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# The Role of History of Science in Enhancing Physics and Chemistry Education

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*Abstract*: Contemporary education research underscores the significance of integrating historical insights into university-level Physics and Chemistry instruction. Traditional pedagogical approaches, rooted in a static 20th-century view of science, are being challenged. This study explores the dynamic nature of scientific knowledge by investigating the historical evolution of key concepts in these disciplines. By understanding the parallelism between historical knowledge construction and students' own learning experiences, it aims to address their learning challenges. Emphasising metascientific knowledge and the dynamic character of science, the findings advocate for the incorporation of historical perspectives to enrich comprehension and improve educational practices in these fields. Future research in this area holds the potential to further enhance science education at the university level.

*Keywords*: Scientific Knowledge, External Representations Development, Thermodynamics.

## 1. Introduction

The teaching of Physics and Chemistry at the university level has traditionally been presented as a static and definitive view of science that was established in the early 20th century.

Within the realm of modern science education, a resounding emphasis resonates on the intrinsic worth of historical insights and the metascientific knowledge, serving as the bedrock for the enhancement of pedagogical approaches.

Exploring the evolution of taught concepts reveals the dynamic nature of knowledge creation and its profound impact on the challenges encountered in student learning. This study delves into this phenomenon by conducting a meticulous documentary analysis within two distinct research areas. The first area scrutinises the historical development of some aspects of Organic Chemistry, focusing specifically on the evolution of the benzene structure and resonance concept. In the second case, it explores into the historiography of thermodynamics laws in order to trace the foundational influence of eminent scientists as Planck and Fermi. These figures marked the inception of thermodynamics instruction in classical textbooks and their work continues to endure as essential study materials in Physics classrooms.

This paper recovers the outcomes obtained in the framework of two postgraduate studies (Farré 2013, Quintero 2021) which underscore the pivotal importance of integrating historical perspectives in university-level Physics and Chemistry education. By doing so, students' comprehension will be enriched, providing them with a broader context for the concepts they must study, and effectively addressing the learning obstacles they may encounter along their educational journey.

This work aims to examine the role of the history of science to emphasise the importance of merging historical perspectives into Physics and Chemistry education at the university level. By reviewing the historical evolution of taught concepts, we gain insight into the dynamic nature of scientific knowledge construction and its implications for student learning. Simultaneously, it provides an opportunity to understand some of the learning difficulties that students face due to a certain parallelism between historical construction of scientific knowledge and personal construction of scientific knowledge by individuals (Farré & Lorenzo 2012).

## 2. Contribution of History of Science to rethink Science Teaching

Science education involves the systematic dissemination of scientific knowledge, principles, and methodologies within planned frameworks at formal educational levels and informal contexts, such as museums and science clubs. It encompasses various disciplines, including Physics, Chemistry, Biology, and Earth Sciences, with the goal of instilling a comprehensive understanding of scientific concepts and fostering analytical thinking. The overarching objective is to cultivate a scientifically literate populace capable of contributing to advancements in research, technology, and innovation, thereby playing a pivotal role in societal progress and addressing complex global challenges. Given its substantial societal implications, scientific research in science education has emerged as an indispensable field of study.

In this manner, Science Education constitutes an expansive domain of knowledge that has undergone significant development since the latter half of the twentieth century. It incorporates contributions from a myriad of specific disciplines, as illustrated in Fig. 1, forming a metascientific realm of knowledge.

