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Educação

INTERACTIONS: DESIGN, IMPLEMENTATION AND EVALUATION OF A COMPUTATIONAL TOOL FOR TEACHING INTERMOLECULAR FORCES IN HIGHER EDUCATION

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Intermolecular forces are a useful concept that can explain the attraction between particulate matter as well as numerous phenomena in our lives such as viscosity, solubility, drug interactions, and dyeing of fibers. However, studies show that students have difficulty understanding this important concept, which has led us to develop a free educational software in English and Portuguese. The software can be used interactively by teachers and students, thus facilitating better understanding. Professors and students, both graduate and undergraduate, were questioned about the software quality and its intuitiveness of use, facility of navigation, and pedagogical application using a Likert scale. The results led to the conclusion that the developed computer application can be characterized as an auxiliary tool to assist teachers in their lectures and students in their learning process of intermolecular forces.

Keywords: educational software; teaching; intermolecular forces.

INTRODUCTION

On the introductory disciplines in the Chemistry course, matter is presented to students as consisting of small particles, which are held together by weak attractive forces that exist between them.[1] Such forces are called intermolecular forces, which are responsible for a large number phenomena in our lives, which may explain, for example, the effects of adsorption (chromatography) and viscosity, different physical states, trends in solubility, the differences in melting and boiling points, interactions between drugs and receptors, among many other observations.[2]

Over the recent decades, the authors have reported the difficulties of students in understanding the concepts of particulate matter[1,3-6] and the intermolecular forces.[7,8] For example, it was mentioned that students confuse the energy associated with the intermolecular forces with the necessary energy to break a bond within the molecules.[3]

There were also reports of misunderstanding on the part of students, such as thinking that the particles grow when passing from the solid to the liquid state,[9] and that in the process of boiling water, water molecules are broken and the bubbles observed are made of hydrogen and oxygen.[10]

Verification of the students' difficulties in understanding the intermolecular forces has resulted in efforts of researchers to discuss the concept from different teaching approaches, such as physical properties,[11-16] educational games,[17] computer investigations,[18-21] infrared spectroscopy,[22] laboratory experiments[2,23-30] and "love"[31] to help students understand the concept.

Normally, the textbooks in higher education from the theme, intermolecular forces, has been covered in a fragmented way in several chapters using only figures that do not provide enough information to create a phenomenon's clear image in the student's mind.

Use of information technology in education has been discussed for many years,[32,33] and computational didactic tools,[34-44] such as software, videos, animations and tutorials have been produced and are available in the internet as a complementary alternative to static learning resources present in books. However, there are few resources available on the internet which cover intermolecular forces. They are mostly videos, hypertexts and some simple animations without interactivity.

This scenario motivated us to develop a useful, interactive and free of charge educational software[45] in Portuguese and English that covers several topics of intermolecular forces. This software works mainly on interactivity aiming to support chemistry educators and students beyond textbook to improve teaching-learning on the concepts related to the intermolecular forces.

EXPERIMENTAL

Software development

In order to make the most of their future profession, various skills and abilities should be developed by graduate students in chemistry during the course, through dynamic and creative spirit in the search of new educational alternatives aimed at understanding concepts, laws and principles of Chemistry; writing and critical evaluation of teaching materials; as well as having the basic knowledge in the use of computers and their application in teaching Chemistry.[46] The multi-dimension of chemical concepts was employed as the conceptual framework in the design of the software, presenting itself as a didactic computational tool to assist traditional textbooks, and especially the wide range of everyday situations where intermolecular interactions are present.

The software Interactions is user-friendly and easy to navigate and was developed using the Adobe Flash platform because it allows easy and efficient development of many functionalities, while making it possible to run in Microsoft Windows, Apple Mac OS and almost all Linux releases. Its content treats in a pedagogically useful manner many introductory intermolecular forces topics encountered in the majority of undergraduate textbooks of general chemistry and in organic chemistry and was organized in 18 different topics:

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introduction, types of intermolecular forces, boiling point, chromatography (thin layer), column chromatography, DNA, dyes, melting point, percentage of alcohol in gas, physical states, salting-out effect, solubility, surface tension, surfactants, viscosity, matching species and a quiz (Scheme 1).

