CONTRIBUTIONS OF LAKATOSIAN THEORY TO THE EVALUATION OF EXPLANATORY MODELS OF INTERMOLECULAR FORCES MADE BY UPPER-SECONDARY SCHOOL STUDENTS

Ana Carolina Gomes Miranda
Federal University of Ouro Preto, Brazil
E-mail: ana.miranda@ufop.edu.br

Maurícius Selvero Pazinato
Federal University of Rio Grande do Sul, Brazil
E-mail: mauriuspazinato@gmail.com

Abstract

The focus of the present study is the learning processes of concepts related to hydrogen bonds, which were developed using a didactic sequence (DS). Based on the perspective of Imre Lakatos, it was observed whether the explanatory models created by upper-secondary students form progressive transition sequences, which are similar to what Lakatos, in his text The History of Science*, calls a "problem" that increases the explanatory/heuristic power of the model. To evaluate the evolution of these models, which generally consist of progressive transitions, four phases were developed: 1) the categorization of answers obtained in the DS in Realist, Empiricist or Rationalist zones, as well as an attribution of scores; 2) the determination of a score range for said zones; 3) hierarchical cluster analysis (HCA) and 4) an analysis of the progressive transition of the explanatory models. A continuous review of the ideas expressed by the students during their learning of the subject revealed that a significant share of students progressed conceptually. In a general way, it can be said that the activities developed in the DS contributed substantially to the progressive transition of the explanatory models made by most students. Furthermore, the approach of the DS toward the subject of hydrogen bonds allowed the students to interpret the phenomena studied using their knowledge of Chemistry.*
Keywords: *London force and dipole-dipole interactions, progressive transition, chemistry teaching*

Introduction

Intermolecular interactions are a key point for understanding the properties of materials, e.g. melting and boiling points, solubility, density and viscosity; furthermore, they permeate several fields of knowledge based on the understanding of everyday phenomena. In addition, according to the official education documents of Brazil, upper-secondary students must: understand the properties of substances and materials in terms of interactions between atoms, molecules or ions; understand the concepts of boiling and melting points and their relationships with the nature of substances; understand the concepts of density and solubility and their dependence on temperature and the nature of the material, and recognize that the technological applications of substances and materials are related to their properties (Mec, 1998). Alongside the curricular guidelines for upper-secondary education, more recently the National Common Curricular Basis (Mec, 2018) emphasized that students need to develop skills and abilities related to the topic in question. Among them, the following stand out: using Chemistry

https://doi.org/10.33225/pec/23.81.176 ISSN 1822-7864 (Print) ISSN 2538-7111 (Online)

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 2, 2023

codes and nomenclatures to characterize materials, substances or chemical transformations; understanding methods and procedures typical of the natural sciences and applying them in different contexts; and relating physical, chemical or biological properties of products, systems or technological processes to their intended purposes.

Some studies (Santos, Almeida, & Filho, 2020; Cooper, et al., 2015) indicate that the subject of intermolecular forces has not been taught efficiently. They even state that the topic has the potential to generate alternative concepts in the scientific models created by students. In another study (Miranda, et al., 2018), bibliographical research was carried out in Brazilian and international journals to detect the main trends in the teaching and learning of intermolecular forces. This study identified gaps in learning processes that include the most recurrent alternative concepts. They are there are no significant differences between intermolecular forces and chemical bonds; intermolecular forces are stronger than intramolecular bonds; there is a hydrogen bond in all molecules containing hydrogen, and the strength of this interaction is measured by the number of hydrogen atoms that the molecule has, e.g., the interactions between molecules of CH_4 are more intense than those of NH_3. This evidence motivated us to elaborate a Didactic Sequence (DS) in an attempt to promote a more coherent learning process in upper-secondary classes, that is, in accordance with the currently accepted scientific models.