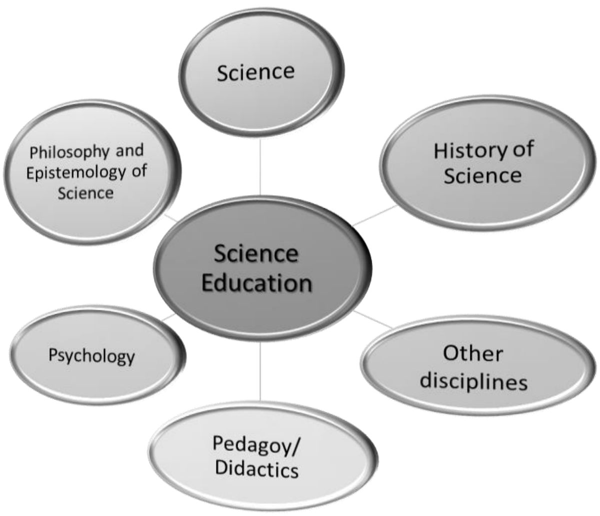


**Fig. 1.** Disciplines related to Science Education (figure created by the authors).

Particularly, the history of science serves as a source of understanding about the origin of crucial concepts, events, political influences, controversies, among other aspects. Moreover, history contributes to recognizing science as a collection of human and social activities with a dynamic nature, offering significant insights for teaching and learning processes. To achieve this perspective, the history of science should be presented with a contextualised vision that avoids reinforcing common sense stereotypes.

A valuable source of historical occurrences lies within the disciplinary textbooks used in classrooms.

However, traditional manuals often accentuate a Whig historiography. Hence, it is crucial to establish some criteria for scrutinising the historical aspects within textbooks collaboratively with teachers to facilitate enhanced and enriched instruction.

In university practice, textbooks are frequently regarded as supporting independent learning. Consequently, engaging with a science textbook implies possessing sufficient knowledge to comprehend the significance of new semantic categories and various modes of presentation.

Our research, conducted through the examination of particular textbooks on the presentation, description, and explanation of some specific scientific topics over a certain period identified key points for collaboration with science teachers in a progressive reformulation of their educational practices, considering the incorporation of historical events. Among the indicators that enable an analysis of the portrayal of science in textbooks are the inclusion of historical references, allusions to scientific research, the modes of validating knowledge presented, the stated purpose of science, and the type of language employed.

The following paragraphs seek to delineate two distinctive case studies concerning scientific textbooks, shedding light on the consequential impact of historical perspectives as strategic tools to enhance science education. In examining specific scientific textbooks, we delve into the historical underpinnings embedded within them. Scrutinising the integration of historical perspectives in these cases, we aim to showcase how a nuanced consideration of historical contexts contributes to the pedagogical richness of the educational material. These instances serve as illustrative examples, demonstrating the potential of historical perspectives to enhance the educational experience.

### *2.1 History beneath science textbooks: The Benzene' case*

In the particular case of Organic Chemistry, the first textbook that played a relevant role in teaching this discipline was the one published by Armstrong in 1874. It treated each family of compounds by describing some particular substances in-depth, and it didn't differentiate compounds into aliphatic or aromatic families. Otherwise, the book by Perkin Jr. and Kipping, published ten years later, distinguished both compounds' series. It included first the aliphatic compounds and later the aromatic ones (Wheeler & Wheeler 1982). Nowadays, textbooks follow the Armstrong tradition without differentiating the aliphatic and aromatic series. In particular, we can find the topic of aromatic compounds in the middle of the book, before the treatment of the topic of carbonyl compounds. The chapters corresponding to aromatic compounds include approximately twice as many reactions as complete mechanisms, and the problems and exercises focus on reaction product predictions, followed by those on synthesis pathways (Houseknecht 2010).

As Niaz (2005) indicated, almost twenty years ago, Chemistry textbooks used a "rhetoric of conclusions". Generally, they present knowledge as it is definitive, without explanation of the scientific endeavour. However, textbooks usually present benzene and aromatic compounds studies using a brief historical introduction. Likewise, the importance given to historical aspects varied according to the textbooks and their year of edition (Farré & Lorenzo 2010, Lorenzo & Farré 2014). Among eighteen books published between 1920 and 2008 which are detailed in Table. 1, we found that only four presented a too-brief version of the history. Contrarily, textbooks by Fieser & Fieser, in both the 1948 and 1966 editions, presented a chapter specifically dedicated to treating the topic. Therefore, most of the authors narrated past events to contextualise the topic, meanwhile Fieser & Fieser used history as a rhetorical and argumentative instrument.

Generally, a historical narrative communicates the elucidation process of the actual benzene structure. That could be auspicious, although it should be analysed the historical narrative used (Chamizo 2007, de Rezende & Silva 2007):

- Diachronic history: This narrative implies a contextualised vision of science, which considers at the same time the temporal-spatial, social, political and cultural dimensions. It tells the past from the past.

