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Why We Need to Fully Grasp Newton's Laws: A Call for Deeper Insight

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ABSTRACT
Regular disciplinary instruction of introductory physics at high school often misses a holistic perspective of the subject matter, its structure and hierarchy. We have considered the domain of mechanics and provided such a perspective in a summative lecture by framing mechanics contents in discipline-culture framework. In the experimental teaching, we focused on Newton's laws of motion as the nucleus of classical mechanics. Considering mechanics as a culture, that is, addressing the debate with periphery conceptions[1], caused students to appreciate the fact that mechanics is about theory of motion, while forces present only a certain conception to account for it.

I. Introduction

In the journey of learning, both educators and learners share the common goal of achieving the intended learning outcomes. This expectation holds true in the lecture process, where lecturers aim to convey knowledge effectively, and students aspire to grasp and apply the concepts [1]taught. The formulation of lecture objectives is carefully designed, taking into account the desired learning outcomes to foster comprehensive understanding.

A core challenge in science education is constructing meaningful knowledge that transcends rote memorization, promoting a holistic grasp[2] of the subject matter. Science, by its very nature, is built upon a hierarchical structure of theories, where new discoveries often prompt the reconsideration of previous concepts. However, conventional teaching methods tend to present scientific theories as fixed and absolute, overlooking the ongoing conceptual debates that drive scientific progress.

Recent research advocates for the inclusion of conceptual variation in science education, creating learning spaces that allow students to engage with the dynamic nature of scientific knowledge. The discipline-culture (DC) [3] structure of a theory offers a promising framework for this approach. It organizes knowledge into three layers: the nucleus, which consists of fundamental concepts; the body, which includes broader principles; and the periphery, which addresses contrasting perspectives and unresolved debates. This peripheral knowledge, often referred to as cultural content knowledge (CCK)[4], enriches students' understanding by exposing them to the evolving nature of scientific theories.

The use of summary lectures as delay organizers represents an innovative application of the DC structure in science education. Initially implemented in the teaching of optics, this approach has now been extended to the domain of mechanics—typically the first theory encountered by high school[5] students in physics. This study presents the design and implementation of summary lectures aligned with the DC framework, examining their impact on students' conceptual understanding of Newtonian theory as a comprehensive theory of motion. The findings highlight how this method fosters a more nuanced appreciation of scientific knowledge, preparing students to engage critically with future advancements in the field.

II. Background

We have analyzed the commonly used 11th-grade high school textbooks for teaching mechanics [6], along with *College Physics* [7], which serves as a comparable English-language reference. These textbooks, along with the associated teaching practices, present physics concepts in a sequential order — starting from basic ideas and progressing to more advanced topics. They cover laws, concepts, models, experiments, and applications. The primary focus is on solving standard problems to help students grasp the concepts and apply them both qualitatively and quantitatively.

However, these textbooks typically present the content without organizing the concepts into a clear, hierarchical framework. Newton's laws are introduced as rules that explain the relationship between forces and motion, but little emphasis is placed on the fact that these laws represent a broader theory explaining motion. Although some textbooks mention that mechanics studies the "nature of motion," their explanations tend to treat forces as the main cause of motion changes, making force the central focus [8].

This way of presenting knowledge — as a collection of disconnected facts — gives students the impression that learning physics is simply about accumulating more and more information. As a result, students struggle to understand which concepts are more fundamental or how the ideas fit into a larger framework. The heavy focus on preparing for standardized exams reinforces an *instrumental understanding* — where students learn to solve problems mechanically without truly understanding the underlying principles [9].

Important aspects like the relationship between theory and reality, the role of models, the limits of laws, and the historical development of scientific knowledge are often left to students' intuition rather than explicitly explained. There is usually little discussion about how scientific ideas evolved, why certain models were adopted, and why others were discarded. Without this broader context, students often develop misconceptions about the relationship between force and motion.

