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Educação

COVERAGE OF INTERMOLECULAR FORCES IN ORGANIC CHEMISTRY TEXTBOOKS

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The paper analyzes fifteen organic chemistry textbooks commonly used in Brazilian universities to examine intermolecular forces' coverage in them. The findings revealed that the intermolecular forces are spread over a few pages (less than 1%) in a fragmented way, and over several chapters that do not provide enough information to help create a clear image in the student's mind. Thirteen textbooks contained end-of-chapter problems related to intermolecular forces. However, less than 1.3% of the total (212) are associated with intermolecular forces. This deficient approach to intermolecular forces in Organic textbooks can lead to teachers' lack of interest in teaching the subject, leading to students failing to learn this important organic chemistry topic.

Keywords: intermolecular forces; organic chemistry; textbooks.

INTRODUCTION

Intermolecular forces (IMFs) are weak attractive forces used to explain the attraction between particulate matter. They are responsible for many phenomena in our lives, like the effects of adsorption (chromatography) and viscosity, adhesion, cohesion, differences in melting and boiling points, physical states of the compounds, solubility, among many other observations.

The mastery of intermolecular forces is crucial to chemistry students because the IMFs play a central role in predicting and explaining how molecular-level systems behave in chemical and biological systems. Thus, the importance and diversity of IMFs make them a valuable component of curricula in chemistry, biochemistry, and biology courses.

Unfortunately, authors have reported students' difficulties understanding the concepts of particulate matter and the intermolecular forces.[1-17] Also, students have problems understanding how molecules are held together without chemical bonds between them,[1,2] melting and boiling processes,[7,8] and rarely can draw and explain the types of IMFs between chemical species.[9,10]

Although study guides, solution manuals, websites, and applications are increasingly used as complementary educational tools by instructors in their disciplines, textbooks still play a vital role in determining course curricula, both in specific content and pedagogical approaches.

Dense courses like Chemistry, a content-filled subject, make most instructors derive their course material directly from textbooks by considering their coverage and presenting the contents.[18] The best option will be that one that motivates students to spend the highest time interacting with the book.

This study analyzes organic chemistry textbooks to determine common patterns and assess how they introduce the intermolecular forces' contents. Moreover, the manuscript's information can help organic chemistry instructors choice about adopting an organic chemistry textbook considering the IMFs content.

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BACKGROUND

Professors' opinions

In over two decades of teaching intermolecular forces in organic chemistry courses in Brazilian Universities, we considered this subject poorly presented in the textbooks. That made it difficult for us to explore that subject properly. To investigate whether this is a personal complaint or if other colleagues shared this same dissatisfaction, we invited Brazilian and French professors to answer an electronic form with problems on the topic.

We asked professors two main questions:

i) Do you consider the intermolecular forces an important content in organic chemistry?
ii) How do you evaluate the way how textbooks present the intermolecular forces?

One hundred and eleven Brazilian (from twenty-five universities)[19] and twenty French professors (from six French universities)[20] answered the electronic form, and the results are in Table 1.

Table 1. Brazilian and French professors' evaluations of the content of intermolecular forces in the organic chemistry textbooks

Rating	Brazilian (%) (N =111)	French (%) (N =20)
Excellent	1.80	0.00
Good	31.53	20.00
Average	51.35	50.00
Bad	13.51	25.00
Awful	1.81	5.00

All professors considered the intermolecular forces an important subject in organic chemistry. However, only 66.67% of the Brazilian professors and 80.00% of the French professors considered average/bad/awful how the organic chemistry textbooks present the intermolecular forces. The survey's results motivated us to investigate the IMFs in more detail in widely adopted organic chemistry textbooks in Brazil.

ORGANIC CHEMISTRY TEXTBOOKS

We analyzed fifteen organic chemistry textbooks (Table 2) currently used by Brazillian professors to prepare their lectures.