- Whig or anachronic history: It is the opposite case; the narrative imposes the patterns of the present on the past. It appears as if current scientific knowledge evaluates the science of past times. Also, this type of narrative shows a linear cumulative continuity of scientific knowledge, which speaks of an advance of science in positivist terms.
- Recurrent history: To reach a complete version of past events is an unrealizable ideal because the judgments of historical actors are inaccessible. Therefore, an intermediate way to deal with this limitation is this type of narrative. It reveals how concepts emerge from each other through a sequence of corrections or rectifications. When a new concept appears, it introduces a reorganisation of the field of study and an evaluation of previous knowledge.
- Pseudo-history: This is a common-sense history. In this narrative, events are oversimplified or distorted. Also, common stereotypes about science and scientific work are reinforced. Examples of this situation are exaggeration of scientific discoveries' drama, selection of some facts and protagonists and not others, and representation of some scientists as "heroes". Furthermore, in this narrative style, current ideas and theories appear as they are inevitable, constituting an "objective truth" achieved through "the scientific method".

**Table 1:** Textbooks reviewed

| Year of Spanish edition | Author(s) | Editor/ Publisher | Printing location | Analysed pages |
|---|---|---|---|---|
| 1920 | Holleman, A. | Marín | Barcelona | 336-342 |
| 1942 | Holleman, A. & Richter, F. | Marín | Barcelona | 413-420 |
| 1943 | Schlenk, W. | Ediciones Morata | Madrid | Vol. II, 1-7 |
| 1945 | Karrer, P. | Marín | Barcelona | 428-437 |
| 1948 | Fieser, L. & Fieser, M. | Atlante | México | 513-524 |
| 1960 | Klages, F. | Editorial Reverté | Barcelona | Vol. I, 125-129 |
| 1966 | Fieser, L. & Fieser, M. | Ediciones Grijalbo | Barcelona | 1105-1123 |
| 1969 | Brewster, R. & McEwen, W. | Médico–Quirúrgica | Buenos Aires | 539-547, 573-574 |
| 1976 | Allinger, N., Cava, M., De Jongh, D., Johnson, C., Lebel, N. & Stevens, C. | Reverté | Buenos Aires | 317-345, 488-492 |
| 1985 | Morrison, R. & Boyd, R. | Fondo Educativo Interamericano | México | 574-591 |
| 1994 | Mc Murry, J. | Grupo Editorial Iberoamérica | México | 499-526 |
| 1999 | Carey, F. | McGraw Hill | Madrid | 370-405 |
| 2000 | Fox, M. A. & Whitesell, J. | Pearson Education | México | 64-71 |
| 2004 | Mc Murry, J. | Thomson | México | 498-507 |
| 2004 | | | Madrid | 679-694 |
| 2006 | Carey, F. | McGraw Hill | México | 432-472 |
| 2008 | Mc Murry, J. | Cenage Learning Editores S.A. | México | 516-538 |
| 2008 | Bruice, P. Y. | Pearson Educación | México | 287-311, 640-651 |

The historical narrative staged in the textbooks changed over the years. Books' authors included passages that evaluate, judge and reinterpret past events in the historical accounts presented in the textbooks, as is shown in the subsequent cites (translation is ours):

> Not all early deductions were so sure and some even turned out to be wrong (Fieser & Fieser 1948, p. 517).

> Kekulé suggested (incorrectly) that there was a rapid equilibrium interconverting the two isomers of 1,2-dichlorobenzene (Wade 2004, p. 679).

However, in all cases, the authors described the problem of structural elucidation of benzene as a challenge that chemists had to face. This situation was evident in the first six texts (published between 1920 and 1960). In the pages of these books and three others published until 1976, it was possible to read how some hypotheses arose and the reason for refuting them. In addition, from reading Allinger et al. book, we could infer that the interpretation of the same experimental data can vary, and scientists can propose different hypotheses or models from the same data. So, the oldest books (except Klages 1960) presented a recurrent historical narrative. Its narrative allowed us to see how some concepts emerge from others and the rectifications and corrections that occur in the development of science.

From Brewster & McEwen (1969) onwards, elements of pseudo-history began to predominate, such as the simplification or distortion of some events. This pseudo-history narrative was notable in the Morrison & Boyd (1985) textbook.

> On the other hand, some believe that Kekulé intuitively anticipated our modern concept of delocalised electrons by some 75 years [...] (Morrison & Boyd 1985, p. 577).

