

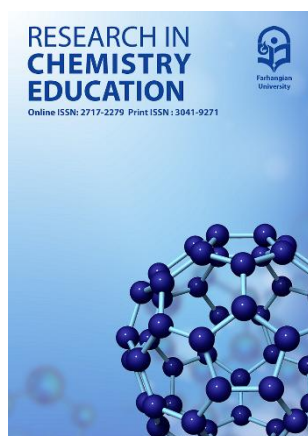


# The evolution of fundamental concepts in organic chemistry: Hydrocarbons in Iranian secondary school chemistry textbooks and their information content and importance based on shannon entropy

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## Abstract:

**Background and Objective:** This study examines the changes in the basic concepts of the chemistry of different branches of hydrocarbons (alkanes, alkenes, alkynes, and aromatics) in high school chemistry textbooks from 1971 to 2021. **Methods:** This applied study, following a historical method, uses content analysis. Shannon entropy is applied to data processing and validation. Textbooks from 1975, 1985, 1999, 2009, and 2019 were samples. **Findings:** The concepts were extracted and counted, and their frequencies were calculated. The results show that in 1975 aromatics had the highest frequency (32.04%) and alkenes the lowest (20.24%). In 1985, aromatics and alkenes were highest (28.07%) and alkynes lowest (21.05%). In 1999, alkenes were highest (29.41%) and alkynes lowest (19.61%). In 2019, alkanes were highest (50.00%) and aromatics lowest (9.09%). In 2019, alkenes were the highest (50.00%) and alkynes and aromatics lowest (9.09%). **Conclusion:** Comparisons across branches show alkanes peaked in 1999 (50.00%) and were lowest in 1975 (22.81%). Alkenes peaked in 2019 (50.00%) and were lowest in 1985 (20.24%). Alkynes peaked in 1975 (22.62%) and were lowest in 2019 (9.09%). Aromatics peaked in 1975 (32.54%) and were lowest in 2019 (9.09%). Shannon entropy analysis shows alkenes had the highest information content and also importance, and aromatics had the lowest. Across years, the highest information content was in 1985 and the lowest in 2019. The highest importance was in 2019 and the lowest in 1975.

**Keywords:** Key ideas; Fundamental concepts; Experimental sciences; Chemistry; Shannon entropy; Importance.

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## Introduction

By studying the past, human being engages with the present and strive for their future; in fact, by drawing upon past experiences, they construct the future (Hosseini Rouholamini, 2006). Today, many thinkers and specialists in education, who advocate for new perspectives and fresh approaches to educational reform, believe that planning for a fundamental reconsideration of the past and current performance of educational systems in each country must be carried out in the light of examining the historical background of educational transformations and analyzing the current state of their systems (Aghazadeh, 2004). Careful study and analysis of historical developments enable curriculum planners and textbook authors to build a better future by considering both the achievements and shortcomings of the past (Delavar, 2006).

In centralized education systems like Iran, textbooks play a key role because they summarize the main ideas, concepts, facts, and rules of a subject. One of the most important curricula in the education system of any country is that of secondary education. Within this framework, the curriculum and textbooks of the natural sciences (chemistry, physics, biology, and geology) hold particular significance. Perhaps in the past century, no subject has undergone as many changes worldwide as the natural sciences. The content of science courses, by its very nature, has attracted the attention of educational specialists due to the era of information explosion. With the rapid expansion of technology in the twentieth century and the comprehensive advancement of science and industry, the need for teaching and learning the natural sciences became more pronounced than ever. In 1957, the Soviet Union succeeded in launching its first spacecraft into orbit. This event marked a fundamental transformation in the planning and teaching of various branches of science, including chemistry. In response, the United States convened the Woods Hole Conference to introduce major changes in its science education programs. In the early 1960s, projects on science education and curriculum planning were implemented in the United States and England, each exerting long-lasting influence on the design and development of science curricula at the elementary and secondary levels. Several African and Asian countries, inspired by the frameworks of these projects, developed new curricula adapted to their national and regional characteristics (Badrian, 2016).

By the late nineteenth century, most schools in England and other developing countries offered chemistry within the framework of the natural sciences curriculum. Until the end of the nineteenth century, chemistry was regarded as an experimental, laboratory-based science, with its educational programs focusing primarily on teaching laboratory techniques and skills for preparing and analyzing chemical substances (Hofstein, 1988). In the early twentieth century, the importance of science and technology led to greater attention being paid to the teaching of sciences such as chemistry, which serve as the foundation of technological innovation and economic development. The expansion of chemical industries, including explosives, fertilizers, dyes, textiles, pharmaceuticals, and various petroleum and coal-derived products, made systematic chemistry education at lower levels even more necessary.

In the United States, the first edition of chemistry education content with a communicative approach was published in 1964. In 1970, the design and development of chemistry curricula with an interdisciplinary approach began, culminating after three years of continuous effort by chemistry teachers and faculty at the University of Maryland. In 1988, the American Chemical Society published the *Chemistry in Society* project, emphasizing interdisciplinary approaches and societal issues. In 1991, Johnston, a specialist in chemistry education, introduced the teaching of thinking at macroscopic, molecular, and symbolic levels, presenting it in the form of a triangular framework. In 2004, Mahaffy, another chemistry education expert, proposed the Science–Technology–Society–Environment approach, adding a fourth dimension, human factors, to Johnston's levels (Badrian, 2016).

Chemistry is characterized by its lawful, observable, predictive, and partly theoretical nature (Taber, 2019). In fact, chemistry encompasses ontological, epistemological, and ethical knowledge (Erduran & Kaya, 2019). Like other natural sciences, chemistry is dynamic and continuously evolving, with critical evaluation of existing findings serving as the foundation

for generating new knowledge. Historical studies have shown that such scientific efforts often lead to more effective models and methods (Kampourakis, 2018).

Today, chemistry influences all aspects of our lives. Its applications and related technologies in healthcare, medicine, food production (quality and quantity), energy and water supply, industry, economy, and daily life are rapidly expanding. Therefore, balancing the essence of chemistry with its societal applications and fostering interaction between chemistry, society, and the environment is essential (Van Heuvelen et al., 2020).

In Iran, chemistry holds particular importance both as a major branch of the natural sciences and due to the country's rich resources in oil, gas, minerals, and petrochemical industries, as well as its historical and cultural heritage. Following the establishment of Darul-Funun, chemistry and physics were taught together under the subject of 'Natural Sciences.' From 1902 onward, physics and chemistry were taught as independent subjects (Motamedi, 2012).

