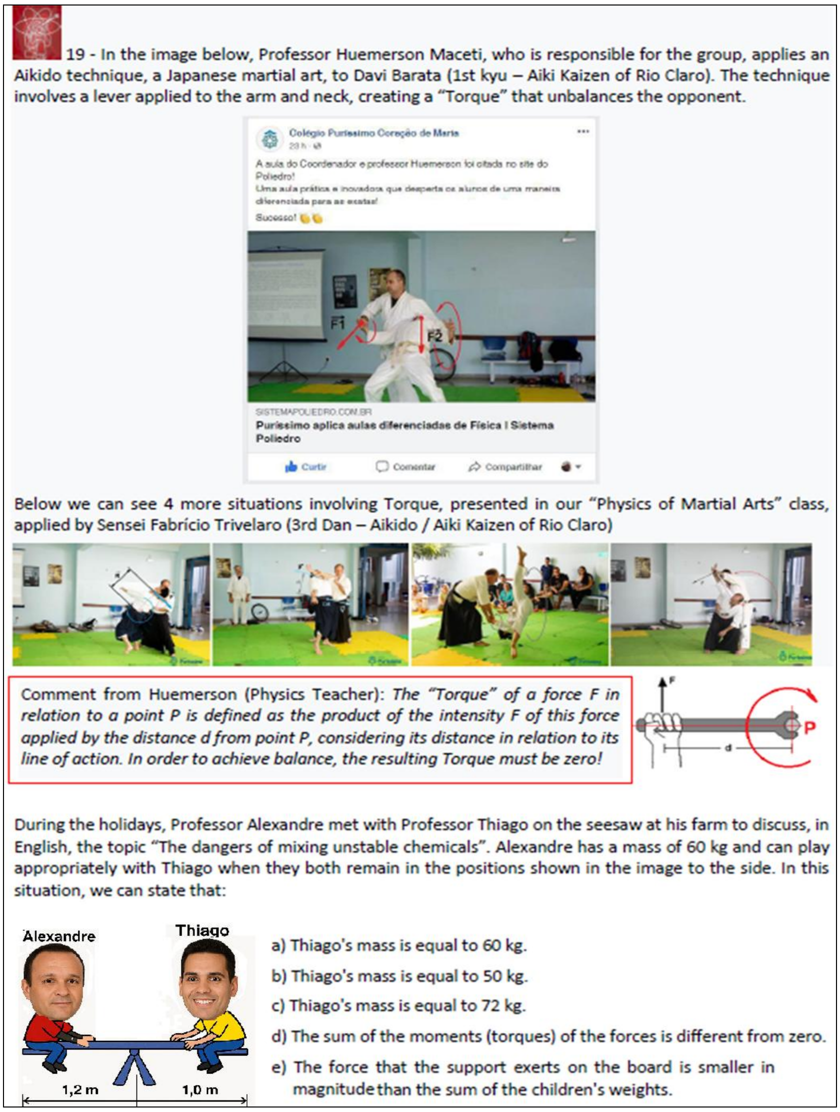
Fig 12 showcases Senseis Davi Barata, Fabrício Trivelato, Hélio Hoshina, and Huemerson Maceti from **Aiki Kaizen Rio Claro/SP**, the dojo that organized the Aikido workshop for high school students. The extensive experience of Senseis Fabrício and Hélio was particularly crucial in ensuring precise movements that allowed for accurate observation of Applied Physics principles.

The school also has a merit-based entrance exam for high school called **“O Mérito é Todo Seu!” ("The Merit is All Yours!")**, which included questions involving Aikido. One such question from the exam is shown in **Fig 13**.

Fig 10: Workshop Space Setup

Fig 11: Experiencing the Effects of Angular Momentum Conservation

Fig 12: Davi (1st Dan), Fabrício (4th Dan), Hélio (2nd Dan) and Huemerson (1st Dan) - Senseis from Aiki Kaizen – Rio Claro – Workshop Organizers



19 - In the image below, Professor Huemerson Maceti, who is responsible for the group, applies an Aikido technique, a Japanese martial art, to Davi Barata (1st kyu – Aiki Kaizen of Rio Claro). The technique involves a lever applied to the arm and neck, creating a "Torque" that unbalances the opponent.

Below we can see 4 more situations involving Torque, presented in our "Physics of Martial Arts" class, applied by Sensei Fabrício Trivelaro (3rd Dan – Aikido / Aiki Kaizen of Rio Claro)

Comment from Huemerson (Physics Teacher): *The "Torque" of a force F in relation to a point P is defined as the product of the intensity F of this force applied by the distance d from point P, considering its distance in relation to its line of action. In order to achieve balance, the resulting Torque must be zero!*

During the holidays, Professor Alexandre met with Professor Thiago on the seesaw at his farm to discuss, in English, the topic "The dangers of mixing unstable chemicals". Alexandre has a mass of 60 kg and can play appropriately with Thiago when they both remain in the positions shown in the image to the side. In this situation, we can state that:

a) Thiago's mass is equal to 60 kg.
b) Thiago's mass is equal to 50 kg.
c) Thiago's mass is equal to 72 kg.
d) The sum of the moments (torques) of the forces is different from zero.
e) The force that the support exerts on the board is smaller in magnitude than the sum of the children's weights.

Fig 13: Question from the "O Mérito é Todo Seu!" Exam

6. Multidisciplinary Discussions

Further discussions addressed topics such as self-defense and the use of physics in martial arts. Other martial arts, including Jiu-Jitsu, Capoeira, Boxing, Karate, and Judo, were incorporated into the debate, recognizing the diversity of students who practice these martial arts.

These pedagogical innovations demonstrate the potential of integrating martial arts principles into physics education. This approach enhances student engagement, fosters deeper conceptual understanding, and connects theoretical concepts with practical experiences relevant to students' interests and everyday lives.

7. Conclusion

This article presented a systematic analysis of the conceptual correspondences between Aikido principles and basic physics fundamentals, particularly conservation laws, universal constants, and symmetries. The results demonstrate that these correspondences provide a valuable pedagogical framework for teaching complex physical concepts.

The proposed integrative approach represents a bridge between embodied-experiential knowledge and abstract-mathematical understanding, potentially easing the cognitive transition that many students find challenging. By grounding abstract physical concepts in concrete bodily experiences, this approach can make theoretical physics more accessible and meaningful.

We conclude that incorporating Aikido principles, along with those from other martial arts, into physics teaching not only enriches the educational experience but also honors the integrative vision of Aikido's founder, Morihei Ueshiba. Ueshiba frequently highlighted the connections between his art and the universal principles of nature. As he himself once stated:

"Aikido is the realization of love. You must love nature and the universe itself as your own being" - a philosophy that resonates deeply with physics' endeavor to achieve a unified understanding of the cosmos.

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- Aiki Kaizen Aikido School – Rio Claro
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