The Interactions uses a combo box to access all intermolecular forces topics which are presented through short introductory texts along with graphical simulations, figures, video and animations. They were prepared and carefully designed aiming to build a connection to the text and concepts making them easier to be remembered by the user, facilitating the teaching and learning processes.

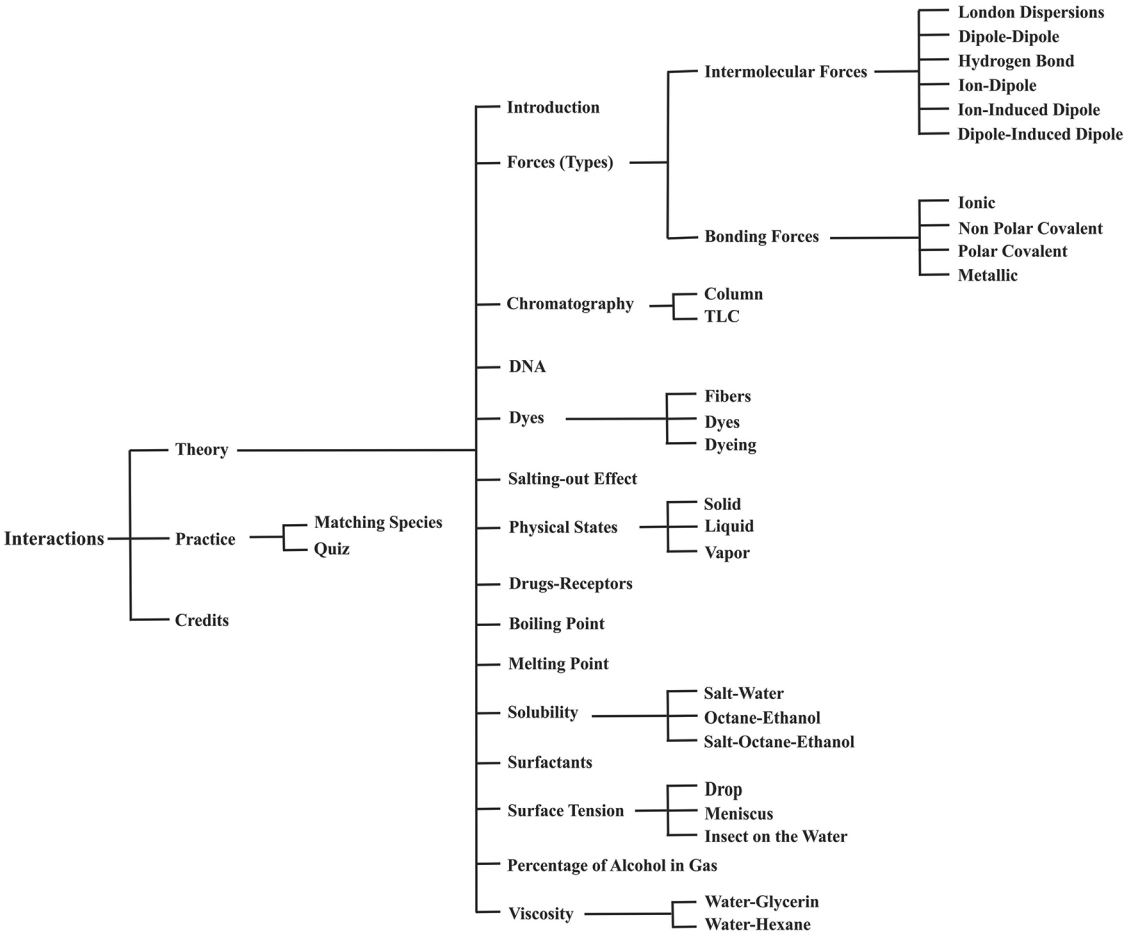
Once the users select a topic such as "Types of intermolecular forces" and clicks on "go", a short introductory text and a set of animations appear which help them in the understanding of the four different types of chemical bonds (ionic, polar covalent, nonpolar covalent and metallic) and another six types of the intermolecular forces (London dispersion, dipole-dipole, hydrogen bond, ion-dipole, ion-induced dipole, dipole-induced dipole). In this same section, the user can click on "more" and access another screen where all animations are presented together emphasizing their average relative energies (Figure 1a).