Following this, theoretical foundations were sought that could help in the interpretation of the conceptual evolution of this topic by upper-secondary students. Within this perspective, the relationship between the epistemology of science and the evolution of knowledge in the school context has been recognized by philosophers of science, psychologists, researchers and educators (Carey, 1985; Gil-Pérez, 1993; Duschl, & Gitomer, 1994; Niaz, 1998; Laburú & Niaz, 2002; Martorano, 2012). It is believed that the theory of Imre Lakatos on the progress of science can be a tool for investigating the conceptual evolution of studied subjects. According to Niaz (1998), the epistemology of science based on the assumptions proposed by Lakatos has didactic-pedagogical implications that can bring important benefits to teaching and learning.

For Lakatos, the progress of science portrays what he defines as a methodology of Scientific Research Programmes (SRP). An SRP consists of several theories that progressively evolve, and the process of science is characterized by the competition between rival Research Programmes. SRPs are characterized by methodological rules: “some tell us what paths of research to avoid (negative heuristic), and others what paths to pursue (positive heuristic)” (Lakatos, 1971, p. 162).

Analogously, this perspective can be used in Chemistry teaching to analyze whether the explanatory models of upper-secondary students form progressive transition sequences (Niaz, 2001), similar to what Lakatos, with regard to scientific progress, calls the “problem” that increases the explanatory/heuristic power of a given model or theory.

Research Problem

The study of intermolecular forces is of critical importance to understand phenomena found in daily life. However, we acknowledge that teaching and learning these concepts is not as easy as it appears. This issue, which is essential to Chemistry, demands the teacher pay attention to class development, mainly in the approach to theories, laws and models in order to avoid the distortion of content. As for the students, besides personal effort and study, learning the content of intermolecular forces demands a high capacity of abstraction, as well as the transition between the matter representative levels so that the concepts can form sequences of progressive transition. Within this context, the question that guided this research was: "How to evaluate the explanatory models of upper-secondary students about the nature of intermolecular forces, based on the relationship between Lakatosian theory and the levels of representation of chemical knowledge?"

Research Focus

With these considerations in mind, the aim of this study is to observe how the explanatory models of upper-secondary students about intermolecular forces form progressive transition sequences based on the development of a didactic sequence.

Research Methodology

General Background

This study followed the principles of mixed methods (qualitative and quantitative) research. participants were 29 students enrolled in the first year of upper-secondary education at a Federal Institute in the state of Rio Grande do Sul, Brazil. Data were collected by means of questionnaires applied before, during and after the development of a didactic sequence (DS) on the subject of intermolecular forces. The DS was organized based on the theoretical assumptions recommended by Zabala (1998) and an adaptation of the structuring criteria proposed by Dolz, et al., (2004). According to the authors, DSs consist of activities with a progressive level of cognitive complexity in terms of the approaches that students must develop to solve certain problems. For Zabala (1998), DSs are a set of ordered and articulated activities to achieve educational objectives. In addition, the author states that the use of this strategy is an important tool to reflect on and improve teaching practices since it expresses different elements of actions that educators can adopt, such as decisions on the selection and organization of subjects, resources, spaces, time and methods of evaluating the learning process.

Regarding the concepts related to the subject of intermolecular forces, essential topics for understanding the nature of these interactions were developed, as well as their influence on the physical properties of materials. The DS was organized in three didactic units (DU):

- Nature of intermolecular forces DU: developed in 6h/classes to promote an understanding of the electrostatic nature of intermolecular interactions.
- London force and dipole-dipole interactions DU: lasted three classes, totaling 6 hours/class, whose main objective was to understand the electrostatic nature of the dipole-dipole interaction due to the distribution of electrical charges and the formation of electric dipoles.
- Hydrogen bonding DU: developed in 6h/classes with the aim of understanding the electrostatic nature of the hydrogen bond at an atomic-molecular level.

In total, six weeks of application were necessary, amounting to a month and a half of effective development of all activities. However, this study focused on the description and analysis of the London Force and dipole-dipole interactions unit, which discussed fundamental aspects for the understanding of intermolecular forces in upper-secondary education.

Sample

52 students from two classes of the first year of upper-secondary education participated in this research, 26 in the technical course in Chemistry and 26 in the Industrial Automation course, which are integrated into upper-secondary education.