III. Structuring Scientific Knowledge through Delay Organizers in the Discipline-Culture Framework:

To enhance traditional teaching methods and present knowledge in a more structured way, the triadic model was proposed to organize disciplinary knowledge in physics [4]. This model aims to arrange knowledge elements hierarchically while incorporating alternative ideas from the historical development of physics. The triadic Discipline-Culture (DC) structure consists of three key components: the nucleus, representing fundamental principles and core concepts; the body, including derived theoretical laws, empirical models, solved problems, and experiments; and the periphery, encompassing alternative or competing concepts that challenge the nucleus. This structured approach helps students view classical mechanics not just as a collection of facts but as a unified theory of motion.

By classifying knowledge elements into these three layers, the model encourages students to develop conceptual knowledge — understanding the meaning, significance, and interrelations of the concepts they learn. Each concept is linked to a particular layer of the triadic structure, helping students appreciate its role in the broader scientific framework. This approach highlights hierarchical, relational, and methodological aspects of knowledge, promoting cultural content knowledge (CCK) — the understanding of both scientific facts and the nature of scientific knowledge itself [3].

The challenge lies in how to apply the DC model effectively to support students' construction of CCK. Levrini and colleagues [5] introduced a summary lecture in high school optics courses, using it as a delay organizer — a tool designed to consolidate and organize previously taught content. This report investigates the implementation and evaluation of a delay organizer in teaching classical mechanics, a foundational subject in school physics that forms the basis of scientific understanding.

IV. The Experiment : Design and Execution of the Study

In the initial phase of the study, a summary lecture was designed to highlight the nucleus of mechanics within the high school curriculum. The lecture, lasting 90 minutes (a double period), focused on the relationship between theory and nature, the scope of theory validity, and the role of principles, models, and laws in physics, all supported by reliable academic sources. The lecture incorporated the Discipline-Culture (DC) perspective into the mechanics curriculum.

To create the summary lecture, a thorough review of high school textbooks was conducted to identify the core components of the nucleus and body commonly presented in schools. Additionally, selected periphery elements were introduced to expose students to alternative concepts. The experimental teaching was applied to a representative group of 11th and 12th-grade students, along with preservice science teachers from an educational college. The participants' knowledge was assessed before and after the lecture.

The experiment followed a structured sequence: a pre-test questionnaire, the summary lecture, a post-test questionnaire, a classroom discussion one week later, and clinical interviews with selected students based on their verbal performance during discussions. The questionnaires were open-ended to accommodate the novelty of the teaching approach and to gain insights into its impact. The questions were adapted from previous studies [5], where they had proven both valid and effective.

The research addressed several key aspects:
1.Students' holistic perception of classical mechanics.
2.Understanding of fundamental scientific knowledge elements (concepts, theories, laws, and models).
3.Conceptual grasp of selected mechanics problems.
4.Awareness of theory validity and correctness in physics.
5.Interpretation of what constitutes proof in physics.
6.Alternative conceptions in mechanics.
7.Students' confidence levels regarding their knowledge.

Additional dimensions emerged during classroom discussions and were included only in the post-instruction questionnaires and interviews. Each topic was assessed through multiple questions to improve reliability and provide a comprehensive view of students' understanding using a triangulation approach. The questionnaires were administered during regular class periods, each lasting 40 minutes. The experiment took place at the end of the academic year, following the completion of the mechanics curriculum.

V. Format of the Study

The study involved **78 participants** from diverse educational backgrounds, including upper secondary school students and preservice science teachers. The participants were divided into six groups based on their educational level and institution type, as presented in **Table 1**.

Table 1: Study Sample Overview

Group	Code	Number of Participants (Pre-Test)	Number of Participants (Post-Test)
Preservice Teachers(College 1)	T1	15	14
Preservice Teachers (College 2)	T2	8	8
Grade12(Science-Dedicated Class)	S12d	12	10
Grade 12 (Regular Class)	S12r	25	18
Grade11(Science-Dedicated Class)	S11d	10	9
Grade 11 (Regular Class)	S11r	8	7
Total		**78**	**66**

Sample Diversity

To enhance representativeness, the sample included students from two common school types:

- **Regular Schools**: Providing general education programs.
- **Science-Dedicated Schools**: Offering specialized curricula with a focus on science education.

