Entropy Theory in the Context of Physics Education

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Abstract: Entropy, initially a concept in thermodynamics describing the degree of disorder in a system, has been extended to information theory and non-equilibrium thermodynamics. The article proposes that the physical classroom teaching system can be viewed as a dissipative structure, promoting the orderly development of students' cognition through openness, non-equilibrium states, and fluctuation mechanisms. Specific strategies include opening up teaching content and methods, creating non-equilibrium state experiments, introducing cognitive fluctuations, and utilizing non-linear effects. These approaches help to stimulate students' desire for knowledge, optimize the teaching process, and achieve efficient physical classroom teaching.

Keywords: Entropy Theory, Physics Teaching, Dissipative Structure, Open System, Non-equilibrium State

1. Introduction

In the exploration of innovative paths in physics teaching, entropy theory offers a unique perspective. Entropy, a concept originally belonging to physics, has transcended the boundaries of natural science and permeated into the fields of social science and even pedagogy. This article aims to elaborate on how entropy theory guides the construction of a more efficient and orderly physics teaching model. By applying the principles of entropy theory to teaching practice, we can better understand the dynamic changes in students' cognitive systems and adopt corresponding strategies to promote students' in-depth understanding and application ability of knowledge. The introduction will briefly introduce the basic concepts of entropy theory and how it is related to the construction of physics teaching models, revealing a new teaching philosophy and method for readers.

2. The Concept and Significance of Entropy Theory

Entropy is a concept that has been continuously deepened and generalized and can be divided into four developmental stages.

The first stage: It originated from the thermodynamic equilibrium state function $\delta S = \frac{\delta Q}{T}$,constructed by the German physicist Rudolf Clausius in 1865, which means the ratio of heat to temperature, used to express the second law of thermodynamics. Later, Ludwig Boltzmann linked entropy with the microscopic state function of the system, providing a statistical interpretation of the entropy concept, making entropy a measure of the degree of disorder in the system organization. Clausius proposed the principle of entropy increase in his paper "On the Nature of the Motive Power of Heat."

The second stage: In 1944, the founder of quantum mechanics, Erwin Schrödinger, introduced the concept of negative entropy, suggesting that living organisms need to continuously absorb negative entropy to counteract the increase in entropy produced in life, maintaining themselves at a stable low-entropy level.

The third stage: In 1948, the founder of information theory, Claude Shannon, expanded the microscopic concept of S to the field of information. In his classic paper "A Mathematical Theory of Communication," he used axiomatic methods to propose the concept of information entropy, measuring

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the uncertainty of information source signals in the communication process. Using probability theory, he defined the negative entropy theorem of information: an open system that acquires information is equivalent to absorbing negative entropy, which can reduce the system's uncertainty and disorder and tend to be orderly; when information is lost, the system's entropy increases, and the degree of disorder increases accordingly. Therefore, information and entropy are complementary to each other, information is equivalent to negative entropy, and entropy is the measure of the information lost by the system.

The fourth stage: Nobel Prize winner, Belgian scientist Ilya Prigogine, began with the definition of entropy in non-equilibrium systems, introducing a series of new concepts. He expanded thermodynamics from equilibrium to non-equilibrium states and further to far-from-equilibrium states, ultimately proposing the theory of dissipative structures, which caused a revolution in the field of macroscopic physics. This theory is a product of the deepening of the concept of entropy, a science that studies the nature, stability, and evolution of dissipative structures using the methods of thermodynamics and statistical physics. Its research object is open systems, discussing the mechanisms, conditions, and laws of the system's transformation from chaos to order. The theory of dissipative structures posits that: an open system far from equilibrium, supplied continuously by the external environment with energy and matter, when a certain parameter in the system reaches a critical value through "fluctuations," will break the original equilibrium structure and enter a state of disorder far from equilibrium. At the same time, the system begins a higher-level reorganization in time and space, thereby generating a tremendous super energy of the system, and ultimately the system will spontaneously enter a new state of dynamic, functional order. Dissipative structures require continuous "renewal," that is, continuous exchange of matter and energy with the external environment to maintain their orderly state. In the theory of dissipative structures, entropy and order are two main concepts. The formation of dissipative structures requires three conditions: first, the system must be an open system far from equilibrium; second, there are non-linear interactions between different elements of the system; and third, fluctuations lead to order.