It is noteworthy that some students did not participate in all the interventions related to the subject of intermolecular forces, and, therefore, exclusion criteria were established, such as:
- Not answering two or more instruments - Students who did not answer two or more collection instruments. It is believed that students who did not attend at least two classes dedicated to intermolecular forces could, in this case, interfere with the research results. Thus, these criteria restricted the number of participants. Of the 52 initial students, 29 were considered subjects for data analysis.

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 2, 2023

Instrument and Procedures

Data collection took place before, during and after the development of the DS. It should be noted that the DS was designed to promote the progressive transition of the explanatory models created by the participating students. In this way, to facilitate the data collection process and subsequent analysis, the activities were separated into research phases: - Initial phase – application of the initial diagnostic questionnaire; - Intermediate phase – development of activities proposed in the DS; - Final phase – application of a final diagnostic questionnaire.

Table 1
Phases, Descriptions Activities and Data Collection Instruments.

London Force and Dipole-Dipole Interactions DU		
Phase	Description of activity	Instruments
Initial	Application of the initial diagnostic questionnaire.	Questionnaire regarding: the identification of dipole-dipole and London interactions, the electrostatic nature of the dipole-dipole interaction due to the distribution of electric charges and formation of electric dipoles; the nature of the London forces by polarizability, as well as the magnitude of these interactions in rationalizing observable macroscopic properties; influence and magnitude of these interactions on the physical properties of substances
Intermediate	- Solution of the initial problem	Instruments organized according to the sequence of the seven methodological steps proposed for the discussion and resolution of problems, proposed by Schmidt (1983): Reading the Problem, identification and clarification of unknown terms; Identification of the problems proposed by the statement; Formulations of explanatory hypotheses; Summary of hypotheses; Formulations of learning objects; Study and research of the issues raised in the learning objectives; Re-discussions of the problem and sharing of new knowledge acquired in the study phase to the group.
	Investigative experimental activity	Instrument to collect pictographic data on the submicroscopic representation of dipole-dipole interactions and London forces.
Final	Application of the final diagnostic questionnaire.	Questionnaire for final data collection.

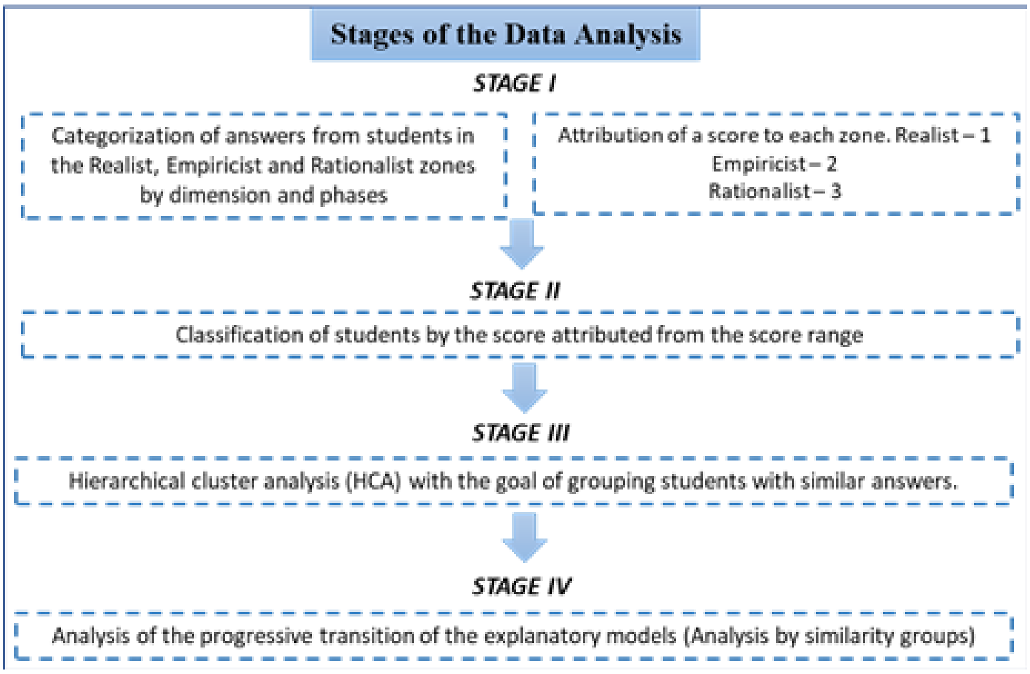
Table 1 presents, in a simplified way, the phases of the study, as well as descriptions of the activities carried out and the data collection instruments used during the DS. To understand in detail the development of the didactic sequence, in addition to the aspects, consult Miranda (2018).