In the topic "Chromatography (Thin Layer)", the software presents a short introductory text about the subject, which has its understanding facilitated by an animation in which three compounds are moving through a thin layer where the different compounds' interactions with the eluent and silica are emphasized, resulting in their distributions on the plate. By clicking the button "more" at the bottom of this same screen, the user is brought to another screen where he can access a short introductory text and interacts with the software to see three animations and explore the influence of the choice of eluent (very polar, slightly polar and ideal) in the realization of TLC. In the topic "column chromatography", two animations illustrating the separations of a mixture with three components as they descend to the stationary phase (Figure 1b).

In "Dyes", short texts present the structures of two fibers (wool and cotton) and some dyes. By clicking the button "more" at the bottom, the user can combine fibers with two dyes (Fluorescent 32 and Direct Red 81) and see four animations which simulate the dyeing process of the fibers (Figure 2a), highlighting the existing intermolecular interaction between fiber and dye. In the topic "DNA", a short introductory text presents the DNA, their bases and the interactions between them, showing the action of intermolecular forces in defining the three-dimensional structure. In the topic "Salting-out effect", the effect is presented from texts, photos, video and animations. Initially, the user can view the effect macroscopically through a sequence of photos that leads to a video showing the phase separation in a real experiment. An animation also illustrates the molecular view of a separation of molecules of water and isopropanol by the addition of ammonium sulfate emphasizing the intermolecular forces acting in the separation process of the phases.

In "Matching species", the user can train the identification of dominant types of intermolecular forces between 49 possible pairs of species, which can be selected from two columns with 7 different species each. For each pair selected, an animation shows the dominant intermolecular force between the selected species (Figure 2b).

In "Physical states", three animations assist in understanding how the intermolecular forces act at different temperatures, resulting in different states of matter. In "Drug-receptor", two examples of