Another example was that Kekulé's oscillating hypothesis was put forward in 1865 instead of 1872. Furthermore, in its pages, Thiele was attributed the formula that had been put forward by Robinson. In the same way, Bruice explicitly stated that:

> In 1865, the German chemist Kekulé suggested a way to resolve this dilemma. He proposed that benzene is not a single compound but rather a mixture of two compounds in rapid equilibrium (Bruice 2008, p. 289).

Then, starting with McMurry (1994), textbooks presented elements of Whig historiography, in which a linear advancement of science predominates. As an example of the latter, we can point out the exclusion of the ozonolysis experiments of o-xylene. In this way, authors selected information when constructing the historical account to avoid controversies and prioritise an image vision of science that advances linearly and inexorably towards the truth.

A special mention should be made of the included formulas in the different textbooks. In general, they were consistent with the importance given to historical narrative. Likewise, there was a logical dependence on the development of the topic at the time of publication of the book. Therefore, in the oldest books, the representations of benzene were closer to the empirical developments of the time and, consequently, have a hypothetical character. In later texts, the formulas fundamentally were part of the story and presented consensual knowledge. The latter was fundamentally evident from 1966 onwards, when authors used multiple representations to account for the structure of benzene (Fig. 2).

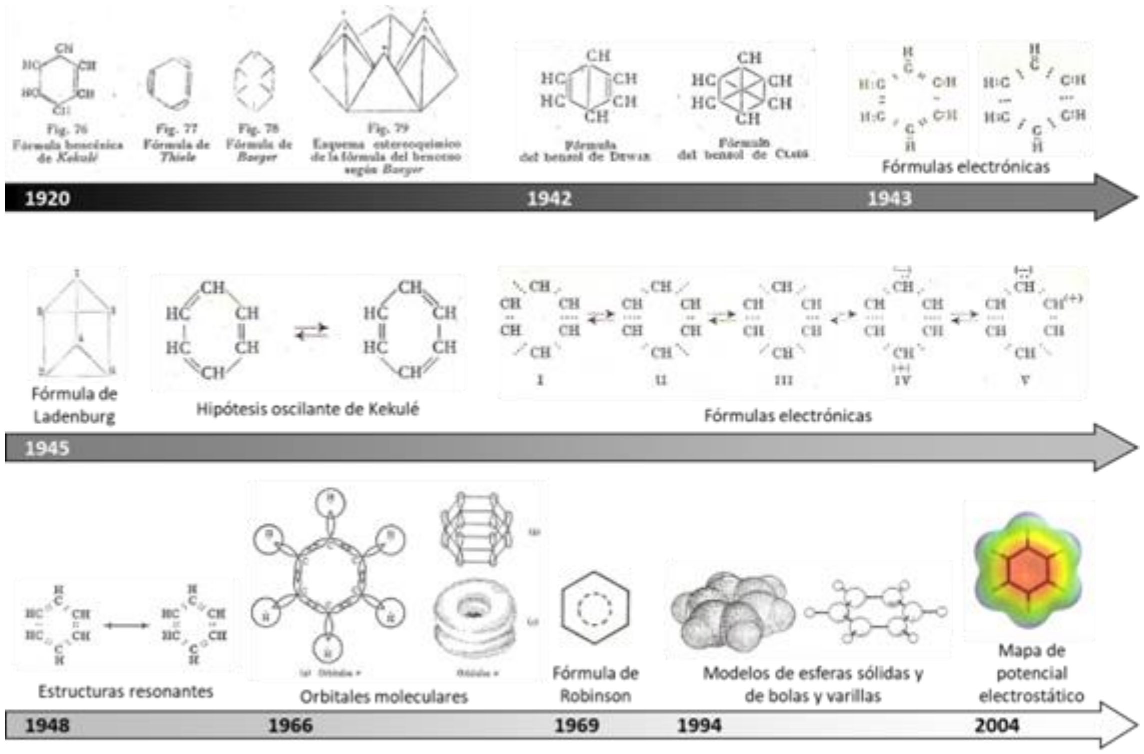


**Fig. 2.** Different representations of the benzene structure presented in textbooks (figure created by the authors).

### *2.2 The case of the Thermodynamics*

This section highlights the significant influence of eminent scientists as architects of the mode of comprehension through the integration of scientific research and its adaptation to textbooks for instructional purposes.