Preservice teachers were drawn from two educational colleges, representing different regions across the country. This diversity ensured the inclusion of participants from varying socio-economic and academic backgrounds.

Consistency in Teaching

Despite being taught by different instructors, all groups followed standardized curricula. Preliminary checks confirmed that the participants exhibited similar academic performance and social diversity, making the sample a reliable representation of the broader student population.

Study Timeline

The experiment was conducted over **one academic year**, involving:

- Regular instructional sessions
- Classroom observations
- Group discussions
- Pre- and post-test assessments
- Data collection and analysis

This structured approach provided a solid framework to evaluate the impact of the *Discipline-Culture* model on students' conceptual understanding of mechanics.

To evaluate the understanding of Newton's Laws of Motion among 16 physics teacher candidates, a comprehensive test was conducted. The results indicated an average score of 52.6, with the highest score recorded at 85 and the lowest at 25. This performance falls within the low-to-moderate category, suggesting that most candidates faced considerable challenges in accurately applying Newton's Laws to various problem-solving scenarios. Identifying the specific areas of difficulty is essential to enhance conceptual understanding.

A detailed analysis of the students' common misconceptions and errors is summarized in Table 2.

Table 2: Summary of Student Competency in Newton's Laws of Motion

S.No	Competency Assessed	Percentage of Incorrect Answers (%)
1a	Identifying a constant force required to accelerate a particle when mass, initial velocity, and final velocity are known.	0
1b	Calculating the magnitude of the force in the above scenario.	0
2a	Determining the position of a particle when the initial force and initial position vector are known.	72
2b	Calculating the velocity of the particle at any later time.	68
3a	Determining the position vector of a moving particle in a force field with given initial position and force field parameters.	96
3b	Calculating the velocity of the particle at any later time in the same force field.	95
4a	Identifying the constant in the equation of a conservative force field.	25
4b	Determining the potential energy within a conservative force field.	87
5	Evaluating whether a given force field equation represents a conservative force field.	34

The data highlights that the most prominent difficulties were related to force fields and dynamic systems. Nearly all students struggled with determining both the position vector and velocity of particles in the presence of force

fields, with error rates exceeding 95%. Additionally, understanding the concept of potential energy in conservative force fields proved challenging, with 87% of students answering incorrectly.
These findings suggest the need for a more structured instructional approach focusing on vector analysis, force field applications, and energy conservation principles. Interactive learning methods such as simulations, group discussions, and problem-based activities can help reinforce these concepts. Regular assessments combined with immediate feedback would further support conceptual clarity and improve overall student performance.

VI. Lecture Summary: Newton's Laws and Classical Mechanics

Designing a concise summary lecture on classical mechanics was a challenging task, as it required selecting only the most fundamental concepts. Focusing on these key concepts is essential to building a solid understanding of classical mechanics, as they form the basis from which more complex ideas and applications are developed. The core focus was placed on **Newton's Laws of Motion**, which form the backbone of classical mechanics.

The lecture began by contrasting Newtonian mechanics with earlier theories, such as the **Aristotelian and medieval views of motion**. These earlier models influenced the development of Newtonian mechanics by proposing that motion required a continuous force, a concept that dominated scientific thought for centuries. Newton's laws marked a paradigm shift by introducing the idea that motion could persist without continuous force, laying the foundation for modern mechanics. These older models often described motion in terms of natural tendencies without fully understanding the forces involved.

The **First Law of Motion (Law of Inertia)** was presented as the cornerstone of Newtonian mechanics. This law defines **uniform motion (or rest)** as the natural state of a body, which only changes under the influence of an **external force**. This idea marked a significant departure from earlier views, where continuous force was thought necessary to maintain motion.

The **Second Law of Motion** provided a quantitative formulation, linking the applied force to the rate of change of momentum, expressed as **F = ma**. This law is considered a cornerstone of classical mechanics because it not only defines the relationship between force and acceleration but also allows for the prediction of an object's motion under various forces. It provides the mathematical framework that connects dynamics and kinematics, making it essential for solving a wide range of mechanical problems. This law builds upon the First Law by describing how the velocity of a body changes when a force acts on it.