Data Analysis

The data analysis to evaluate the conceptual evolution of the participants was divided into four stages, as shown in Figure 1.

ISSN 1822-7864 (Print) ISSN 2538-7111 (Online) https://doi.org/10.33225/pec/23.81.176

Figure 1
Stages of Data Analysis



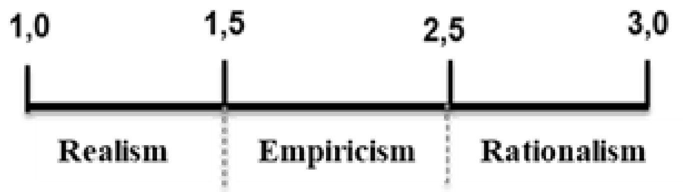
In stage I, the responses of students were read, transcribed into Microsoft Office Excel® spreadsheets and grouped into the categories suggested by Pazinato (2016) in the three stages of the study, as described in Table 2. Thus, score 1 was assigned for students who presented realistic conceptions of the subject in their ideas, score 2, for empiricist ideas and score 3, for rationalist conceptions.

Table 2
Description of Philosophical Zones

Philosophical zone	Description	*Score*
Realist	They present non-scientific notions. They represent ideas associated with common sense, characterized by naive, subjective and intuitive ways of enunciating a certain concept.	1
Empiricist	They begin to use scientific terms derived directly from observation, experimentation or experimental data. They present ideas with a greater degree of abstraction than the previous zone and generally do not establish many relationships between concepts.	2
Rationalist	They present scientific ways of thinking about the concepts in question. The ideas are complex and interrelated, most of the time with great power of abstraction. In this zone, there is a higher level of reflection on the scientific concepts researched.	3

In the second stage, the average of the answers of each student per phase of the research (initial, intermediate and final) was calculated, which represents the predominant zone of the students' ideas. For this, Score ranges were determined for each philosophical zone, in order to obtain an overview of the origin of the student's knowledge, as shown in Figure 4. This is justified by the plurality of thoughts, since, often, for a given concept, responses from different philosophical areas were presented throughout the research. It is noteworthy that in each of the phases (initial, intermediate and final) data were collected that served as support to analyze the progressive transition. For example, in the initial phase, seven questions were used (Q1 to Q7). In this way, the classification for student E5's ideas was: Q1 realistic (1), Q2 realistic (1), Q3 realistic (1), Q4 empiricist (2), Q5 empiricist (2), Q6 realistic (1) and Q7 empiricists (2). Therefore, the average of the answers was calculated (1+1+1+2+2+1+2/ 7 = 1.4) and this student presented a predominantly realistic notion about the hydrogen bond. Score ranges were determined to obtain an overview of the ideas presented by students, as explained above. This same procedure was repeated for the other students in all phases of the research.

Figure 2
Score Range



In the third stage, a statistical method for HCA - *Hierarchical Cluster Analysis* – was used, which allows for optimizing data by grouping students with similar answers (Hair, 2005) and prevents the analysis of progressive transition sequences from becoming exhaustive and repetitive. For each group formed from the aforementioned technique, a subject was randomly chosen that represents the ideas of the entire group to demonstrate the analysis of the progressive transition, that is, to evaluate the conceptual evolution during the approach of the content of intermolecular forces, contemplated in step IV.

In addition, the matter representation levels were also considered for the evaluation of progressive transition sequences. In this analysis, the categories proposed by Martorano (2012) were adapted, as shown in Table 3

Table 3
Description of Proposed Categories of Representation of Chemical Knowledge Levels

Category	Description
MEM –Macroscopic explanatory model	This category will include students who are able to present their pictographic representations only with macroscopic characteristics, that is, descriptive and functional representations of the phenomena under study.
SEM–Submicroscopic explanatory model	This category will include students who represent phenomena through entities from the submicroscopic world and through the use of specific chemistry terms.
LEM–Linked explanatory model	This category will include students who make linked relationships between submicroscopic and macroscopic levels, as well as representation of phenomena through scientifically accepted models.