Although all analyzed textbooks present intermolecular forces, the examination of Table 1 revealed that they do that in a small number of pages (0.9% on average). Besides, topics related to intermolecular forces are spread over several chapters (4.8 on average) in all books, with no specific chapter to address the theme. This weak approach to intermolecular forces in textbooks can lead to teachers' lack of interest in teaching the subject, failing to learn this vital organic chemistry topic.

COVERAGE OF TOPICS RELATED TO INTERMOLECULAR FORCES

We have also surveyed the organic chemistry textbooks currently used in Brazilian universities to reveal which topics related to the intermolecular forces are included in them. We analyzed 34 issues distributed in five categories: i) types; ii) physical properties; iii) biomolecules; iv) analytical techniques; and (v) other. Tables 3-8 summarize the results of the search.

Types of intermolecular forces

Table 4's data reveals that textbooks introduce five types of intermolecular forces (hydrogen bonds; London forces; dipole-dipole; ion-dipole, and dipole-induced dipole) in different ways.

86.7% of the books present hydrogen bonding and provide examples. However, 13.3% of them only offer examples of this type of interaction but do not explain it. 80.0% of the books present the London forces. While 80% of the books explain and provide examples of London forces, 6.7% of the books only introduce the dipole-dipole interactions by giving examples, and no explanation is given.

93.3% of the books present the ion-dipole interactions. However, only 40% of the books explain and provide examples of this type of interaction, while 53.3% show examples to introduce the interaction with no explanation.

Only 13.4% of the books present the dipole-induced dipole interaction, while the ion-induced dipole interaction is not present in any book.

Physical properties

Physical properties are closely related to organic compounds' physical properties; however, organic chemistry textbooks present (or not) them in very different ways (Table 5). Melting point, boiling point, and solubility are the physical properties presented in most books: 93.3%, 93.3%, and 100.0%, respectively. These physical properties are explained with examples, figures, and graphs and are usually introduced in those chapters which present the functional groups.

Density is a topic present in 60% of the books. However, only 40% of the books explain this property and provide examples. In 20% of the books, density is mentioned without defining its relationship with the intermolecular forces.

Other physical properties, such as vapor pressure, surface tension, adhesion-cohesion, capillarity, and viscosity, are not mentioned in at least 80.0% of the books surveyed. Besides, in none of the cases, the books explain the relationship between these properties and the intermolecular forces neither provide any examples. Some textbooks introduce those physical properties (except adhesion-cohesion) through examples, but no explanation is given.

Biomolecules

Biomolecules are closely related to the intermolecular forces. IMFs are responsible for attractive forces between the biomolecules and other 3D structures like DNA, proteins, and drugs. Table 6 shows that at least 80.0% of the books present all seven biomolecules by relating them to IMFs in different ways. Besides, 86.7% of the books introduce interactions between drugs and receptors; however, 20.0% of this total only present examples of interactions between drugs and receptors but do not explain the intermolecular forces' action. The same takes place with four other biomolecules in 6.7% of the books.

Table 2. Comparison of total of pages, number of pages on IMFs, number of chapters covering any topic related to the IMFs, and number of problems related to the IMFs in organic chemistry surveyed

Author	Publisher	Edition	Total Pages	Total Problems	IMFs Pages[a]	IMFs Topics[b]	IMFs Chapters[c]	IMFs Problems[d]
Brown, W. H.[21]	Cengage	6th	1194	1463	14	9	12	44
Bruice, P. Y.[22]	Pearson	7th	1293	1918	14	11	6	21
Carey, F. A.[23]	McGraw-Hill	7th	1229	1435	17	7	12	09
Clayden, J.[24]	Oxford	1st	1512	585	7	5	5	00
Hoffmann, R. V.[25]	Wiley	2nd	476	94	1	1	1	00
Jones Jr., M.[26]	W. W. Norton	4nd	1220	1467	3	3	1	04
Klein, D.[27]	Wiley	1st	1295	1895	11	6	2	11
Loundon, G. M.[28]	W. H. Freeman	6th	1485	1837	28	5	2	32
McMurry, J.[29]	Cengage	8th	1262	1842	5	4	3	03
McMurry, J.[30]	Cengage	2nd	1044	1384	5	6	3	03
Smith, J. G.[31]	McGraw-Hill	3rd	1178	2149	25	14	8	51
Solomons, T. W. G.[32]	Wiley	10th	1164	1266	9	9	1	12
Stowell, J. C.[33]	Wiley	3rd	335	230	1	1	1	01
Vollhardt, P.[34]	W. H. Freeman	6th	1270	1702	14	8	9	06
Wade Jr., L. G.[35]	Pearson	6th	1262	1417	14	4	6	15