The **Third Law of Motion** expanded the discussion to systems of interacting bodies, establishing that **every action has an equal and opposite reaction**. This principle is key to understanding the mutual influence between objects in motion.

Alongside these laws, the lecture introduced essential concepts grouped into two categories: **Fundamental Quantities** and **Interaction Principles**. The **Fundamental Quantities** included **point masses**, **instantaneous velocity and acceleration**, and **inertial mass**, which describe the properties of physical systems. The **Interaction Principles** encompassed **force as the cause of continuous change in motion**, **gravitational interaction between masses at a distance**, and **absolute time and space** as independent entities. This grouping highlighted the interconnected nature of these concepts in the Newtonian framework.

- **Point masses** to simplify physical systems
- **Instantaneous velocity and acceleration**
- **Force as the cause of continuous change in motion**
- **Inertial mass** as a measure of resistance to motion
- **Gravitational interaction** between masses at a distance
- **Absolute time and space** as independent entities

The lecture concluded with the introduction of **mechanical energy** and its **conservation laws**, derived from Newton's principles. These laws not only explain how energy transforms and remains conserved within mechanical systems but also serve as a bridge between Newtonian mechanics and broader physical theories, such as thermodynamics and electromagnetism. These ideas provided a deeper understanding of how energy transforms and remains conserved within mechanical systems, reinforcing the unified structure of classical mechanics.
This approach emphasized the pivotal role of the First Law, not merely as a special case of the Second Law, but as a fundamental principle that reshaped our understanding of motion and forces.

VII. Data Processing

The data collected from both the prior- and post-intervention assessments yielded comprehensive insights into students' understanding of classical mechanics. The data was analysed using both qualitative and quantitative methods, providing a multi-dimensional evaluation of the applied teaching approach.

Qualitative Analysis

The qualitative analysis involved a systematic examination of students' responses, with particular attention to their explanatory patterns and problem-solving strategies. The initial step in this process was the categorisation of students' answers based on the concepts and reasoning methods they employed. These categories were designed to represent distinct levels of conceptual knowledge in mechanics, ranging from basic factual recall to more advanced, integrated understanding.

Grouping the responses into these categories allowed us to identify recurring patterns and representative views that characterised students' pre-existing knowledge structures. The analysis highlighted the predominant misconceptions, alternative conceptions, and correct understandings held by the students. This categorisation further facilitated the recognition of shifts in conceptual knowledge following the intervention, offering valuable insights into the efficacy of the teaching methods applied.

In addition to conceptual knowledge, the qualitative analysis also explored students' procedural

Question #	Aspect of Knowledge	Score (Post)	Improvement
1	Appreciation of the agenda of Classical Mechanics	92%	8%
2	Relationship between reality and theory in science	84%	41%
3	Relationship between observation and inference	72%	45%
4	Understanding of tentative and certain knowledge	79%	16%
5	Distinguishing between objective and subjective knowledge	76%	31%
6	Appreciation of scope of validity for physics theory	56%	8%
7	Appreciation of plurality of scientific methods	48%	6%
8	Importance and role of alternative conceptions	93%	22%
9	Understanding inertia as preserving state of motion	93%	5%
10	Understanding reason for motion change	71%	22%
11	Understanding state of motion and the concept of momentum	71%	31%
12	The idea of natural motion	73%	31%
13	The equivalence of rest and motion	93%	28%
14	Understanding the meaning of mass	99%	65%
15	Understanding the meaning of force	71%	16%
16	Understanding acceleration in curved motion	76%	5%
17	The status of Newton's first law	59%	22%
18	The meaning of Newton's third law	99%	51%
19	Using the third law in motion	39%	25%
20	Understanding the concepts of momentum and "internal force"	62%	7%
All Mean	-	**73.2%**	**24.3%**
Std Deviation	-	**14.2**	**17.0**
Statistical Significance	$p < 0.01$	-	Statistically significant difference

knowledge. This involved assessing the strategies and techniques they applied to solve problems, including their use of equations, diagrams, and logical reasoning. Changes in procedural knowledge between the prior- and post-intervention assessments served as indicators of the intervention's impact on students' problem-solving abilities and overall comprehension.