The case under consideration pertains to the subject of thermodynamics, given its paramount importance in comprehending phenomena in Physics and Chemistry. Simultaneously, it poses numerous challenges for teaching and, more significantly, for learning. Thermodynamics is a branch of science dedicated to the macroscopic realm and foundational concepts of Physics, encompassing energy. These principles enable the explanation and prediction of a wide array of phenomena. This understanding is crucial for comprehending unification processes, as it unveils connections between seemingly unrelated fields. Moreover, it is indispensable for analysing socio-scientific issues related to the use of natural resources and the impact on both the environment and society (Doménech *et al.* 2007).

Furthermore, thermodynamics plays a central role in the production, conservation, and transfer of all forms of energy, extending beyond chemical reactions. Consequently, it is imperative for aspiring science professionals to grasp its principles, given their relevance to pressing global issues of our time, including the energy crisis, pollution, and global warming. The laws of thermodynamics are fundamental when considering alternative forms of energy and the efficiency of their conversion processes.

Max Planck and Enrico Fermi established seminal works in formulating thermodynamic laws, marking the inception of thermodynamics education. These foundational contributions persist as essential study materials for this crucial topic in Physics and Chemistry, retaining their relevance to the present day. Classical thermodynamics examines phenomena in systems from a macroscopic perspective, with physical properties such as temperature or pressure being observable and measurable factors. These relationships form the cornerstone of thermodynamics, known as its fundamental laws. They include the Zero Law – also named as the Zeroth Principle or Thermodynamic Equilibrium – the

First Law – which involves the Conservation of Energy Principle – the Second and the Third Law. These distinguished physicists were the authors of the first textbooks for teaching on thermodynamics, and those texts continue to serve as fundamental references in university education. Table 2 presents the initial two textbooks on thermodynamics, which were the subjects of the documentary analysis in this study.

**Table 2:** Textbooks considered

| Year edition | Author(s) | Title of the book | Printing location: Editor/ Publisher |
|---|---|---|---|
| 1897 | Max Planck | Wärmelehre | Leipzig: Verlag Von Veit & Comp (German) |
| 1903 | | Treatise on Thermodynamics | London: Longmans, Green, And Co (English). |
| 1945 | | | New York: Dover publications, (English, analyzed version). |
| 1936 | Enrico Fermi | Thermodynamics | New York: Prentice-Hall (English) |
| 1985 | | Termodinámica | Buenos Aires: EUDEBA (Spanish, analysed version) |

Max Planck's German book on thermodynamics is titled "Wärmelehre", translating to "Theory of Heat" or "Treatise on Thermodynamics" in English. In Spanish it is known as "Tratado de Termodinámica". Planck's work is widely recognized as a seminal publication in the instruction of thermodynamics. This piece signifies a pivotal moment in the evolution of thermodynamics education and is invaluable for those interested in its development. In the preface to the original 1897 edition, the author acknowledges frequent requests to summarise their work on thermodynamics, rendering this text particularly significant. Planck meticulously revised all the material in his notes, providing detailed and clear evidence to augment the concise descriptions. His objective was to present thermodynamics consistently in a textbook that also serves as a lucid introduction to the subject for students. It's worth noting that Rudolf Clausius had previously adapted his renowned work "Die Mechanische Wärmetheorie" (1876) as a textbook.

There are three approaches to presenting thermodynamics. Firstly, the kinetic theory of heat, pioneered by Joule, Clausius, and Maxwell and significantly expanded by Boltzmann, offers a comprehensive exploration of heat movement. Secondly, the Helmholtz method relies on general assumptions about the mechanical motion of heat. Finally, a third method, not explored in this text, is favoured by Planck. He advocates for an inductive representation that references the mechanical nature of heat while commencing with simple empirical facts. These include the foundational principles of thermodynamics, from which a multitude of statements about Physics and Chemistry phenomena can be derived. The book initiates with a discussion on empirical evidence concerning heat transfer among bodies attempting to achieve equilibrium. The author provides a structured analysis, demonstrating that the feature of thermal equilibrium in bodies is transitive, and employs this to introduce the notion of temperature.