Until 1960, chemistry education in Iran followed curricula from France and Belgium, focusing on the description of elements and chemical phenomena. In 1962, commissions within the Supreme Council of Education invited outstanding teachers nationwide to collaborate on curriculum planning for chemistry, which was then approved by the Supreme Council of Culture. Textbooks were authored by translating materials from France and England, adapting them to the approved curriculum with a descriptive approach. These textbooks remained in use until 1973. The establishment of the Iranian Center for Educational Research and Curriculum Planning in 1971 coincided with major global changes in curricula. Theories of Bruner, Ausubel, and Bloom's taxonomy gained followers in Iran, leading to fundamental changes in chemistry curricula inspired by international projects such as the American *Chemical Education Study*, the *Chemistry Communication Approach*, and England's *Nuffield Project*. These new programs, revolutionary for Iran's educational system, faced strong resistance from teachers, who opposed the shift from descriptive to conceptual chemistry. In descriptive chemistry, emphasis was placed on formulas, problem-solving, and writing complex equations, with final assessments allocating 50% of grades to problem-solving and 50% to essay questions (Khalkhali, 2006).

After training courses for chemistry teachers, they gradually became familiar with new methods and approaches, and new textbooks were introduced from 1973 onward. The new chemistry curriculum, referred to as '*Modern Chemistry*,' continued to be implemented in most European and Asian countries in an integrated manner, adapted to the needs and local characteristics of each nation (Samiei & Alvandi, 2018). The new chemistry curriculum, continued in Iran until 1993, when the educational system shifted to a credit-based structure, which was first term-based and later became year-based. This led to new curricula, implemented until 2000. However, during implementation, numerous challenges arose. Consequently, in 1999, the drafting of a new chemistry curriculum guide was undertaken by the Office of Curriculum Planning and Textbook Development. This guide drew upon components of '*Project 2061*', U.S. science education standards, and the '*Chemistry in Society* project'. Based on this guide, new textbooks were authored and used in Iranian schools until 2016 (Secretariat of the Supreme Council of Education, 2000)

From 2011 onward, in line with the Fundamental Transformation Document of Education and the 6-3-3 curriculum structure, and with attention to the domains of training and learning in the National Curriculum, new approaches were adopted. These emphasized scientific and technological literacy, learners' personal experiences in real contexts, contextual orientation, interdisciplinary themes such as thinking skills and wisdom, life skills, and educational packages. Based on these approaches, new chemistry textbooks for upper secondary schools were authored, published, and implemented (Secretariat of the Supreme Council of Education, 2012).

Several studies have been conducted in Iran and abroad. For example, Saghafi (2011) carried out research titled '*The History of Chemistry Education in Iran from the Establishment of Darul-Funun to 1941 (1851–1941)*'. This study assessed the evolution of modern chemistry until 1941, along with the development of chemistry textbooks.

Bagheri Chimeh (2015) conducted a study titled '*Chemistry in Darul-Funun*', which investigates the historical and social factors behind the need for modern sciences during the Qajar era and the establishment of Darul-Funun, with a particular focus on chemistry. Milanović and colleagues (2015) conducted a study titled '*High School Chemistry Textbooks in the Nineteenth Century*'. This article aimed to gain insight through the analysis of high school textbooks written by Sima Lozanić (1895) and Mita Petrović (1892), examining the extent to which scientific knowledge in chemistry was conveyed to secondary students in Serbia during the second half of the nineteenth century, and the principles upon which these textbooks were based. In both books, however, the authors' efforts to connect chemistry with everyday life and to highlight various applications were evident.

Given that in most countries, including Iran, curriculum planning is manifested through textbooks, and that each curriculum typically remains in effect for at least a decade, historical periods are defined for such studies. A historical period for a textbook refers to the span of years during which the textbook remained largely unchanged, with minimal modifications and no fundamental restructuring.

### Research Aim and Questions

Considering the importance of high school chemistry textbooks in shaping scientific understanding of fundamental concepts in organic chemistry, particularly hydrocarbons, and the impact of this branch of chemistry on various industries, including petrochemicals, the main objective of this study is to examine the evolution of fundamental concepts of hydrocarbons in Iranian chemistry textbooks using George Beredy's method, and to determine their informational load and significance through Shannon entropy, within the time frame 1971–2021.

Accordingly, this study seeks to answer the following questions:

1. What is the frequency percentage of fundamental hydrocarbon concepts (alkanes, alkenes, alkynes, aromatics) in chemistry textbooks of the upper secondary level across different historical periods between 1971 and 2021?
2. What is the frequency percentage of fundamental concepts within each hydrocarbon category (alkanes, alkenes, alkynes, aromatics) in chemistry textbooks of the upper secondary level across the same historical periods?
3. Based on Shannon entropy, what is the informational load and degree of importance of the fundamental hydrocarbon concepts (alkanes, alkenes, alkynes, aromatics) in chemistry textbooks of the upper secondary level during the period 1971–2021?

### Methodology

Given the nature of the research title, the intended objectives, the questions posed, and the characteristics outlined for research in the field of educational sciences, the present study is of a historical, descriptive, and mixed type (qualitative and quantitative). Historical research is defined as the systematic process of searching for facts and subsequently using the information to describe, analyze, and interpret the past (Rasouli & Atashani, 2014).

When we think of historical research, a process of searching, summarizing, and interpreting past events comes to mind, in which researchers employ logical reasoning (Khoinejad, 2006). In this method, the researcher, without any intervention, reports what has been observed or concluded, faithfully and without omission, while adhering to principles of integrity (Delavar, 2016). The statistical population of this study consists of chemistry textbooks used in the upper secondary level during the historical periods under consideration. Accordingly, the sample size is identical to the statistical population. The unit of content analysis

in this study is the words related to basic concepts of chemistry in the text of Iranian high school chemistry textbooks in the selected years. Basic concepts are the concepts that are first introduced in chemistry textbooks in this academic year.

The qualitative part of the research examines the content of these sources and classifies their concepts into analytical categories using the George Beredy method. The quantitative part is dedicated to analyzing the frequency and importance of basic hydrocarbon concepts in the period under consideration using the Shannon entropy method.