Research Results

Table 4 presents the results referring to steps I and II. Hence, the percentage of students who remained in the zones of the initial, intermediate and final phases of the research is shown.

Table 4

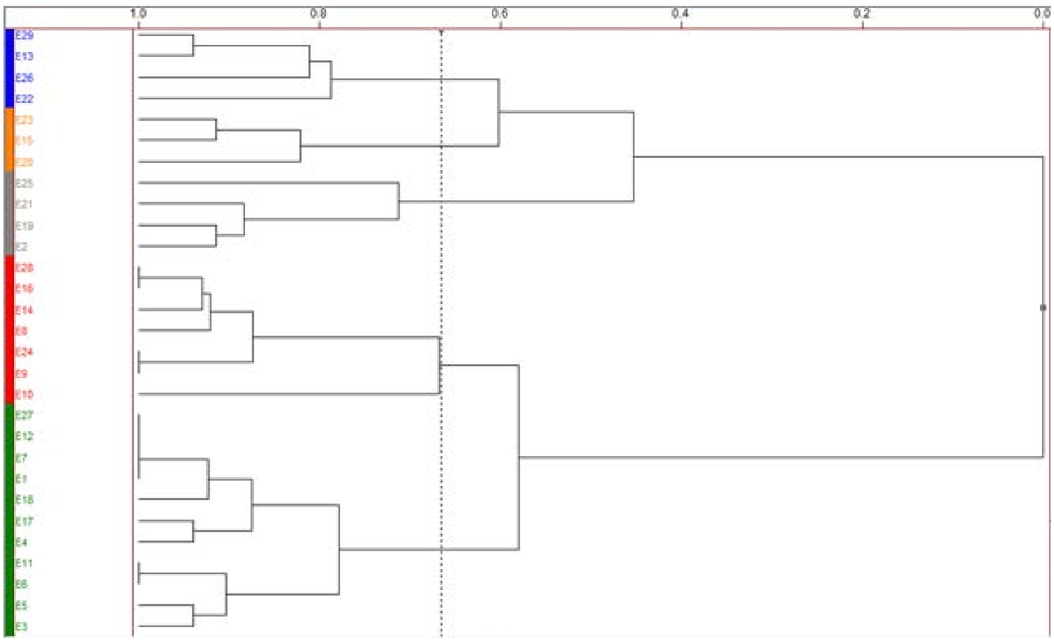
Categorization of Responses on Intermolecular Forces in the Initial, Intermediate and Final Phases of the Research

Zones	Score range	Percentage per research phase %		
		Initial	Intermediate	Final
Realist	1.0-1.4	31.0	-	-
Empiricist	1.5-2.4	65.5	27.5	31.0
Rationalist	2.5-3.0	3.5	72.5	69.0

After analyzing stages I and II, the HCA was used to group students with similar responses. The dendrogram obtained from the HCA is represented in Figure 3. The branches of the Dendrogram indicate five groups of students (I-V) with 65.5% (0.655) of similarity.

Figure 3

Dendrogram Obtained from the HCA Using the Ward/Incremental Method and the Euclidean Distance