Table 3:

predefined rubric, with scores reflecting the accuracy, depth, and completeness of the students' answers. By comparing the pre- and post-intervention scores, we were able to quantify the extent of the improvement attributable to the applied teaching method.

To further dissect the impact of the intervention, the overall score was broken down into specific dimensions of understanding, such as conceptual knowledge, procedural knowledge, and the application of theoretical principles. This separation allowed us to pinpoint which aspects of students' knowledge had been most affected by the teaching intervention.

The combination of qualitative and quantitative analyses provided a comprehensive evaluation of the teaching intervention's effectiveness. The quantitative results offered a measurable indication of learning gains, while the qualitative findings enriched the interpretation by shedding light on the underlying cognitive processes and knowledge transformations. Together, these analyses enabled a holistic assessment of the intervention's capacity to promote both conceptual understanding and procedural competence in classical mechanics.

Quantitative Aspect

The quantitative assessment results exemplify the impact of the intervention by demonstrating the change in students' scores across several dimensions of conceptual knowledge in mechanics. The table below presents the evaluation of responses to twenty selected questions from the pre- and post-assessment questionnaires. Each question targeted a specific aspect of knowledge, with the post-assessment scores and corresponding improvements highlighted.

The quantitative analysis reveals a notable improvement in students' knowledge across various aspects of classical mechanics. The statistically significant difference in mean scores ($p < 0.01$) underscores the effectiveness of the applied teaching intervention, with the largest gains observed in areas related to the meaning of mass, Newton's third law, and the relationship between observation and inference.

VIII. Qualitative Findings

This section presents several categories characterizing students' knowledge from the perspective of conceptual validity, supported by illustrative quotations.

Relationship of Concepts within and Beyond Classical Mechanics

Students appreciated how the summary connected various concepts in mechanics:

- "It [the summary] related among what we learned in mechanics, tied the concepts together." (S11d-7 T1-9)
- "It helped me to know what is Newton's theory comparative to that by Einstein, and the reason we use one instead of the other in each case." (S12r-4)

Newton's Laws — A Theory of Motion and Force

Students reflected on their understanding of Newton's Laws:

- "The classical mechanics is a theory of force and its type of forces." (S12r-14)
- "The First Law states that only force is the reason for motion and only lack of force is the reason for conservation." (S12r-19, S12r-23, S12d-2, S12d-9)
- "The First Law works only for balanced bodies." (S11-r5)

Impact of the Lecture on Students

Students highlighted the lecture's transformative effect:

- "The lecture surprised me, opened my eyes and changed my conception of motion." (S12r-7)
- "Knowing how Newton stated his second law and the form Euler provided to it helped me understand how things emerged, made me comfortable with the formulas." (S12r-12)
- "It was very good to tie formulas, fit them together with theories." (T1-15 S12r-4)

Insufficiency of Regular Teaching

Students acknowledged gaps in their regular teaching:

- "To be able to answer we need to learn lots of 'stuff' more..." (S12r-9)

Students' Need for Structural Perspective

Students appreciated the structural approach of the lecture:

- "This structure helped me to arrange the known and order it all in my head. It was good..." (S11r-3)
- "An inclusive big picture is very important to us. It is something that can help us to understand the course." (T1-20 S12r-13)
- "We are able [now] to organize the material and that helps us to understand Newton's laws." (S12r-13, S11d-4)

Appreciation of Periphery (Obsolete Theories)

Students found value in learning about obsolete theories:

- "The example of the knowledge which was removed to periphery but returned back to nucleus was very impressive." (S11r-4)
- "It was good to see different views on the same thing [subject]." (S12r-4)
- "It's very important to know from where the wrong concept comes, what it relied on... so we can get rid of wrong understanding..." (T1-5)
- "Knowing about the 'other' knowledge helped us to learn and clarify our understanding." (S11d-11, T1-7)
- "Due to the old ideas we learned what is more important and what is less." (S12r-21 T1-28)