The concept of entropy has evolved to the point where it has far exceeded its initial rigorous scientific applications, transforming from a thermodynamic concept that simply described the micro-world into a concept that spans natural and social sciences. For instance, by integrating entropy and dissipative structure theory from thermodynamic systems with business management, the principle of increasing entropy illustrates the evolution of management systems from order to disorder, fundamentally explaining the necessity of business management. According to the theory of dissipative structures, the evolution of management systems from disorder to order fundamentally explains how enterprises should be managed.

3. Construction of a Physics Teaching Model Guided by Entropy Theory

The physics classroom teaching system is a complex open system composed of multiple factors. The interactions among its internal elements satisfy non-linear relationships and are far from equilibrium. Moreover, under the inducement of fluctuations, the system can continuously structure and stratify, thus moving from disorder to order. Therefore, the physics classroom teaching system is a dissipative structure, and the principles of entropy theory can be applied to try to construct an optimized physics teaching model.

The cognitive system of students can also be regarded as a dissipative structure. The process of students' knowledge learning is essentially a process of continuous transition of a dissipative structure from low-level order to high-level order: with the continuous input of new knowledge, students' cognitive structures also continuously achieve self-enrichment and stratification. Entropy theory believes that a dissipative structure far from equilibrium must open up to the outside world and frequently exchange matter, energy, and information with the environment in order to move from a low-level state to a high-level state, and from disorder to order. Since the reduction of the total entropy value of the system can only be achieved under the influence of the external environment, it is necessary to first maximize the openness of the system. Therefore, the primary task of the physics teaching model guided by entropy theory is to create an open teaching environment. Creating an open system is to enable the system to better enter a higher level of orderly state. To achieve this goal, a non-equilibrium state should also be created to break the original low-level orderly state of the system. Prigogine believed that non-equilibrium is the source of order. A teaching system with internal dynamics and external vitality must be a heterogeneous and non-equilibrium system with differences. Triggering students' cognitive conflicts and stimulating their desire for knowledge through the transformation to order is an effective method of creating a non-equilibrium state and being far

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from equilibrium. It can be seen that the second procedure of the physics teaching model guided by entropy theory is to create a non-equilibrium state. In fact, while creating a non-equilibrium state, fluctuations are also introduced into the system. Fluctuations lead to order, emphasizing the decisive role of fluctuations in achieving system order when the non-equilibrium teaching system has the objective conditions for forming a dissipative structure. Applying the fluctuation mechanism to the teaching system is to seize the small fluctuations in the teaching system or to take some appropriate measures to create small fluctuations, and through non-linear effects, make the fluctuations grow from small to large, from local to global, and develop into huge fluctuations, promoting the system to jump to a new orderly state. Non-linear effects play an important role in system upgrading. "Non-linear and linear are relatively independent relationships. Linear actions have the characteristics of independence, symmetry, and uniformity, which can make the evolution of things tend to be rigid and monotonous; while non-linear actions have the attributes of relevance, non-uniformity, and asymmetry." The relationships between teachers, students, and teaching media exhibit typical non-linear characteristics. The relationship between the three changes with the environment, making full use of the changes in environmental information, using them to promote the reform of the teaching system, spontaneously adjusting their relationships with each other, optimizing the teaching process, and moving towards order.

4. Interpretation of the Elements of the Physics Teaching Model Guided by Entropy Theory

4.1. Establishing an Open Teaching System

4.1.1. Opening Up Teaching Content

Effectively promoting the evolution of students' thinking, abundant curriculum resources are crucial. Physics teaching should be open to the frontiers of physics, beyond textbooks, beyond the classroom, and open to students, breaking down disciplinary barriers to achieve interdisciplinary permeation, while also diversifying evaluation methods and standards.