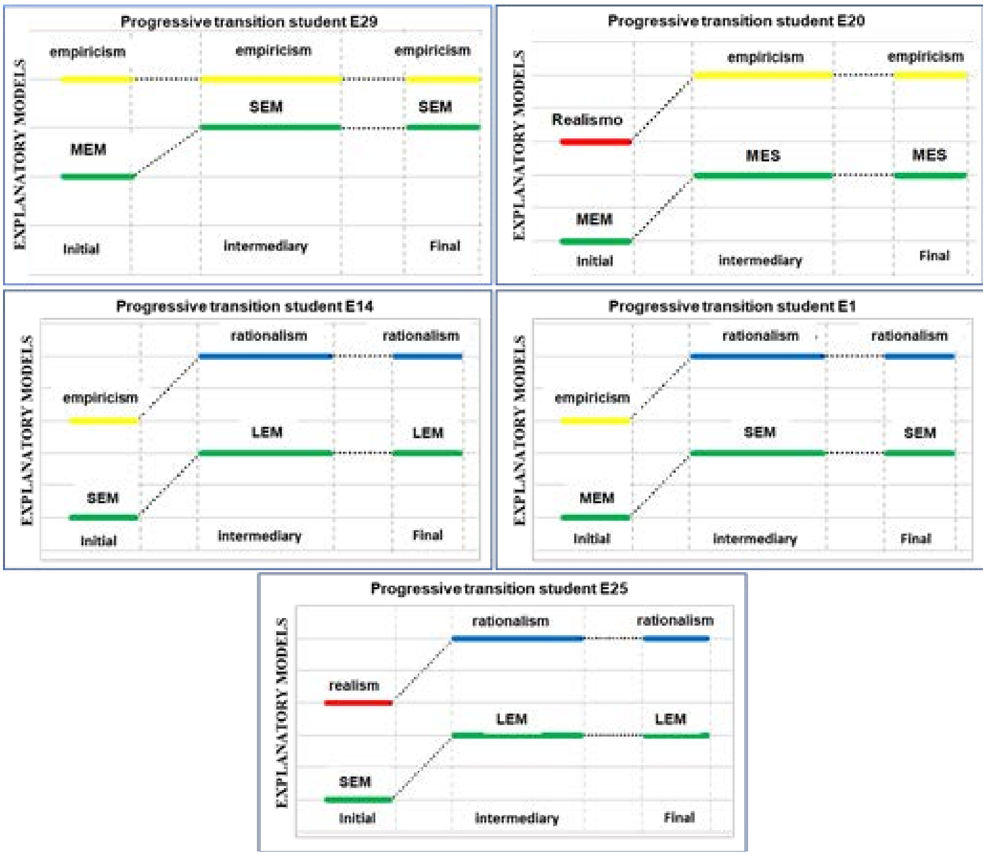
Thus, from the results obtained in the HCA, Table 5 was created. It presents the grouping of students with similar answers, as well as the subject chosen to describe the development of the progressive transition sequence of the explanatory models.

Table 5
HCA Groups and Students Chosen to Develop the Progressive Transition Sequence

	Students	Progressive Transition
Group I	E29 E13 E26 E22	E29
Group II	E23 E15 E20	E20
Group III	E25 E21 E19 E2	E25
Group IV	E28 E16 E14 E9 E10	E14
Group V	E27 E12 E7 E1 E18 E17 E4 E11 E6 E5 E3	E1

In view of the above, the progressive transition sequences of the students mentioned in Table 5 will be presented below. Thus, Figure 4 shows the analysis of the progressive transition of the students in the London forces dimension and dipole-dipole in the three phases of the research. In addition, it shows graphs that represent the evolution of the explanatory models of students E29, E20, E25, E14 and E1, (representatives of the groups specified in Table 2), respectively.

Figure 4
Progressive Transition of Students E29, E20, E25, E14 and E1 in the Three Phases of the Research



PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 2, 2023

Discussion

At the end of the DS, it can be seen that most students (20) managed to evolve conceptually. It was noticeable that they understood that a dipole-dipole interaction, for example, occurs between molecules containing the bond connecting two different atoms, in which the electrons are not shared symmetrically, presenting an electric dipole moment (μ) and forming a permanent dipole. In this way, when close to each other, the molecules attract each other through the partial charges of opposite signs located in each molecule. In addition, they understood the London forces and the influence of these interactions on physical properties.

However, it was detected that a group of students still had empiricist ideas, failing to form progressive transition sequences of their explanatory models, that is, there was no significant conceptual evolution during the research phases, as observed in the representatives of groups I and II, E29 and E20, respectively. The aforementioned aspects were evaluated during the discussion of this section, in which important themes that could guide the causes of learning difficulties and resistance to conceptual changes were addressed. Authors such as Duschl and Gitomer (1991) studied the philosophy of science to affirm the gradual and evolutionary nature of conceptual changes, as opposed to the image of radical changes proposed by a philosophy based on Kuhnian assumptions. The authors are attentive to the transpositions of the philosophy of science to the understanding of the learning process in the classroom and highlight important information regarding students' resistance to changes.