Scheme 1. *Software map*

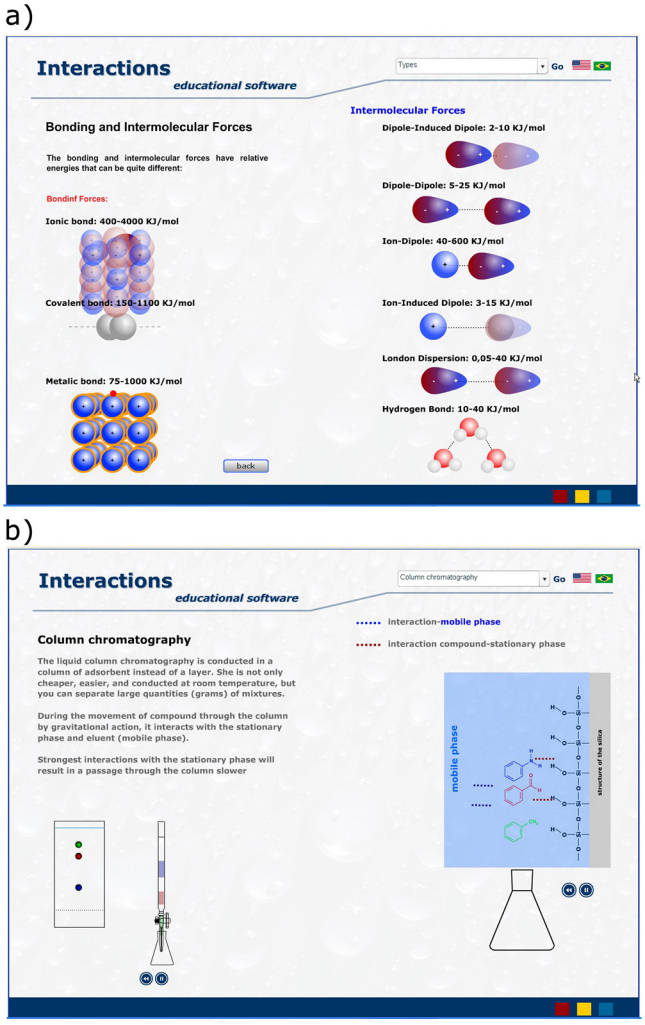


Figure 1. *a) Types of intermolecular forces; b) Chromatography column*

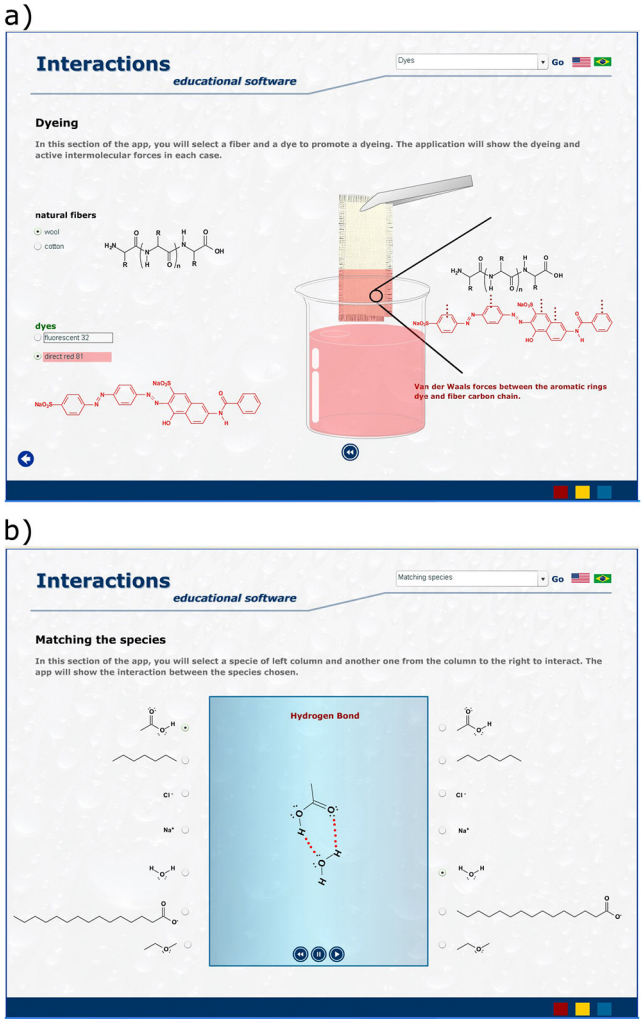


Figure 2. *a) Dyeing process; b) Matching the species*

interaction between drugs and their receptors are presented. In both cases, the user can select different intermolecular interactions between the drugs and the receptors to see them on the screen.

Topics "Boiling Point" and "Melting point" allow that user to explore interactively the influence of carbon number and branching in alkanes on them physical properties through interactive graphs. When selecting "Solubility", the process of solubilization is displayed with the aid of three animations, which assist the user in the understanding of the prevalent intermolecular forces in the mixtures salt-water, octane-ethanol and water-ethanol-octane, defining the trends of solubility in each case.

While in "Surfactants", an animation helps the understanding of the action of soap molecules on a drop of oil, which results in the formation of a micelle soluble in water. In the "Surface Tension", the concept is presented aided by a short text, images and animations into three different examples: droplet and meniscus shapes and an insect walking on a water surface.

In "Percentual of alcohol in gasoline", the user can view the macroscopic process of determining the alcohol content in the gasoline through an animation which offers to user the possibility to calculate the percentage of alcohol content in gasoline inserting some variables and clicking on the button "Calculate". With the aid of an animation, it is also possible to see a molecular view of the phenomenon of migration of the present alcohol in the gasoline to the aqueous solution of NaCl, which occurs during the separation of the phases' process. When selecting "Viscosity", the concept is introduced by a short text, which has its understanding aided by two animations which simulate the passage of a small sphere with different speeds through two different solvents. In this case, the user can understand that the speed of the ball is dependent on the number and type of the prevalent intermolecular forces, which result in different viscosities of liquids.

In the topic "Quiz", the software offers to user the opportunity to test their knowledge of the subject from an objective quiz with 50 questions. After answering the last question, the software informs the percentage of correct responses, identifies issues that have right and wrong answers, and provides a feedback of all issues.