In teaching, the grasp of teaching materials not only needs to be accurate but also needs to be open. For example, in the teaching of the concept of "inertia," after students understand and master the concept of inertia, it is appropriate to loosen up and introduce the past and present life of the concept of inertia: as physical research deepens, people's understanding of the essence of inertia is continuously developing. First, Galileo proposed the concept of inertia through inclined plane experiments; then Newton developed Galileo's ideas on inertia, established the law of inertia, and proposed the view of "absolute space"; then Mach, in his criticism of absolute space, put forward the idea that "inertia originates from gravity"; on this basis, Einstein established the general theory of relativity, believing that inertial motion is free motion in curved spacetime. With the advancement of cutting-edge research, following the thoughts of past masters, one can directly step into the essence of contemporary views on space and time.

4.1.2. Opening Up Teaching Methods

The opening up of teaching methods entails the rational coordination of various teaching approaches to fully engage students' multiple enthusiasms. Therefore, teachers should not only integrate traditional, intuitive, demonstrative, narrative, discussion-based, and experimental teaching methods but also make full use of multimedia computers for their ability to disseminate large amounts of information, provide vivid images, simulate experiments that are difficult to operate manually, quickly process experimental data, and represent knowledge in multiple ways. To adhere to the openness of teaching, it is necessary to play to strengths and avoid weaknesses by using a variety of teaching methods comprehensively.

For instance, when teaching the topic of "wave patterns," various intuitive teaching methods are employed to overcome the difficulty of abstraction. Demonstrations of various wave phenomena such as water waves, rope waves, and spring waves are shown first; then, a wave demonstrator is used to simulate the formation of transverse and longitudinal waves, guiding students to observe the motion of individual particles, adjacent particles, and the entire mass of particles; next, computer courseware is utilized to demonstrate the fluctuation of transverse and longitudinal waves, as well as the motion of individual particles; finally, metaphors or analogies in language are also used to further deepen students'

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understanding of waves. For example, to illustrate the characteristic that particles do not "drift with the waves" during the wave process, Einstein once made an analogy: "A rumor travels to Edinburgh, but the person who started the rumor did not travel back and forth between the two places." The "rumor wave" is not a physical wave, but it has the basic characteristics of a wave: it has a source, a medium, and a propagation mechanism.

4.2. Creating a Non-equilibrium Teaching System

As a discipline fundamentally based on experimentation, physics education emphasizes the construction of students' cognitive systems through non-equilibrium processes from an experimental perspective. Practical experience in experimental teaching has shown that novel, unique, and fascinating phenomena demonstrated during the experimental process can effectively immerse students in an eager state of problem-solving, known as a "fervent and frustrated" state. This persistent "fervent and frustrated" state of students is an indication that their thinking is far from equilibrium.

4.2.1. Novelty Experiments

Psychological research indicates that when the human brain is exposed to the stimulation brought about by novel phenomena, a dominant excitation center emerges, placing the brain in a state of intense and pleasurable activity. Consequently, the novel and unique phenomena demonstrated during the experimental process often provide a strong sensory stimulus to students, placing their thinking in a non-equilibrium state.

For instance, when studying the topic of "total internal reflection of light," we first have students observe a "silver light bulb" submerged in water, which shines with a silver glow, looking quite distinctive and piquing the students' interest significantly. Then, after removing the light bulb from the water and having students observe it again, they exclaim in surprise, realizing it is just an ordinary incandescent light bulb with no remarkable appearance. Observing these novel experimental phenomena, along with the strong stimulus perceived, effectively places students in a non-equilibrium state.

4.2.2. Puzzling Experiments

"Thought begins with questions and surprise." Questions are the driving force behind students' acquisition of knowledge; it is through doubt that inquiry and active thinking occur. In physics experimental teaching, the strong cognitive conflicts caused by puzzling experiments can effectively create a non-equilibrium state of thought.