Historical periods are defined as spans of years during which a textbook remained unchanged or underwent minimal modifications. Based on this principle, each period encompasses several years. Within the corpus of Iranian secondary school chemistry textbooks, the following historical periods were identified:

- (1963–1975): Coordinated textbooks, with emphasis on 1975.
- (1976–1992): The 5–3–4 system, with emphasis on 1985.
- (1992–2002): The credit-based system, with emphasis on 1999.
- (2003–2016): With emphasis on 2009.
- (2016–2021): The 6–3–3 system, with emphasis on 2019.

In this research, chemistry textbooks of the upper secondary level from 1971 to 2021 were examined. Based on the stability of grade levels, the chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 were selected as the sample.

Subsequently, the fundamental concepts related to each branch of hydrocarbons, namely alkanes, alkenes, alkynes, and aromatics, were extracted for the selected years. The number of fundamental concepts was then counted, and the resulting data were converted into frequency percentages for each case, recorded in the relevant tables, and illustrated through charts. Based on these charts, comparisons were made, and data analysis was carried out.

Using Shannon entropy, the informational load and degree of importance of the fundamental concepts in each branch of hydrocarbons (alkanes, alkenes, alkynes, and aromatics) were determined and compared. Descriptive statistics were employed to display and compare the frequency of indicators, while Shannon entropy was applied to calculate the degree of importance of each indicator (Adel, 2001).

Preparation, organization, and processing of results constitute the three main stages of the Shannon entropy method (Adel, 2001). In practice, this study began by constructing a matrix table according to the years under investigation and the branches of hydrocarbons (alkanes, alkenes, alkynes, and aromatics) arranged in rows and columns. The data were then normalized, and the informational load (entropy), anti-entropy, and degree of importance were calculated.

### Data Analysis Method

Two levels of analysis were used to analyze the data:

*1. Descriptive analysis:* To display and compare the frequency of basic concepts in different branches of hydrocarbons (alkanes, alkenes, alkynes, and aromatics) in the selected years, it was carried out with the George Beredy model (Beredy, 1964), which includes description, interpretation, juxtaposition, and comparison. In the description stage, which is the first stage of the Brady's model, the research components were noted based on the evidence and information available in the aforementioned textbooks so that sufficient information would be available for review and criticism in the next stage. In the second stage, which is the interpretation stage, the information described in the first stage will be analyzed. In the third stage, which is called the juxtaposition stage, the information collected in the previous two stages was classified to create a framework for comparison. In the fourth stage, which is called the comparison stage, review and comparison were carried out with respect to the details in the field of answering the research questions.

2. *Shannon Entropy Analysis*: There are several methods for data analysis, which are based on determining the percentage of frequency of categories. These methods often have their own computational problems that reduce the validity of the results obtained. Therefore, to validate the results, a compensatory technique called Shannon Entropy is used. The Shannon Entropy method is derived from information theory, which deals with data processing. And makes the results more valid. To determine the information load and the degree of relative importance of each branch in the time periods studied. In this method, first a matrix was set up in which the years studied were placed in columns, and different branches of hydrocarbons (alkanes, alkenes, alkynes, and aromatics) were placed in rows. The data were then normalized, and the entropy, anti-entropy, and importance coefficient values for each branch were calculated. The operational steps for calculations related to Shannon Entropy are as follows.

1) First, the frequency of messages is counted according to categories in proportion to each respondent and classified in a table similar to Table 1. The following steps are performed based on the data in the frequency table.

**Table 1-** Frequency form of text categories, questions, and images by respondent

Index Respondent	Index (Category)1	Index (Category)2	...	Index (Category)n
	$X_1$	$X_2$		$X_n$
Respondent 1 ( $A_1$ )	$F_{11}$	$F_{12}$	...	$F_{1n}$
Respondent 2 ( $A_2$ )	$F_{21}$	$F_{22}$	...	$F_{2n}$
Respondent m ( $A_m$ )	$F_{m1}$	$F_{m2}$	...	$F_{mn}$

$j =$  index of the symbol,  $i =$  index of the respondent,  $m =$  number of respondents,  $n =$  number of messages,  $F_{ij} =$  frequency of messages

After drawing the table and collecting the data, the following steps are performed in order: 1) Using the following equation, we normalize the frequency of categories for each respondent and record it in Table 2.

$$P_{ij} = \frac{F_{ij}}{\sum_{j=1}^n F_{ij}}; (i = 1, 2, \dots, m; j = 1, 2, \dots, n)$$

$P_{ij}$  = Frequency matrix normalized data

**Table 2-** Normalized data of categories

Index Respondent	Index (Category)1	Index (Category)2	...	Index (Category)n
	$X_1$	$X_2$		$X_n$
Respondent 1 ( $A_1$ )	$P_{11}$	$P_{12}$	...	$P_{1n}$
Respondent 2 ( $A_2$ )	$P_{21}$	$P_{22}$	...	$P_{2n}$
Respondent m ( $A_m$ )	$P_{m1}$	$P_{m2}$	...	$P_{mn}$

2) It is calculated using the following information load (entropy) relationships.

$$E_j = -k \sum_{i=1}^m [P_{ij} \ln P_{ij}]; (j = 1, 2, \dots, n) \quad ; \quad K = \frac{1}{\ln(m)}$$

$L_n$  = Logarithm

$P_{ij}$  = normalized frequency matrix (balanced)

$E_j$  = Information load of the relevant category

The information load does not indicate the number of messages in the book or content, but rather how a category or message is distributed in the book. We put the information load obtained from the above formula in a table like Table 3.

**Table 3-** Information load of categories

Indexs (Categories)	$X_1$	$X_2$	...	$X_n$
Information load ( $E_j$ )	$E_1$	$E_2$	...	$E_n$

3) Next, we divide the information load of each category ( $n, \dots, 2, 1$ ) by the total information load of that category according to the following equation to obtain the importance coefficient of that category.

$$w_j = \frac{E_j}{\sum_{j=1}^n E_j}; (j = 1, 2, \dots, n)$$

$W_j$  = Category importance

$W$  is a scale that determines the importance coefficient of the  $j$ th category in a message with respect to all respondents, and the categories resulting from the message can also be ranked with respect to the vector  $W$  (Adel, 2001).

## Results

The present study examines the trend of changes in the fundamental concepts related to organic chemistry, specifically hydrocarbons, in Iranian secondary school chemistry textbooks from 1970 to 2021. To ensure methodological consistency and uniform conditions across the examined historical periods, concepts related to saturated cyclic hydrocarbons were excluded from the analysis due to their negligible content and lack of influence on statistical calculations.