According to Niaz (1998), those beliefs that are resistant to change can be compared to the "hard core" of a scientific research program; that is, this core is what defines the program, takes the form of a hypothesis within which the program develops and, as a result, removing or altering it will cause it to degenerate. According to the author, students resist changes in their core convictions by creating "auxiliary hypotheses" to defend them. These supporting hypotheses can offer springboards for the development of new teaching strategies. Still, according to Niaz (1998), it is important to explore the relationship between core beliefs and students' alternative conceptions. For this, it is essential that the alternative conceptions are interpreted within the epistemological assumptions because, in this way, an alternative conception does not become a mere mistake and resembles a paradigm. According to the author, this similarity can help it become a candidate for change. Similar to the learning process, Lakatos (1970) observes that, in science, the core of a Program develops slowly through a long and slow process of trial and error and never emerges out of the blue. In this way, the act of learning is a slow process and requires the use of methods that favor the students to overcome their core convictions.

Furthermore, Miranda et al., (2022) argue that empiricism is still rooted in teaching practice and in teaching materials used in basic education. The empiricist conception continues to be adopted by teachers, being strongly inspired by the work of Sir Francis Bacon, who proposed an empiricist-inductive method. In this way, proven knowledge is absolute knowledge and, therefore, unquestionable, which implies the exacerbated application of general rules for the concepts under study.

In view of this, the aforementioned author argues that effective learning in science involves a slow process of change that should be directed not only towards the assimilation of concepts but mainly towards new modes of reasoning, epistemological demands and cognitive values.

Regarding the ability to move between the levels of matter representation, it was observed that the students were able to represent their pictographic models, through more complex, interrelated and submicroscopic schemes. For Miranda et al., (2022) the exacerbated use of principles, laws and the application of general rules without submicroscopically considering the phenomena under study is related to a purely empiricist view of the construction and application of scientific knowledge. With this in mind, we believe there was a deepened understanding of

https://doi.org/10.33225/pec/23.81.176 ISSN 1822-7864 (Print) ISSN 2538-7111 (Online)

concepts related to intermolecular forces, and the activities developed effectively contributed to the progressive transition of the students' explanatory models.

Conclusions and Implications

In order to achieve the objectives proposed in this work and respond to the research problem: "How to evaluate the explanatory models of upper-secondary students about the nature of intermolecular forces, based on the relationship between Lakatosian theory and the levels of representation of chemical knowledge?", a didactic sequence was created for the construction of knowledge on the topic of intermolecular forces. A DS was developed based on experimental activities of an investigative nature, problem-solving and modeling activities, with a view to conceptual evolution on the part of the students, so that their explanatory models could form progressive transition sequences, increasing the heuristic power of this model.

It was noticed that there was a significant percentage of students who managed to progress during the research. It is concluded that the use of differentiated activities in the teaching of intermolecular forces, within a constructivist perspective, in which students become active subjects in the construction of knowledge, significantly favors the learning process. Therefore, the results revealed that these interventions were important for the subjects to be able to evolve conceptually and form progressive transition sequences of their explanatory models, that is, they progressively managed to increase the heuristic power of these models.

In addition, this research still has numerous possibilities for studies on the topic addressed. The Brazilian educational context needs more research that conjectures the interpretation of everyday phenomena through the understanding of the content of intermolecular forces. Also, it is extremely important that epistemological issues are included in initial training curricula and in discussions of continuing teacher training, since epistemological aspects are fundamental for a more critical training and for overcoming the empiricist model still influential in Brazilian education.

Acknowledgements

The Federal University of Ouro Preto, CAPES and CNPq.

Declaration of Interest

The authors declare no competing interest.

References

Carey, S. (1985). *Conceptual change in childhood* (6th ed.). MIT Press.