The second crucial term is the quantity of heat, evident from empirical observations. When bodies of different materials, but with the same temperature, come into contact with a reference body, they induce varying temperature fluctuations in this body. Temperature and heat quantity, along with the mechanical properties of bodies, constitute the conceptual foundation of Planck's heat theory. The final section of the book explores the practical applications of the theory, considering homogeneous systems, systems with varying aggregate states, gaseous systems, and dilute solutions. Lastly, Nernst's theorem is discussed, providing absolute values for entropies. Planck's book presents the theory in an easily understandable and concise manner, offering verbal explanations that connect the background and context of the developed theory with physical phenomena. The cover of Planck's book, distributed by Dover Publications, is depicted in Fig. 3.

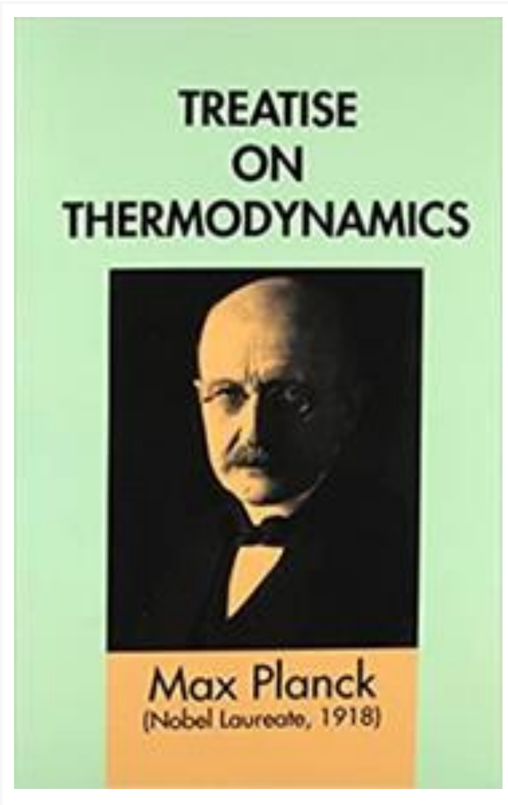


**Fig. 3**: The Cover Page of 'Treatise on Thermodynamics' Published by Dover (Source: Dover, 1945).

The preface of Fermi's Thermodynamics reveals that it was compiled from notes taken during a course taught by Enrico Fermi at Columbia University in New York during the summer of 1936. Fermi presents it as an introductory treatise on thermodynamics, with some references to statistical thermodynamics anticipated. In comparison to the worldview of pure classical thermodynamics, the perspective established by statistical thermodynamics differs significantly. It involves the transition from macroscopic variables to a viewpoint that considers variables related to the average of quantities associated with a vast number of particles. This shift is from a deterministic perspective to one that encompasses a statistical viewpoint, where probabilities become apparent. It is assumed that the reader is acquainted with the basic principles of thermometry and calorimetry to adequately comprehend the subject matter. The author provides minimal contextual information, only indicating the university and date of the lecture, and expresses gratitude to Dr. Lloyd Motz, a professor at the institution who reviewed the manuscript and provided notes.

In the introduction to Fermi's text, the author defines thermodynamics as the study of the transformation between heat and mechanical work, and vice versa, a crucial concept to bear in mind in the context of this 1936 course. It is noteworthy that physicists had only recently established that heat is a form of energy convertible into other forms. Previously, scientists conceived of heat as an immaterial fluid that remained unchanged, with heating considered the transfer of this fluid between bodies. The author explores two distinct theories that held a place in the history of Physics. This topic is intriguing as Physics textbooks often present fundamental concepts as facts without acknowledging superseded theories or alternative explanations from other historical periods.

The author underscores the importance of acknowledging the contributions of French engineer Sadi Carnot (1796-1832), who, employing the theory of caloric fluid, successfully elucidated the constraints of transforming heat into work in 1824, commonly known as the Second Law of Thermodynamics, as previously mentioned. Fermi anticipates addressing this topic in Chapter III. Regarding the author's observation, it is noteworthy how a fluid perspective on heat allowed for an explanation of the limitations in transforming it into mechanical work, despite this being considered inadequate from our present understanding. Furthermore, Fermi notes that R. J. Mayer, in 1842 (as used by the author), discovered the equivalence between heat and mechanical work and formulated the principle of conservation of energy, the first law of thermodynamics.