Initially, secondary school chemistry textbooks published between 1970 and 2021 were reviewed. Considering the stability of educational grade levels, the chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 were selected as the statistical sample. Subsequently, the fundamental concepts related to each branch of hydrocarbons, alkanes, alkenes, alkynes, and aromatics were extracted for the selected years. The obtained findings are presented in Tables 4 to 8.

**Table 4-** Fundamental hydrocarbon concepts in secondary chemistry textbooks, 1975

Key ideas	Fundamental Concepts	Number
<b>Alkanes</b>	Occurrence in nature; nomenclature; isomerism; physical and chemical properties (4); methane (3 preparation methods), chemical properties (3); halogenated derivatives (nomenclature, isomerism, physical and chemical properties: 5)	21
<b>Alkenes</b>	C=C bond; nomenclature; isomerism; physical and chemical properties (4); polymerization; ethylene (preparation, physical and chemical properties: 5); plastics	17

<b>Alkynes</b>	C≡C bond; nomenclature; isomerism; physical and chemical properties (3); acetylene (2 preparation methods, 7 properties); rubber (structure, vulcanization, synthetic rubber)	19
<b>Aromatics</b>	Benzene (preparation (3), physical properties, chemical properties (6), chemical structure and ortho-isomerism...), Toluene (8), Naphthalene (preparation, physical properties, chemical properties), Xylene, Aniline (3).	27
<b>Total</b>		84

**Table 5-** Fundamental Hydrocarbon Concepts, 1985

Key ideas	Fundamental Concepts	Number
<b>Alkanes</b>	Methane (expanded formula, dot model, ball-and-stick model, properties, combustion, chlorination mechanism, effect of halogens, homologous series); isomerism; nomenclature	13
<b>Alkenes</b>	Ethylene (Expanded structural formula, explanation of certain properties based on the double bond, reaction with chlorine and pathway analysis, reaction with hydrogen halides (3), combination with oxygen, polymerization, homologous series), nomenclature, isomerism, geometric isomerism, and the mechanism of addition reactions in alkenes (3).	16
<b>Alkynes</b>	Preparation (2); physical and chemical properties of acetylene; addition reactions; polymerization (2); homologous series	12
<b>Aromatics</b>	Benzene (Determination of molecular formula, types of elements and empirical formula, structure, hydrogenation, preparation from acetylene, X-ray imaging of the molecule, substitution and addition reactions with chlorine, hydrogenation reaction from the energy perspective, electronic structure (1)), study of substitution reactions of benzene (nitration, alkylation), hydrocarbons homologous to benzene, effect of chlorine on toluene (2), oxidation of toluene.	16
<b>Total</b>		57

**Table 6-** Fundamental hydrocarbon concepts, 1999

Key ideas	Fundamental Concepts	Number
<b>Alkanes</b>	Methane structure and properties; combustion; chlorination mechanism; homologous series; isomerism; nomenclature	14
<b>Alkenes</b>	Reactivity; addition reactions; mechanisms; enthalpy of hydrogenation; combustion enthalpy; carbocation stability; Markovnikov's rule	15
<b>Alkynes</b>	Acetylene preparation; hybridization; combustion enthalpy; reactions; acidity comparison	10
<b>Aromatics</b>	Benzene derivatives; nitration; alkylation; resonance; directing effects; sulfonation and chlorination mechanisms	12
<b>Total</b>		51

**Table 7-** Fundamental hydrocarbon concepts, 2009

Key ideas	Fundamental Concepts	Number
<b>Alkanes</b>	Methane models; straight-chain and branched alkanes; isomerism; combustion; octane number; nomenclature	11
<b>Alkenes</b>	Functional groups; C=C bond; ethene; polyethylene; hydration; nomenclature	6
<b>Alkynes</b>	C≡C bond; acetylene; nomenclature	3
<b>Aromatics</b>	Benzene; naphthalene	2
<b>Total</b>		22

**Table 8-** Fundamental hydrocarbon concepts, 2019

Key ideas	Fundamental Concepts	Number
Alkanes	Physical and chemical properties; structure; nomenclature; combustion enthalpy	7
Alkenes	Double bond; reactions with water and bromine; combustion enthalpy; polymerization; Teflon; LDPE; HDPE	11
Alkynes	Properties, combustion enthalpy	2
Aromatics	Benzene; naphthalene	2
<b>Total</b>		<b>22</b>

An examination of the data in Table 4 regarding hydrocarbons in secondary school chemistry textbooks in 1975 shows that, out of 84 recorded concepts, the highest number pertains to aromatics with 27 instances, while the lowest relates to alkenes with 17. Similarly, based on the data in Table 5 for 1985, out of 57 recorded concepts, the highest numbers are for aromatics and alkenes, each with 16 instances, while the lowest is for alkynes, with 12 instances. According to the data in Table 6 for 1999, out of 51 recorded concepts, the highest number pertains to alkenes, with 15 instances, while the lowest number relates to alkynes, with 10 instances. Table 7 indicates that, out of 22 recorded concepts for 2009, the highest number pertains to aromatics with 12 instances, while the lowest relates to alkynes with 3. Finally, in 2019, out of 22 recorded concepts, the highest number pertained to alkenes with 11 instances, while the lowest related to alkynes and aromatics, each with 2.

Subsequently, the alignment and comparison of fundamental concepts within each branch of hydrocarbons were carried out, with the results presented in Tables 9 to 12.

**Table 9-** Comparison of fundamental concepts in alkanes (1975–2019)

Year (AD/SH)	Fundamental Concepts	Number
1975	Occurrence in nature; nomenclature; isomerism; physical & chemical properties (4); methane (3 preparation methods, 3 chemical properties); halogen derivatives (nomenclature, isomerism, physical & chemical properties: 5)	21
1985	Methane (expanded formula, dot model, ball-and-stick, properties, combustion, chlorination mechanism, halogen effects, homologous series); isomerism; nomenclature	13
1999	Methane (homologs; chlorination & mechanism; chain & substitution reactions; alkyl halides; caffeine extraction; pesticides & pollution; CFCs; physical & chemical properties; isomerism; nomenclature)	14
2009	Methane (ball-and-stick model, space-filling); straight-chain & branched alkanes; isomerism; some properties; complete & incomplete combustion; octane number; nomenclature; alkyl groups	11
2019	Physical & chemical properties; straight-chain & branched alkanes; structural formula; nomenclature; combustion enthalpy	7

In Table 9, the basic concepts related to alkanes in secondary chemistry textbooks in selected years (1975, 1985, 1999, 2009, 2019) have been compared. Accordingly, the basic concepts of alkanes have generally shown a decreasing trend during these years, decreasing from 22 concepts in 1975 to 7 concepts in 2019.