For example, when studying the topic of "momentum theorem," the teacher demonstrates the "Falling Egg from a Height" experiment: an egg is suspended by a thin thread, raised to a height using a support and pulley, and then released to fall. The first time it lands on a table, the egg breaks; the second time it lands on a thick foam mat, it remains intact. While the students are astonished and cheering, their thinking is stimulated to deviate from equilibrium, generating a desire to learn and explore.

4.2.3. Contradictory Experiments

Some physical experiments present results that contradict students' prior knowledge or the predicted phenomena, and the "self-contradictory" outcomes that arise under different conditions can often put students' thinking in a dilemma, a situation where they feel trapped and unable to proceed or retreat. This encourages students' thinking systems to move away from a non-equilibrium state and achieve a higher state of order.

For example, in teaching the measurement of resistance using the "voltage-amperage method," students initially react indifferently because their previous learning has told them that these two types of circuits are equivalent. To break this equilibrium and stimulate contradiction, the following contradictory experiment is conducted: A large demonstration ammeter is used to measure the resistance of the same large resistor with both types of circuits, yielding measurements of 5.2kΩ and 2.0kΩ; then the same small resistor is measured, with results of 5.0Ω and 3.6Ω. The significant discrepancy in the measurement results creates a strong external stimulus, quickly engaging the students' thinking.

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4.3. Emphasizing the Trigger Mechanism of Thought — Introducing Fluctuations

Fluctuations represent a transition, mutation, or disturbance, manifesting in innovative thinking as "giant fluctuations" such as intuition, inspiration, and sudden enlightenment. During the teaching process, if teachers can actively create a conducive thinking environment, they can effectively induce the occurrence of "giant fluctuations" in students' thinking. Therefore, teachers should be attentive and grasp various "fluctuation" phenomena inside and outside the teaching system in a timely manner, promoting the system's evolution towards directions that favor the formation and development of branches, and preventing the emergence of a chaotic state in the teaching system.

For example, in the teaching of "electromagnetic oscillation," after the teacher sets up the scenarios of Figure 1(a) and (b) for students to think about, a quick-thinking student might ask, "What if the charged capacitor and inductor are connected?" After the teacher affirms the creativity of the question, they project Figure 1(c) circuit, asking students to expand their thinking and bring up any possible questions, viewpoints, opinions, and ideas for evaluation by their peers and for reference in subsequent teaching.

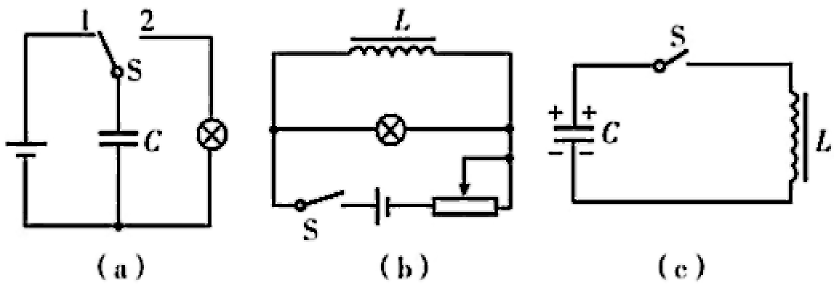

Figure 1: Teacher's Projection

Student A: The current is at its maximum the instant switch S is closed because the capacitor is charged to its fullest, and the voltage is at its peak.

Student B: The current is zero the instant switch S is closed due to electromagnetic inertia, and the current in the circuit gradually increases.

Student C: The current in the circuit definitely changes non-linearly. The theoretical study of the pattern of change is beyond our knowledge scope. Can it be visually displayed through certain instruments?

Student D: The current in the circuit is at its maximum when the charge on the capacitor is zero. At this point, the electric field energy is entirely converted into magnetic field energy in the coil. The magnetic field energy is directly related to the magnetic field B, which in turn is directly related to the current that generates the magnetic field.