RESULTS AND DISCUSSION

Evaluation of the software by chemistry educators

Using an electronic form containing 10 statements, this software was tested and evaluated by 52 chemistry educators (Table 1), where 15 of them were from our own University, 32 educators from other 28 Brazilian universities,[47] 1 educator from an University abroad[48] and 4 teachers from 1 high school.[49]

The group of evaluators was composed of 71% of males and 29% of females, where 81% had more than 5 years of teaching experience in higher education and 94% had already taught intermolecular forces. All opinions regarding the software were registered using a Likert scale[50-53] for each one of the resources: interface, language, content and usefulness.

The majority of evaluators agreed that Interactions is a user-friendly tool suitable for teaching undergraduate students. The evaluation conducted with the chemistry educators showed 100% of them (statement 1) found the intermolecular forces are very important for understanding other relevant topics in Chemistry and that the largest majority but only 56% (statement 2) agree that the theme is well covered in textbooks. About the software, the evaluators agree that the software is interactive and easy to use (85%, statement 3) which uses a language easy to understand (90%, statement 4) to introduce comprehensive and suitable contents for use in higher education (78%, statement 5). The majority of evaluators also agreed that the software could assist the educators in the teaching process when used in the classroom (93%, statement 7) and increase student interest (81%, statement 8). Then, they agree that the computational tool evaluated can be recommended to students as a supplementary resource to textbooks (93%, statement 9) and contribute to the improvement of student learning (92%, statement 10).

Evaluation of the software by chemistry students

Using electronic and printed forms containing 8 statements, this software was tested and evaluated by 121 chemistry students (Table 2), where 81 of them were from different courses of our own University, 40 students from other 8 Brazilian universities.[54] All opinions regarding the software were registered using a Likert scale[50-53] for each one of the resources: interface, language, content and usefulness. The evaluation conducted with the students showed they agree that software has a nice interface (90%, statement 1) which introduces the contents arousing the curiosity and interest of the user (71%, statement 2). Additionally, the software is interactive and easy to use (75%, statement 4) and presents familiar and representative structures and animations (86%, statement 4), which assist in understanding the content (91%, statement 5). Based in the students' opinions, we can suggest that the software contributes to the learning of the concepts related to the intermolecular forces (91%, statement 6) and is an important teaching tool to complement the contents in textbooks (90%, statement 7), which can improve student performance (88%, statement 8).

Evaluation of the instructional role of the software

A total of 130 students from five different undergraduate courses at Federal University of Ceará participate of the software evaluation. Subset 1 (Bio): was composed of 28 first-year Biology students. Subset 2 (Ani): was composed of 23 first-year Animal Science students. Subset 3 (Foo): was composed of 17 first-year Food Engineering students. Subset 4 (Pha): was composed of 26 first-year Pharmacy students. Subset 5 (Che): was composed of 36 first-year Chemistry students.

All groups of students answered a printed form (diagnostic test) with four questions (DQ) about the intermolecular theme before being presented to the software. Then, the professors asked groups to explore the software at home during one week and after this time the students answered another printed form (final test) with four

Table 1. Distribution of Likert Categories

Statements	Chemistry educator responses, in % (n = 52)				
	TA	A	M	D	TD
1) Intermolecular Forces are very important for understanding other relevant topics in Chemistry	87	13	0	0	0
2) Intermolecular Forces are well covered in textbooks.	06	50	33	10	2
3) Software is interactive and easy to use	50	35	8	8	0
4) Language used in the software is easy to understand.	48	42	6	4	0
5) Software contents are comprehensive and suitable for use in higher education.	40	38	17	4	0
6) Software contents are comprehensive and suitable for use in high school.	38	31	23	8	0
7) The software can assist the educator in the teaching process when used in the classroom.	58	35	8	0	0
8) The use of the software during class can increase student interest.	44	37	13	6	0
9) The software can be recommended to students as a supplementary resource to textbooks.	58	35	8	0	0
10) The software can contribute to the improvement of student learning.	52	40	8	0	0

TA: totally agree. A: agree. M: maybe. D: disagree. TD: totally disagree.