**Table 10-** Comparison of Fundamental Concepts in Alkenes (1975–2019)

Year (AD/SH)	Fundamental Concepts	Number
1975	C=C bond; nomenclature; isomerism; physical & chemical properties (4); polymerization; ethylene (preparation, physical & chemical properties: 5); plastics	17
1985	Ethylene (expanded formula; bond explanation; reactions with Cl <sub>2</sub> & HX; combination with O <sub>2</sub> ; polymerization; homologs); nomenclature; isomerism; geometric isomerism; addition reactions (3)	16
1999	Alkene reactivity; homologs; ethene addition reactions with H <sub>2</sub> , Br, HBr; nomenclature; isomerism; geometric isomers; addition mechanisms; hydrogenation enthalpy; combustion enthalpy; carbocation stability; Markovnikov's rule	15
2009	Functional groups in hydrocarbons; C=C bond; ethene; polyethylene; ethene hydration; nomenclature	6
2019	Double bond; nomenclature of straight-chain alkenes; reactions with water & bromine; combustion enthalpy; ethene polymerization & derivatives; Teflon; LDPE & HDPE	11

Table 10 compares the basic concepts related to alkenes in secondary chemistry textbooks in selected years (1975, 1985, 1999, 2009, 2019). Accordingly, the basic concepts of alkenes have decreased from 1975 to 1999, from 17 to 6, but increased to 11 in 2019.

**Table 11-** Comparison of fundamental concepts in alkynes (1975–2019)

Year (AD/SH)	Fundamental Concepts	Number
1975	C≡C bond; nomenclature; isomerism; physical & chemical properties (3); acetylene (2 preparation methods, 7 properties); rubber (structure, vulcanization, synthetic rubber)	19
1985	Preparation (2); physical & chemical properties of acetylene; some addition reactions (hydrogenation, halogenation, effect of acids); polymerization; homologous acetylene hydrocarbons	12
1999	Acetylene preparation; carbon hybridization; combustion enthalpy comparison; isomerism; alkyne reactions; terminal acetylene; alkadiynes & hydrogenation enthalpy; acidity comparison	10
2009	C≡C bond; acetylene; nomenclature	3
2019	Properties; combustion enthalpy	2

Table 11 compares the basic concepts related to alkynes in secondary chemistry textbooks in selected years (1975, 1985, 1999, 2009, 2019). Accordingly, the basic concepts of alkynes have decreased from 1975 to 2009, from 19 to 2.

**Table 12-** Comparison of fundamental concepts in aromatic, (1975–2019)

Year (AD/SH)	Fundamental Concepts	Number
1975	Benzene (3 preparations, physical & chemical properties, 6 reactions, structure & ortho-para isomerism); toluene (8); naphthalene; xylene; aniline (4)	27
1985	Benzene (molecular formula, elements, empirical formula, structure, hydrogenation, preparation from acetylene, X-ray diffraction, substitution & addition reactions; energy-based hydrogenation); benzene substitution reactions (nitration, alkylation); homologous hydrocarbons; chlorine effect on toluene; toluene oxidation	16
1999	Benzene; nitro & alkyl derivatives; substitution reactions; resonance hybrid; directing groups; chlorinated benzene isomerism; sulfonation & chlorination mechanisms	12
2009	Benzene; naphthalene	2
2019	Benzene; naphthalene	2

Table 12 compares the basic concepts related to aromatic compounds in secondary school chemistry textbooks in selected years (1975, 1985, 1999, 2009, 2019). Accordingly, the basic concepts of aromatics have shown a decreasing trend from 1975 to 2009, from 27 to 2.

Based on the opinion of experts in the content analysis method, if the reliability coefficient for the extracted data is less than 70 percent, the interpretation of the data will be difficult (Zare-ee et al., 2021). Therefore, to calculate the reliability coefficient of the data obtained from secondary chemistry textbooks in the selected years in relation to the basic concepts of different branches of hydrocarbons and alkynes, the extracted content was provided to four randomly selected chemistry experts, and they were asked to identify the basic concepts of alkynes and calculate their frequency in the selected years. The opinions of the experts are given in Table 13. Then the agreement coefficient was calculated based on the sample formula.

**Table 13-** Experts' opinions on basic concepts related to the alkynes branch in selected years

Area	Frequency	Frequency from the present study	Frequency according to (1st expert)	Frequency according to (2nd expert)	Frequency according to (3rd expert)	Frequency according to (4th expert)
1975		19	18	17	19	17
1985		12	10	12	11	10
1999		10	11	9	10	10
2009		3	3	2	2	3
2019		2	3	2	2	3
Total		46	45	42	44	43

$$\chi = \frac{43 + 44 + 42 + 45}{4 \times 46} \times 100 = 94.56$$

Given that the agreement coefficient was more than 70% (94.56%), the reliability of the data is confirmed and interpretable.

Subsequently, the number of fundamental concepts was counted, and the resulting data were converted into percentage frequencies for each case and recorded in Tables 14 and 15. The results obtained from Shannon entropy calculations, used to determine the information content and degree of importance, were documented in Tables 16 and 17.

**Table 14-** Frequency Percentage of Fundamental Hydrocarbon Concepts, (1975–2019)

Year (AD/SH)	Alkanes	Alkenes	Alkynes	Aromatics	Total
1975	25.00	20.24	22.62	32.14	100
1985	22.81	28.07	21.05	28.07	100
1999	27.45	29.41	19.61	23.53	100
2009	50.00	27.27	13.64	9.09	100
2019	31.82	50.00	9.09	9.09	100

The data in Table 14 shows that in chemistry textbooks of 1975, the highest percentage of abundance in the hydrocarbons branch is related to aromatics with 32.14 percent, and the lowest is related to alkenes with 20.24 percent. While in 1985, the highest frequency was related to aromatics and alkenes together with 28.07 percent each, and the lowest was related to alkynes, with 21.05 percent. In 1999, the highest frequency was related to alkenes with 29.41 percent, and the lowest was

related to alkynes with 19.61 percent. In 2009, alkanes had the highest frequency with 50 percent, while the lowest frequency was related to aromatics with 9.09 percent. In 2019, alkenes had the highest frequency with 50 percent, and aromatics and alkynes had the lowest frequency with 9.09 percent each.