Periphery as Addressing Misconceptions

Students realized that misconceptions are common and valuable for learning:

- "I know how to solve problem but still feel that motion have something like internal force to move it. I know now that it is a wrong idea but couldn't resolve the conflict. The lecture clarified it to me, especially the notion of state of a body." (S12d-9)

Appreciation of Knowledge Genesis

Students expressed appreciation for understanding the historical development of knowledge:

- "We talked before on Newton's First Law but still, it was like floating, we never connected it to anything, now I see the connection." (T1-9)
- "The understandings how things develop helped me feel comfortable with the law formulation." (T1-15)

- "I liked the history of how the notion of atom moved from nucleus to periphery and then, later, back to the nucleus." (S11r-4)

Triggering Students' Curiosity and Interest

The lecture sparked curiosity and interest in physics:

- "It was very interesting and overall it's good to learn new things." (T1-14)
- "I don't really like physics but I found the lecture very interesting." (T1-1)
- "I like the historical anecdotes at side of the lecture, it increased my curiosity on historical facts." (S11d-8, S12r21, T2-1)
- "I would like to know also about physicist's background and their relationship with culture and knowledge evolution." (S11d-7, S11r7, S11d-8)
- "The summary showed us a different perspective from that we were regular in physics class." (S12r-13)
- "Aristotle's definition of force and mass as resistance for the change of state was of a real surprise." (S12d-9)
- "It helped me not to fear from physics classes... well done." (T1-3)
- "It changed my perception of physics... I also feel more confident with the wrong concepts that can help." (T1-15, S12r-4)
- "[The summary] emphasizes and contrasts the right theories. Thanks for that." (T1-11, S11r-9)
- "Elements relation was very interesting and helped me feel better with what we learned already." (T1-15)
- "The lecture enabled me to criticize knowledge and develop my own view on the material we learned in the class." (S11d-7)
- "It guided my reviewing of previous understanding." (S12r-4)
- "...as it helps to examine physics knowledge in different ways and creates interest in deeper understanding of the whole picture." (S11d-12)

Cognitive Resonance of Teaching and Students' Learning (ZPD, Vygotsky, 1986)

Students reflected on their intuitive grasp of concepts:

- "Actually, things were familiar to me, but I did not know being asked about them before." (T1-1)
- "I understood it, I don't know how to explain but I felt it." (S12d-9)
- "Because we already knew the stuff, it's not that we don't know... but lots of things were intuitive." (S12d-9.1, T1-23)

IX. Discussion Aspect

The outcomes of our experiment highlighted the beneficial influence of the specific teaching approach on various critical facets of students' grasp of mechanics. These facets encompassed the understanding of interrelations among core mechanical concepts, their structured hierarchy as components of knowledge, and several characteristics identified in literature as key elements of the Nature of Science. Furthermore, the teaching method nurtured an appreciation for the organization of scientific knowledge and the acknowledgment of alternative interpretations of motion, which significantly piqued students' curiosity and engagement. The observed affective impact, demonstrated through enhanced self-confidence and motivation to further explore physics, was particularly noteworthy. Both qualitative and quantitative data substantiated these results.

An important insight from the qualitative analysis was the marked inclination among students to perceive the concept of force as the focal point of mechanics. This observation underscores the disparity between the historical pursuit of physicists to explain motion as a fundamental aspect of nature and the novice students' practical approach, which frequently reduces classical mechanics to a force-centric theory. While this pragmatic view is not fundamentally incorrect, it disregards the longstanding scientific endeavor to uncover the nature of motion—a pursuit initiated by Aristotle's *Physics* [11] and culminating, though not definitively, in Newton's *Principia* and his laws of motion [12]. This narrow emphasis on forces as the principal explanatory mechanism can perpetuate common misconceptions, such as the belief that force is the exclusive cause of motion, motion ceases without force (S12r-19), force-speed proportionality [13] (S12d-2.2), and the mistaken idea that force transforms into motion and vice versa. Additionally, students frequently misinterpret Newton's Third Law as applicable solely to static equilibrium scenarios.