[a] Number of pages related to IMFs [b] Number of topics related to IMFs [c] Number of chapters covering any topic related to the IMFs [d] Number of problems related to the IMFs.

Table 3. Distribution of intermolecular forces topics coverage in surveyed organic chemistry textbooks

Category	Topics	Textbooks														
		Brown[21]	Bruice[22]	Carey[23]	Clayden[24]	Hoffmann[25]	Jones Jr.[26]	Klein[27]	Loundon[28]	McMurry[29]	McMurry[30]	Smith[31]	Solomons[32]	Stowell[33]	Vollhard[34]	Wade Jr.[35]
Types	London forces	A	A	A	0	0	A	A	A	A	A	A	A	0	A	A
	Dipole-dipole	A	A	A	0	0	B	A	A	A	A	A	A	0	A	A
	Hydrogen bonding	A	A	A	A	B	A	A	A	A	A	A	A	B	A	A
	Dipole-induced dipole	0	0	A	0	0	0	0	B	0	0	0	0	0	0	0
	Ion–dipole	B	A	A	B	B	B	B	A	B	0	A	A	B	A	B
	Ion-induced dipole	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physical proprieties	Boiling point	A	A	A	B	B	A	A	A	A	A	A	A	0	A	A
	Melting point	A	A	A	B	B	A	A	A	A	A	A	A	0	A	A
	Solubility	A	A	A	B	B	A	A	A	A	B	A	A	B	A	A
	Density	A	0	B	0	0	B	0	A	B	0	A	A	0	A	A
	Meniscus and drop format	0	0	0	0	0	0	0	0	0	0	0	0	0	0	A
	Vapour pressure	B	0	0	0	B	0	0	0	0	0	0	0	0	B	0
	Dyes and dyeing	B	0	0	B	0	0	0	B	0	0	A	A	0	B	B
	Salting-out effect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Surface tension	0	0	0	0	0	0	0	B	0	0	0	0	0	B	0
	Adhesion-cohesion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Capilarity	0	B	0	0	0	0	0	0	0	0	0	0	0	0	0
	Viscosity	B	0	0	0	0	0	0	0	0	0	0	0	0	0	B
Biomolecules	Cellulose and Starch	A	A	A	A	0	B	A	A	0	A	A	A	0	A	A
	Carbohydrates	A	A	A	A	0	B	A	A	A	A	A	A	0	A	A
	Fatty acids-Soap-Micelles	A	A	A	A	0	A	A	A	A	A	A	A	0	A	A
	Cell membranes	A	A	A	A	0	B	A	A	A	A	A	A	0	A	A
	DNA	A	A	A	A	0	A	A	A	A	A	A	A	0	A	A
	Enzymes	A	A	A	A	B	A	A	A	A	A	A	A	0	A	A
	Proteins	A	A	A	B	0	A	A	A	A	A	A	A	0	A	A
	Polymers	A	A	A	A	0	A	A	B	B	B	A	B	0	A	A
	Drugs-receptors	A	A	A	A	0	A	A	B	B	B	A	A	0	A	A
An. Tech.	Infrared	A	A	A	A	B	0	A	A	A	A	A	A	0	A	A
	NMR	A	A	A	0	0	A	0	A	0	0	A	A	0	A	A
	Paper chromatography	0	A	0	0	0	0	0	B	0	0	0	0	0	0	0
	Chromatography - TLC	0	A	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chromatography - Column	A	A	A	A	B	A	C	A	A	A	0	A	B	B	A
	Electrophoresis	A	A	A	0	0	A	A	0	A	A	0	A	0	A	A
Other	Graphite	B	B	B	B	0	B	A	B	0	0	A	A	0	B	A
	Crown ether	A	A	A	A	0	A	A	A	A	0	A	A	0	A	A

Notation: A: Topic is explained, and example(s) are provided; B: Topic is not explained, but provide examples; C: Topic is explained, but examples are not provided; 0: Topic is not covered.