**Table 15-** Results of Shannon Entropy Calculations for Different Hydrocarbon Branches in the Period under Study

Parameter	Branch			
	Alkanes	Alkenes	Alkynes	Aromatics
Ej: Information load (entropy)	0.9630	0.9659	0.8574	0.7859
dj: Anti-entropy	0.0370	0.0341	0.1426	0.2141
Wj: Degree of importance	0.0865	0.0797	0.3333	0.5005

As the data in Table 15 show, the highest information load in the studied time period is related to alkenes and the lowest is related to aromatics.

**Table 16-** Results of Shannon Entropy Calculations for Hydrocarbons in the Period under Study

Parameter	Year				
	1354	1364	1378	1388	1398
Ej: Information load (entropy)	0.9888	0.9942	0.9915	0.8587	0.8273
dj: Anti-entropy	0.0112	0.0058	0.0085	0.1413	0.1727
Wj: Degree of importance	0.0330	0.0171	0.0247	0.4163	0.5088

As the data in Table 16 shows, the highest information load in the studied period was in 1985, and the lowest was in 2009.

## Discussion

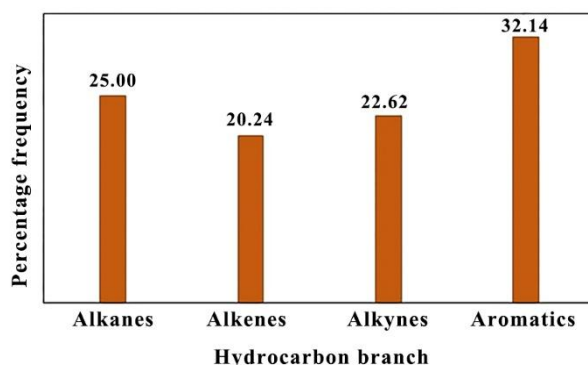
In this study, chemistry textbooks of the upper secondary level from 1971 to 2021 were examined. Considering the stability of grade levels, the textbooks published in 1975, 1985, 1999, 2009, and 2019 were selected as the statistical sample. The fundamental concepts related to each branch of hydrocarbons in organic chemistry, namely alkanes, alkenes, alkynes, and aromatics, were extracted for the selected years. The initial findings are presented in Tables 4 to 8, and their comparative analysis across the studied years is provided in Tables 9 to 12.

Subsequently, the number of fundamental concepts in each branch was counted, with the raw data recorded in Table 14 and the percentage frequencies documented in Table 15. The corresponding charts were drawn, and comparisons and data analyses were conducted based on them. In addition, the results of Shannon entropy calculations are presented in Tables 16 and 17. Based on the findings, the answers to the research questions are as follows:

1 – What is the frequency percentage of fundamental concepts of hydrocarbons (alkanes, alkenes, alkynes, aromatics) in secondary school chemistry textbooks in 1975, 1985, 1999, 2009, and 2019?

The graphs related to the percentage of frequency of the basic concepts of different branches of hydrocarbons (alkanes, alkenes, alkynes, aromatics) in chemistry textbooks of the second year of secondary school in each of the years studied are as follows. An examination of the graphs shows that this trend is not the same in the selected years, for example, while in 1975 aromatics have the highest frequency among the different branches of hydrocarbons with 32.04 percent, in 1985 aromatics and alkenes jointly have the highest frequency with 28.07 percent. And in 1999, alkenes had the highest frequency with 29.41 percent. This trend has been attributed to alkanes with 50.00 percent in 2009 and to alkenes again with 50.00 percent in 2019.

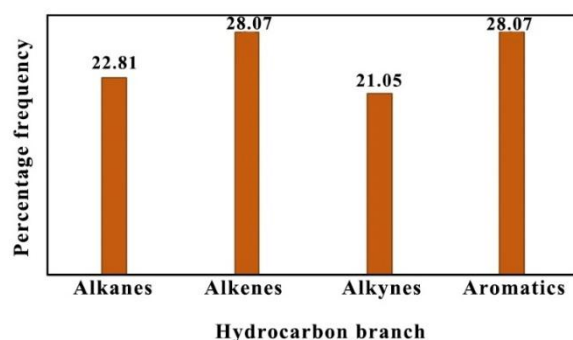
The percentage frequency of fundamental concepts in the various branches of hydrocarbons in secondary school chemistry textbooks published in 1975 is presented in Fig. 1.



**Figure 1-** Comparison of the percentage frequency of different branches of hydrocarbons in 1354 (1975)

As shown in Fig. 1, the highest percentage frequency pertains to aromatic compounds at 32.04%, while the lowest corresponds to alkenes at 20.24%.

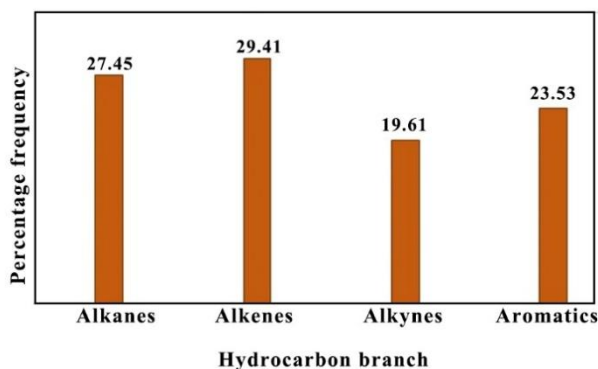
The percentage frequency of fundamental concepts in the various branches of hydrocarbons in secondary school chemistry textbooks published in 1985 is presented in Fig. 2.



**Figure 2-** Comparison of the percentage frequency of different branches of hydrocarbons in 1364 (1985)

As shown in Fig. 2, the highest percentage frequency pertains to aromatic compounds and alkenes, each at 28.07%, while the lowest corresponds to alkynes at 21.05%.

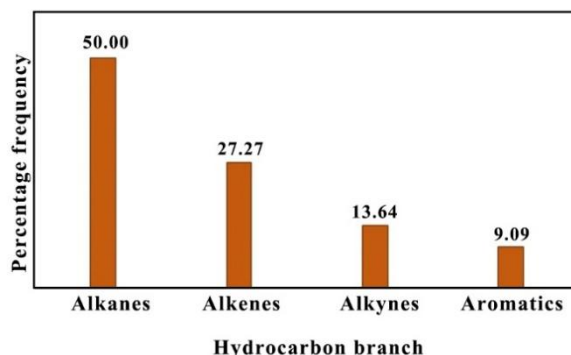
The percentage frequency of fundamental concepts in the various branches of hydrocarbons in secondary school chemistry textbooks published in 1999 is presented in Fig. 3.