Table 2. Distribution of Likert Categories

Statements	Chemistry students responses, in % (n = 121)				
	TA	A	M	D	TD
1) The interface is nice.	21	69	09	01	00
2) The form and content of the application arouse the curiosity and interest of the user.	25	44	29	02	00
3) The structures presented in the software and animations are familiar and representative.	28	58	12	02	00
4) The structures and animation software assist in understanding the content.	48	43	09	00	00
5) Software is interactive and easy to use.	32	43	22	03	00
6) The software contributes to the learning of the concepts related to the intermolecular forces.	43	48	08	01	00
7) The software is an important teaching tool to complement the contents in textbooks.	52	38	10	00	00
8) The software can improve your performance.	39	49	12	00	00

TA: totally agree. A: agree. M: maybe. D: disagree. TD: totally disagree.

similar questions (FQ) to the first one. It's important to emphasize that the students had not had contact with the subject previously in the classroom.

The questions DQ1 and FQ1 estimate whether the students knew, from a list of 19 items, which phenomenon/properties were related with the intermolecular forces. The questions DQ2 and FQ2 estimate whether the students knew, from a list of 11 items, which were types of intermolecular forces. The questions DQ3 and FQ3 assessed students' knowledge to identify the prevalent type of intermolecular forces in four cases. The questions DQ4 and FQ4 estimate students' knowledge to represent the prevalent type of intermolecular forces in two pairs of compounds.

On the final test, the students informed that the average time spent in their studies using the software was 77 minutes. The results of these evaluations are presented in the Figure 3.

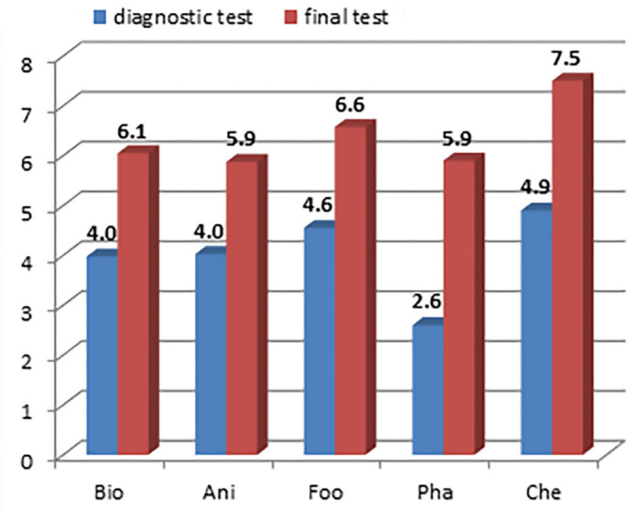


Figure 3. *Average Scores of the Diagnostic and Final Evaluations for Different Audiences: Bio (n=28), Ani (n=23), Foo (n=17), Pha (n=26) and Che (n=36)*

The effectiveness of the instructional role of the software can be proven through the comparison between the scores of the diagnostic and final tests. We can to observe that in all five students sets, theirs scores had increments of 65,2% in weighted average.

Students' opinions

After the final test, the students were stimulated to describe the importance of the software utilization by the professor in the classroom and by themselves at their homes to improve their learning. The responses were much similar and covered the same points. Some students' opinions are listed below:

"The software is very useful to boost a lecture about intermolecular forces, it is very educational and easy to use. The class was much faster, because the teacher does not waste time drawing on the board."

"The software helped greatly in my learning, especially the animations pair collaborated a better understanding. Through the software the lesson becomes more dynamic."

"The software enriches the lesson because it shows in detail the movements and interactions of the molecules, which students might not be able to understand without it."

"The software holds the attention of the student."

"The software is quite educational because it facilitates understanding and visualization of different forces that could be readily explained by a simple drawing in the frame. It stimulates curiosity and student interaction with the subject matter."

CONCLUSIONS

It can be concluded that the software, in the form that was designed and implemented was well evaluated by professors and students and can be used as an auxiliary tool for learning intermolecular forces. In addition, the final tests suggest that the software can contribute to the construction of student knowledge.

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