Analytical Techniques

Infrared, nuclear magnetic resonance (NMR), chromatography, and electrophoresis are analytical techniques closely related to the intermolecular forces. For example, in infrared, the O-H stretching of alcohol results in broad bands (3200-3550 cm^{-1}) when alcohol bonds intermolecularly to another by hydrogen bonding. The chemical shift of hydrogens bonded to oxygen atoms varies if hydrogen is interacting intermolecularly with the solvent. All chromatographic techniques (paper, column, TLC, electrophoresis, among others) promote the separation of organic compounds based on the different types of attraction forces between the organic compound (in the mobile phase) and the stationary phase.

Table 7 shows that the influence of intermolecular forces on infrared spectra is mentioned in 86.7% of the textbooks surveyed. In 80.0% of them, the content is explained by providing examples. In comparison, in 6.7% of the books, the bandwidth phenomenon is presented by showing examples without any explanation related to the hydrogen bonding.

The intermolecular forces are present in only 60% of the textbooks

Table 4. Percentage distribution of coverage on types of intermolecular forces in textbooks

Type of Interactions	Types of Coverage[a]			
	%A	%B	%C	%0
Ion-induced dipole	0.0	0.0	0.0	100.0
Hydrogen bonding	86.7	13.3	0.0	0.0
London forces	80.0	0.0	0.0	20.0
Dipole-dipole	73.3	6.7	0.0	20.0
Ion–dipole	40.0	53.3	0.0	6.7
Dipole-induced dipole	6.7	6.7	0.0	86.6

[a]Notation: A: Topic is explained, and example(s) are provided; B: Topic is not explained, but provide examples; C: Topic is explained, but examples are not provided; 0: Topic is not covered.

Table 5. Percentage distribution of coverage on physical properties in textbooks

Physical Properties	Types of Coverage[a]			
	%A	%B	%C	%0
Boiling point	80.0	13.3	0.0	6.7
Melting point	80.0	13.3	0.0	6.7
Solubility	73.3	26.7	0.0	0.0
Density	40.0	20.0	0.0	40.0
Vapor pressure	0.0	20.0	0.0	80.0
Surface tension	0.0	13.3	0.0	86.7
Adhesion-cohesion	0.0	0.0	0.0	100.0
Capilarity	0.0	6.7	0.0	99.3
Viscosity	0.0	13.3	0.0	86.7

[a]Notation: A: Topic is explained, and example(s) are provided; B: Topic is not explained but provides examples; C: Topic is defined, but examples are not provided; 0: Topic is not covered. [b]Form of the meniscus and the drop.

Table 6. Percentual distribution of coverage on biomolecules in textbooks

Biomolecules	Types of Coverage[a]			
	%A	%B	%C	%0
DNA	86.7	0.0	0.0	13.3
Soap-Micelles	86.7	0.0	0.0	13.3
Proteins/Enzymes	86.7	6.7	0.0	6.6
Carbohydrates	80.0	6.7	0.0	13.3
Cell membranes	80.0	6.7	0.0	13.3
Cellulose and Starch	73.3	6.7	0.0	20.0
Drugs-receptors	66.7	20.0	0.0	13.3

[a]Notation: A: Topic is explained, and example(s) are provided; B: Topic is not explained but provides examples; C: Topic is defined, but examples are not provided; 0: Topic is not covered.