**Figure 3-** Comparison of the percentage frequency of different branches of hydrocarbons in 1378 (1999)

As shown in Fig. 3, the highest percentage frequency pertains to alkenes at 29.41%, while the lowest corresponds to alkynes at 19.61%.

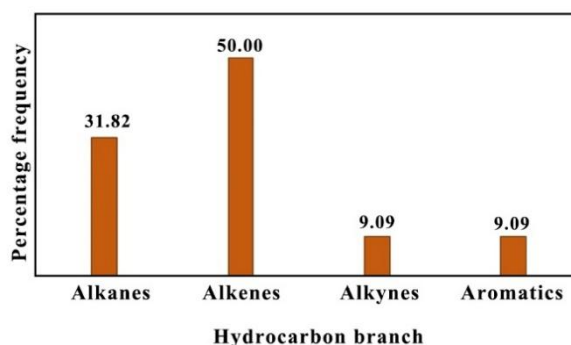
The percentage frequency of fundamental concepts in the various branches of hydrocarbons in secondary school chemistry textbooks published in 2009 is presented in Fig. 4.



**Figure 4-** Comparison of the percentage frequency of different branches of hydrocarbons in 2009

As shown in Fig. 4, the highest percentage frequency pertains to alkanes at 50.00%, while the lowest corresponds to aromatics at 9.09%.

The percentage frequency of fundamental concepts in the various branches of hydrocarbons in secondary school chemistry textbooks published in 2019 is presented in Fig. 5.



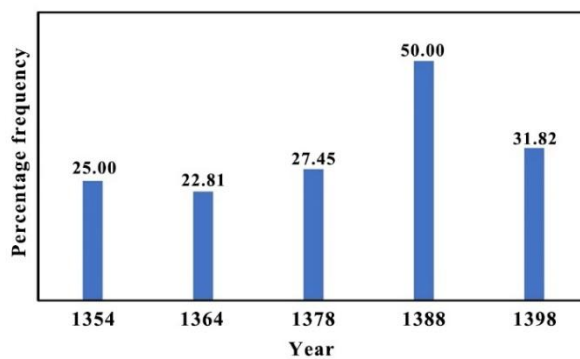
**Figure 5-** Comparison of the percentage frequency of different branches of hydrocarbons in 1398 (2019)

As shown in Fig. 5, the highest percentage frequency pertains to alkenes at 50.00%, while the lowest corresponds to alkynes and aromatics, each at 9.09%.

2 – What is the percentage frequency of fundamental concepts in each branch of hydrocarbons (alkanes, alkenes, alkynes, aromatics) in secondary school chemistry textbooks in 1975, 1985, 1999, 2009, and 2019?

The graphs related to the percentage of frequency of the basic concepts of each branch, namely alkanes, alkenes, alkynes, and aromatics, in the chemistry textbooks of the second year of secondary school in the years under study are as follows. An examination of the graphs shows that this trend is not the same in the selected years; the highest percentage of frequency of alkanes is related to the year 1388 with 50.00 percent, alkenes in the year 2009 with 50.00 percent, alkynes in the year 1975 with 22.06 percent, and aromatics in the year 1975 with 32.14 percent.

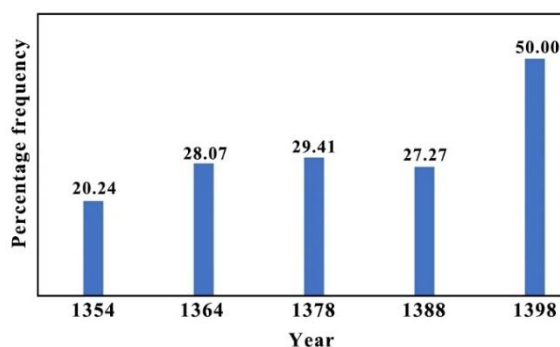
The percentage frequency of fundamental concepts related to alkanes, compared with other branches of hydrocarbons in secondary school chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 is presented in Fig. 6.



**Figure 6-** Comparison of the percentage frequency of alkanes across different years relative to other branches of hydrocarbons

As shown in Fig. 6, the highest percentage frequency of alkanes occurs in 2009 at 50.00%, while the lowest is in 1985 at 22.81%.

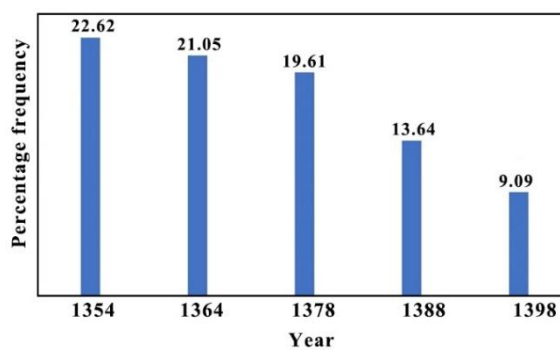
The percentage frequency of fundamental concepts related to alkenes, compared with other branches of hydrocarbons in secondary school chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 is presented in Fig. 7.



**Figure 7-** Comparison of the percentage frequency of alkenes across different years relative to other branches of hydrocarbons

As shown in Fig. 7, the highest percentage frequency of alkenes occurs in 2019 at 50.00%, while the lowest is in 1985 at 20.24%.

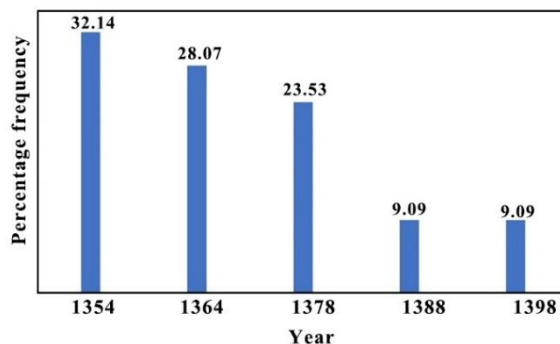
The percentage frequency of fundamental concepts related to alkynes, compared with other branches of hydrocarbons in secondary school chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 is presented in Fig. 8.



**Figure 8-** Comparison of the percentage frequency of alkynes across different years relative to other branches of hydrocarbons

As shown in Fig. 8, the highest percentage frequency of alkynes occurs in 1975 at 22.62%, while the lowest is in 2019 at 9.09%.