Student E: If the initial charge on the capacitor, capacitance, and inductance are all known, what is the maximum value of the current in the circuit?

Student F: The current in the circuit must change periodically, and the period must be related to the capacitance C, inductance L, and the initial charge on the capacitor. What is the relationship?

Creating a supportive and friendly teaching atmosphere, allowing students to enjoy the joy of free thinking in a psychologically safe environment, effectively promotes the occurrence of "giant fluctuations" in thinking, thereby achieving autonomous inquiry-based learning and the transformation of physical concepts.

4.4. Utilizing Non-linear Effects

Non-linear interactions can generate synergistic effects among the various elements of a system, enabling it to evolve from disorder to order, undergoing qualitative changes. The intrinsic driving force behind this is the synergy within the system. Synergy is a universal characteristic of systems; without it, systems would disintegrate under environmental interference, their structure and hierarchy would be damaged, and their functions would vanish or be greatly weakened. In physics classroom teaching, it is good to utilize non-linear effects to promote synergistic interactions among the system's elements. In

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practical teaching, it is necessary to coordinate teaching objectives, teacher-student relationships, and both classroom and extracurricular activities.

For example, during a research-based learning process on "Factors Affecting the Magnitude of Friction," I divided the tasks among students with different intelligence types, as shown in Table 1.

Table 1: Activity Assignment Table for Students with Different Intelligence Types

Types of Intelligence	Main Activities Involved
Linguistic Intelligence	Accurately describe the process and conclusions of physical experiments, integrate materials collected by the group, and draft speaking outlines.
Logical-Mathematical Intelligence	Participate in the design of experimental plans (differentiating between sliding friction and static friction, using the control variable method), analyze experimental data, and summarize experimental conclusions.
Interpersonal Intelligence	Mainly responsible for leading group discussions, raising questions, organizing group cooperation, distributing and collecting materials. Coordinate the work of various groups.
Bodily-Kinesthetic Intelligence	Conduct interviews, gather experimental materials, operate hands-on experiments, and participate in information retrieval.
Intrapersonal Intelligence	Mainly responsible for evaluating collected materials, the experimental design plan, and the experimental conclusions, as well as writing research reports.
Naturalist Intelligence	Participate in general procedures and methods such as searching for information, collecting, processing, manufacturing, and presenting, observe and record experimental phenomena and data.

This teaching method integrates three teaching organization forms—full-class teaching, small group learning, and independent study—in an organic way. This form of synergistic teaching composition is not only conducive to improving teaching quality but also meets the individual learning needs of students. It encourages students to strive for full and extensive information exchange between "person and object," "person and person," and "self and self," achieving a new higher level of balance through the processing of information.

By constructing a physics teaching model in line with the developmental characteristics of students using entropy theory, the essence is to apply entropy theory to continuously introduce various negative entropy flows from outside the physics teaching system and constantly suppress the internal entropy generation of the system itself. This will reduce the total entropy value of the entire physics classroom teaching system and ultimately promote a giant fluctuation throughout the system. This shift allows the physics classroom teaching system to leave its original stable state and transition to a new stable and orderly state, forming a new optimized structure. After experiencing a "chaotic disorder," the physics classroom returns to a clear and orderly state, achieving efficient teaching movements in physics education.

5. Conclusion

By incorporating entropy theory, we have not only optimized teaching strategies but also stimulated students' cognitive potential and facilitated their in-depth understanding of physical concepts. The practice of this teaching model has shown that the introduction of openness, non-equilibrium states, and fluctuation mechanisms has brought new vitality and innovation to physics education. We emphasize that the ultimate goal of education is to cultivate students' innovative thinking and lifelong learning abilities. The teaching model guided by entropy theory is an important step towards this goal. With the continuous advancement of educational technology and the ongoing renewal of educational concepts, we look forward to entropy theory

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playing an even greater role in future teaching practices, helping students to continuously explore, discover, and create new possibilities in the ocean of knowledge.

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