Table 7. Percentage distribution of coverage on analytical techniques in textbooks

Analytical Techniques	Types of Coverage[a]			
	%A	%B	%C	%0
Infrared	80.0	6.7	0.0	13.3
NMR	60.0	0.0	0.0	40.0
Paper Chromatography	6.7	6.7	0.0	86.6
Chromatography - TLC	6.7	6.7	0.0	86.6
Column Chromatography	66.7	20.0	6.7	6.7
Electrophoresis	66.7	0.0	0.0	33.3

[a]Notation: A: Topic is explained, and example(s) are provided; B: Topic is not explained but provides examples; C: Topic is explained, but examples are not provided; 0: Topic is not covered.

at the chapter that introduces the NMR. The forces of attractions are explained with the providing of examples.

86.6% of the books surveyed do not mention the paper chromatography and thin-layer chromatography (TLC) or any relation between them with the intermolecular forces. 86.7% of the books introduce column chromatography and explain its relationship with the intermolecular forces' influence on the process. However, 20.0% of the books just present the technique through examples without explaining the importance of intermolecular forces on separating compounds. Finally, only 66.7% of the books surveyed mention the electrophoresis as an analytical technique related to IMFs.

Other topics related to intermolecular forces

There are other topics related to intermolecular forces whose mastery is essential to the students (Table 8). For example, the intermolecular forces are crucial in the fiber dyeing process. The survey findings revealed that 53.3% of the textbooks do not cover that topic; 13.3% explain the occurrence of intermolecular forces between dyes and fibers and provide examples, and 33.3% of the books only provide examples but do not give any explanation on the influence of the IMFs on the dyeing process.

Table 8. Percentage distribution of other topics related to IMFs in textbooks

Topics	Types of Coverage[a]			
	%A	%B	%C	%0
Dyes and dyeing	13.3	33.3	0.0	53.3
Meniscus and drop[b]	6.7	0.0	0.0	93.3
Salting-out effect	0.0	0.0	0.0	100.0
Polymers	60.0	26.7	0.0	13.3

[a]Notation: A: Topic is explained, and example(s) are provided; B: Topic is not explained but provides examples; C: Topic is explained, but examples are not provided; 0: Topic is not covered. [b] Meniscus and drop shapes.

The shape of meniscus and drops from different liquids depends on the balance between the cohesive and adhesive forces, strictly related to the IMFs. However, 93.3% of the textbooks also do not cover that topic. Only 6.7% of the books surveyed explain the format of meniscus and drops based on IMFs by providing examples.

The salting-out effect is an electrolyte–non-electrolyte interaction whose mastery would help students understand what happens when we add an aqueous saline solution to break the emulsion formed in the liquid-liquid extraction process. Unfortunately, none of the 15 textbooks surveyed covers that content.

Finally, polymers have properties that depend significantly on the forces that act between the chains. 86.7% of the books cover that topic. 60.0% of them explain it by providing examples, while 26.7% only give the examples, failing in the absence of explanation.

The survey of the textbooks identified 212 problems related to at least one of the 31 topics distributed in five categories: i) types; ii) physical properties; iii) biomolecules; iv) analytical techniques; and v) other. However, we highlight that some problems cover more than one topic, then those problems were totalized more than once, increasing the total of problems to 244. Tables 9 and 10 summarize the results of the research. We emphasize that books Clayden[24] and Hoffmann[25] were not listed in Table 10 because there are no problems related to intermolecular forces in them. Detailed information about the problems (numbers and pages where they are in each book) is available in the Supporting Information.

Table 9 shows that only 13 of the 15 books analyzed have at least one problem related to intermolecular forces. On the other hand, Table