The percentage frequency of fundamental concepts related to aromatics, compared with other branches of hydrocarbons in secondary school chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 is presented in Fig. 9.

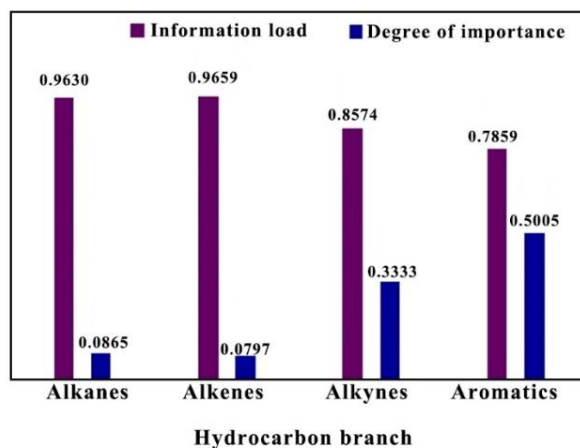


**Figure 9-** Comparison of the percentage frequency of aromatics across different years relative to other branches of hydrocarbons

As shown in Fig. 9, the highest percentage frequency of aromatics occurs in 1975 at 32.54%, while the lowest is in 2019 at 9.09%.

3 – Based on Shannon entropy, what is the information content and degree of importance of the fundamental concepts of hydrocarbons (alkanes, alkenes, alkynes, aromatics) in secondary school chemistry textbooks during the period 1971–2021?

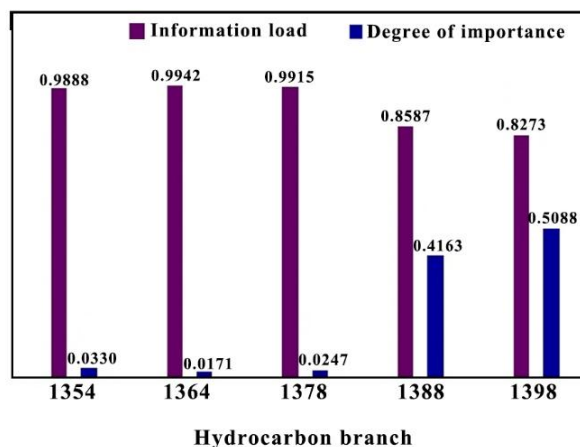
The information content and degree of importance of the various branches of hydrocarbons in secondary school chemistry textbooks published in 1975, 1985, 1999, 2009, and 2019 based on Shannon entropy calculations, are compared in Fig. 10.



**Figure 10-** Comparison of the information content and degree of importance of different branches of hydrocarbons during the studied period.

As shown in Fig. 10, the highest information content pertains to alkenes with a value of 0.9659, while the lowest corresponds to aromatics with a value of 0.7159. Similarly, the highest degree of importance is related to alkenes with a value of 0.9659, and the lowest to aromatics with a value of 0.7159.

The information content and degree of importance of hydrocarbons in secondary school chemistry textbooks during the studied years, 1975, 1985, 1999, 2009, and 2019, based on Shannon entropy calculations, are compared in Fig. 11.



**Figure 11-** Comparison of the information content and degree of importance of hydrocarbons across different years within the studied period

As shown in Fig. (11), the highest information content pertains to 1985 with a value of 0.9942, while the lowest corresponds to 2019 with a value of 0.8213. In contrast, the highest degree of importance is related to 2019 with a value of 0.5088, whereas the lowest is in 1985 with a value of 0.0171.

### Conclusion

The findings of the present study show that topics related to different branches of hydrocarbons, namely alkanes, alkenes, alkynes, and aromatics, in Iranian high school chemistry textbooks in the selected years from 1975 to the present have significant differences in terms of the number of concepts, conceptual density, distribution of trends, and informational load of concepts. In general, these differences reflect the different approaches to curriculum planning and educational goals of the Iranian education system during this period. For example, in chemistry textbooks from 1985 and 1999, the topic of chlorination reaction mechanisms and their energy studies was of interest in the chemistry of alkanes, geometric isomers in alkenes, real alkynes in alkynes, and substitution reaction mechanisms and ortho, meta, and para isomers in benzene derivatives in aromatics. While these topics have been removed from new textbooks written in the 1980s and onwards, in general, since 2004, the implementers of the chemistry curriculum have believed that organic chemistry topics should be distributed sporadically throughout the book instead of being presented in specific chapters. In addition, they have chosen a context-centered approach instead of a subject-centered approach, the manifestations of which are evident in the aforementioned textbooks.

In summary, the present study showed that the concepts of different branches of hydrocarbons in Iranian chemistry textbooks in selected years have significant differences in terms of educational approach, content structure, and prioritization of concepts. Accordingly, it is suggested that by conducting field research and examining the effects of this change in approach, a targeted and needs-based review should be carried out in order to create a balance appropriate to the results of the research. Obviously, in this regard, utilizing the experience of the educational systems of other countries that are leading and successful in teaching chemistry can improve the quality of chemistry textbooks on hydrocarbons. Based on the results of Shannon entropy, it is also suggested that more attention be paid to concepts with higher information load in curriculum design, concept sequencing, and exercise development so that key concepts can be learned in a deep and meaningful way. The results of this study can provide a scientific basis for educational policymakers, textbook authors, and researchers in the field of chemistry curriculum. In terms of limitations, this study focused solely on analyzing the topic of hydrocarbons in the content of chemistry textbooks for the second year of secondary school, and the views of teachers and students on the level of comprehensibility, efficiency, and

effectiveness of educational concepts were not examined. Also, the scope of analysis was limited to official textbooks, and other supplementary educational resources, including workbooks, teacher guides, laboratory activities, and educational aid packages, were not included in the research process.

From the perspective of innovation, this study examined and compared the content of Iranian chemistry textbooks on the topic of hydrocarbon chemistry, and for the first time, systematically analyzed the distribution of basic concepts of hydrocarbon chemistry in its various branches from 2015 to the present, from a historical perspective. The use of Shannon's entropy method to measure the information load and the degree of importance of concepts is one of the methodological innovations of this study, which has enabled a quantitative and objective assessment of the educational weight of concepts. In addition, identifying common and non-common concepts among textbooks in selected years provides a clear picture of the extent of overlap and content differences, which can serve as a scientific basis for revising curricula, improving content balance, and educational policymaking in the field of organic chemistry.

### Conflict of Interest

The authors have declared no conflicts of interest.

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