Fermi further states that in his day, the explanation for the equivalence between heat and dynamic energy had to be interpreted kinetically, reducing thermal phenomena to the disordered movements of atoms and molecules, and considering the study of heat as a specific branch of mechanics. At this juncture, the model of particles is introduced explicitly. In the mechanics of such a massive collection of particles, the intricacies of their individual states and movements become insignificant. Only the average properties of a large number of particles should be considered. This leads to a submicroscopic understanding of the world, with a focus on atomic and molecular kinetics that is associated with statistics. This leads to a submicroscopic understanding of the world, with a focus on atomic and molecular kinetics that is associated with statistics. It is worth noting that, although it states an intention to address pure thermodynamics, there are references to atomic-molecular and statistical models.

Fermi highlights that the approach in pure thermodynamics differs significantly; the fundamental laws are taken as postulates based on experimental evidence, from which conclusions are drawn without considering the kinetic perspective of phenomena. Additionally, it is advantageous because it is independent of the simplified assumptions used in statistical mechanics, resulting in extremely accurate conclusions in pure thermodynamics. Although, according to him, obtaining results without being able to see the processes can sometimes be unsatisfactory, which is why he proposes supplementing the results of thermodynamics with an approximate kinetic interpretation. Furthermore, it is noted that while the first and second laws have their statistical basis in classical mechanics, the third law, introduced by Nernst, can only be interpreted statistically in terms of quantum mechanics. It is anticipated that the third law will be addressed in the final chapter. From the reading of the last paragraphs of the Introduction, it is possible to glean the experimentalist approach the author will adopt to present the theory.

On the other hand, Thermodynamics is a complex field that incorporates a range of abstract concepts. These concepts are organised in various external systems of representation, such as mathematical notations, physical equations and graphs, and are expressed in a specialised technical vocabulary. Thus, the subject can prove challenging. Thermodynamic knowledge, with its own specialised language and a wide array of fundamental concepts, including energy, heat, temperature, enthalpy, entropy, state functions, and thermodynamic potentials, among others, significantly contributes to the comprehension of various natural phenomena (Bain *et al.* 2014, Baran & Sozbilir 2018, Tarsitani & Vicentini 1996).

## 3. Final reflections

The analyses conducted on the Chemistry textbooks at the university level revealed that earlier textbooks commonly featured a historical introduction at the commencement of each new topic. However, during the 1980s, these introductions were omitted, only to be reintroduced after the year 2000.

Concurrently, in university texts within disciplines such as Pharmacology, Pharmacognosy, and Immunology, older textbooks exhibited more historical references compared to contemporary ones. Despite this, one might speculate that these university-level textbooks would follow a trajectory similar to that observed in secondary level textbooks, with historical aspects potentially being reincorporated into topic-specific explanations.

In concluding our exploration, we underscore that textbooks, often concealing more than evident to novice readers, necessitate a recursive reading strategy to unveil their profound content. This approach serves as a crucial tool for those seeking to delve deeper into the complexities of the text.

Our research highlights the importance of studying historical developments across various texts within a specific timeframe. This method proves instrumental in understanding how ideas metamorphose into established scientific facts, thereby providing profound insights into the trajectory of scientific progress.

Contrary to conventional histories of science, our focus transcends mere historical investigation. Instead, we concentrate on the intersection of science and education, demonstrating how historical contexts enrich educational practices. We advocate for a renewed emphasis on the act of reading textbooks as a strategic tool for the ongoing professional development of in-service teachers.

Aligned with the contemporary demand for scientific research to be both transferable and transformative, we contend that science education cannot exist in isolation. Our pedagogical approach seeks to bring about transformation within the classroom by actively engaging with the teaching process. Our aspiration is to cultivate teachers as critical and reflective professionals, empowering them to grapple with the outcomes and inquiries arising from educational research. In this way, our work contributes to the broader endeavour of nurturing educators who possess not only a deep understanding of their subject matter but also the capacity to navigate the evolving landscape of science education in our dynamic society.

This has not been an exploration of the history of science, but rather an inquiry into how education can be significantly enriched by its historical dimensions.

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