Table 9. Number of problems related to imfs in the organic chemistry textbooks

Category	Topics	Textbooks													
		Brown[21]	Bruice[22]	Carey[23]	Jones Jr.[26]	Klein[27]	Loundon[28]	McMurry[29]	McMurry[30]	Smith[31]	Solomons[32]	Stowell[33]	Vollhard[34]	Wade Jr.[35]	Total
Type	Identification of interaction	02	01	03	02	01	01			08				02	20
Physical proprieties	Boiling point	15	08	06	01	04	09			25	06	01	03	08	86
	Melting point	03	05	01	01	04	03	01	01	08					27
	Solubility	13	09	02	01	02	19	01	01	20	06	01	03	07	85
	Density	03	01				01								05
	Vapor pressure														
	Surface tension														
	Adhesion-cohesion														
	Capilarity														
	Viscosity														
	Physical state									01					01
Biomolecules	Cellulose and Starch														
	Carbohydrates														
	Fatty acids-Soap-Micelles	04								03			01		08
	Lipids	01													01
	Cell membranes	01													01
	DNA	04						01	01						06
	Proteins-Enzymes	03	01												04
	Drugs-receptors														
An. Tech.	Infrared														
	NMR														
	Paper chromatography														
	Chromatography - TLC														
	Chromatography - Column														
	Electrophoresis														
Other	Graphite														
	Crown ether														
	Meniscus and drop format														
	Dyes and dyeing														
	Salting-out effect														
	Polymers														
Total of the problems on IMFs		44	21	09	04	11	32	03	03	51	12	01	06	15	212*
% of the problems on IMFs		3.0	1.1	0.6	0.3	0.6	1.7	0.2	0.2	2.4	0.9	0.0	0.4	1.1	

Table 10. Number of problems per category of IMFs in Organic Chemistry textbooks surveyed

Category	Number of Problems	
	Total[b]	%
Type	20	8.2
Physical properties	204	83.6
Biomolecules	20	8.2
Anal. Techniques	00	0.0
Other[a]	00	0.0
Total	244	100.0

[a]Other: Graphite, crown ether, meniscus and drop shape, dyes and dyeing, salting-out effect, and polymers. [b]There were problems related to more than one topic.

10 reveals that the problems cover only three of the five categories surveyed. The vast majority of problems (83.6%) are related to the organic compounds' physical properties. However, no problem discussed the importance of intermolecular forces on the physical properties such as vapor pressure, surface tension, adhesion-cohesion, capillarity, viscosity, and physical state of the organic compounds. Only 8.2% of the problems aim to identify the type of intermolecular force acting between species. 8.2% is regarding biomolecules like fatty acids, soap-micelles, lipids, cell membranes, DNA, proteins, and enzymes. Nevertheless, none of the 244 problems addresses the intermolecular forces' influence on graphite's structure, crown-ether, meniscus and drop shapes, dyes and dyeing, salting-out effect polymers.

Although analytical techniques (infrared, NMR, chromatography, electrophoresis), and other molecules and phenomena (graphite, crow

ether, dyeing, salting-out effect, and polymers) are covered in books by relating them to IMFs (Tables 7 and 8), none of the 244 problems addresses those categories.

The fifteen books analyzed have a total of 20,684 problems (1,378.9 on average). However, only 212 (0.73%) of them are related to intermolecular forces. This low percentage value reveals the little attention that organic chemistry textbooks give to this theme.

CONCLUSIONS

This paper analyzes fifteen organic textbooks most commonly used at Brazilian universities to find out how the books address the intermolecular forces and related topics. We found that all books cover the theme, but none has a specific chapter on IMFs. Regarding the problems associated with IMFs, the subject is usually spread over several chapters, varying from one up to twelve chapters. Thirteen of the fifteen books have at least one problem regarding intermolecular forces. However, the vast majority of problems (83.6%) are related to the organic compounds' physical properties. 8.2% are associated with identifying intermolecular forces between chemical species, and 8.2% are regarding the biomolecules. The absence of problems about the relationship between the intermolecular forces and analytical techniques, organic molecules' structures like graphite and polymers, and important chemical phenomena such as the salting-out effect may negatively impact the students' learning. As textbooks are a powerful and widely used medium for information transmission, we believe that intermolecular forces' coverage is inadequate and needs to have more significant editors' attention in the next editions of the organic chemistry textbooks.

SUPPLEMENTARY MATERIAL

All problems surveyed (and its respective pages) in each book are freely available on the tables 1S – 15S in http://quimicanova.sbq.org.br, in PDF file.

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