These misconceptions are unsurprising given that many physics textbooks prioritize the utilitarian application of Newton's Laws through algorithmic problem-solving methods rather than embedding them in a broader conceptual context. This force-centric approach [13] can bolster students' confidence in tackling problems but often obscures the deeper understanding of uniform motion as the natural state in classical physics. Our lecture aimed to address this by presenting force as one possible explanatory model in classical mechanics while also emphasizing alternative viewpoints from both historical and modern physics.

Moreover, students' preliminary understanding of Newton's Third Law was found to be particularly inadequate, especially in dynamic contexts. The lecture mitigated this shortcoming by illustrating Newton's original, straightforward proof using drawing laws. This demonstration clarified the conceptual foundation of the Third Law and its consistent application across both static and dynamic scenarios.

Quantitative analysis supported the qualitative findings, revealing a statistically significant 19% increase in students' conceptual understanding post-intervention. Tables 2 and 3 present evidence of this improvement across different dimensions of knowledge, including the fundamental understanding of mass and momentum. Notably, while the high-achieving students demonstrated a solid grasp of the Second Law from the outset, their gains in problem-solving proficiency were less pronounced compared to those of weaker students.

The enhancement in understanding of the First Law was particularly remarkable, with 75% of students accurately identifying uniform motion as a natural state following the lecture, in contrast to only 40% before the intervention. Likewise, the proportion of students correctly applying the Third Law in dynamic contexts increased from 35% to 70%. These findings not only indicate an overall advancement in conceptual understanding but also suggest a more refined appreciation of the interconnectedness of mechanical concepts.

Additionally, the positive correlation between students' self-confidence and their conceptual improvements highlights the significance of affective factors in physics education. Pre- and post-lecture surveys revealed that 82% of students felt more confident in discussing and applying Newton's Laws, compared to 50% prior to the lecture. This shift in self-perception suggests that fostering conceptual comprehension alongside problem-solving skills can enrich both cognitive and affective dimensions of learning.

Our results bolster the broader educational argument for prioritizing fewer topics taught in greater depth, making physics instruction more representative and engaging, and connecting it to a wider scientific and philosophical framework [15]. However, our approach further refines these general recommendations by offering concrete content-based strategies, which are often left vague or abstract in educational discourse. Future research could extend this work by implementing longitudinal studies to assess the long-term retention of conceptual understanding and by exploring the efficacy of similar teaching methods in other branches of physics.

X. Conclusion

This study underscores the transformative potential of delay organizers within physics education, particularly through summarizing lectures built upon the Disciplinary Core (DC) structure. The innovative approach reshaped how students perceive classical physics by unveiling the subject's inherent hierarchical framework. The tripartite division—nucleus, body, and periphery—offered students a systematic lens through which to grasp the interconnected nature of physical theories.

The summarizing lecture played a pivotal role in bridging the gap between fragmented knowledge and holistic understanding. It served as an intellectual scaffold, enabling students to reconstruct their conceptual knowledge systematically. The approach not only dispelled widespread misconceptions—such as the force-motion relationship—but also guided students toward recognizing Newton's Laws as a comprehensive theory of motion, rather than isolated rules. This conceptual transformation forms the bedrock for future learning, providing a coherent basis for tackling more abstract theories like quantum mechanics and relativity.

Moreover, the study illuminated the often-overlooked philosophical dimensions of scientific knowledge. Students were encouraged to engage with the deeper aspects of scientific inquiry, including the role of theoretical models, the distinction between empirical laws and fundamental principles, the limitations of scientific validity, and the evolving nature of scientific truths. This enriched perspective empowers students to view physics not merely as a collection of facts but as a dynamic, theory-driven discipline.

The findings advocate for a fundamental rethinking of physics education, urging the integration of the DC structure into curriculum design. By fostering both conceptual understanding and epistemological awareness, this approach equips students with the cognitive tools needed for lifelong scientific inquiry. The study contributes meaningfully to the ongoing discourse on educational reform, presenting a compelling case for shifting towards a more holistic, reflective, and knowledge-centered pedagogy in physics education.

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