Cooper, M. M., Williams, L. C., & Underwood, S. M. (2015). Student understanding of intermolecular forces: a multimodal study. *Journal of Chemical Education*, 92(8), 1288-1298. https://doi.org/10.1021/acs.jchemed.5b00169

Dolz, J. Noverraz, M., & Schneuwly. B. (2004). Sequências didáticas para o oral e a escrita: apresentação de um procedimento [Didactic sequences for speaking and writing: presentation of a procedure]. (21th ed.): Mercado de Letras.

Duschl, R. A., & Gitomer, D. H. (1994). Epistemological perspectives on conceptual change: implications for educational practice. *Journal of Research in Science Teaching*, 12(3), 324-345. https://doi.org/10.1002/tea.3660280909

Gil- Pérez, D. (1993). Contribución de la historia y la filosofía de las ciencias al desarrollo de um modelo de enseñanza/aprendizaje como investigación [Contribution of the history and philosophy of science to the development of a teaching/learning model as research]. *Enseñanza de las Ciencias*, *11*(2), 197-212. https://doi.org/10.5565/rev/ensciencias.4537

Hair, J. R. (2005). *Análise Multivariada de Dados* (5th ed). Bookman.

Laburú, C. E., & Niaz, M. (2012). A Lakatosian framework to analyze situations of cognitive conflict and controversy in students' understanding of heat energy and temperature. *Journal of Science Education and Technology*, *11*(3), 360-385. https://doi.org/10.1023/A:1016064301034

Lakatos, I. (1971). History of science and its rational reconstruction. Boston Studies in the Philosophy of Science. *Boston Studies in the Philosophy of Science, 13*(6), 28-41.

Martorano, S. A. A. (2012). Transição progressiva dos modelos de ensino sobre cinética química a partir do desenvolvimento histórico do tema [Progressive transition of teaching models on chemical kinetics based on the historical development of the subject]. *USP digital library.* https://www.teses.usp.br/teses/disponiveis/81/81132/tde-25022013- 124601/pt-br.php

MEC, Ministério da Educação e do Desporto (1998). Parâmetros curriculares nacionais: Ciências naturais [National curriculum parameters: Natural sciences]. http://portal.mec.gov.br/seb/arquivos/pdf/ciencias.pdf

MEC, Ministério da Educação. (2018). Base Nacional Comum Curricular [Common National Curriculum Base]. http://basenacionalcomum.mec.gov.br/images/BNCC_EI_EF_110518_versaofinal_site.pdf

Miranda, A. C. G. (2018). Ligações Químicas: Transição progressiva dos modelos explicativos de estudantes do nível médio sobre forças intermoleculares [Chemical Bonds: Progressive transition of upper-secondary students' explanatory models on intermolecular forces]. *UFSM Digital Repository* https://repositorio.ufsm.br/handle/1/16510

Miranda, A. C. G., Pazinato, M. S., & Braibante, M. E. F. (2018). Tendências do ensino e aprendizagem de forças intermoleculares a partir da análise de publicações em periódicos nacionais e internacionais [Trends in teaching and learning intermolecular forces based on the analysis of publications in national and international journals]. *Revista Electrónica de Enseñanza de las Ciencia, 17*(2), 394-419. http://reec.uvigo.es/volumenes/volumen17/REEC_17_2_06_ex1290.pdf

Miranda, A. C. G., Pazinato, M. S., & Braibante, M. E. F. (2022). Transição progressiva dos modelos explicativos de estudantes do nível médio sobre a natureza das forças intermoleculares [Progressive transition of explanatory models of Upper-secondary students on the nature of intermolecular forces]. *Investigações Em Ensino De Ciências*, 27(2), 01–22. https://doi.org/10.22600/1518-8795.ienci2022v27n2p01

Niaz, M. A (2001). Rational reconstruction of the origin of the covalent bond and its implications for general chemistry textbooks. *International Journal of Science Education, 23*(6), 623-641. https://doi.org/10.1080/09500690010006491

Niaz, M. A. (1998). Lakatosian Conceptual change teaching strategy based on student ability to build models with varying degrees of conceptual understanding of chemical equilibrium. *Science & Education*, 2(7), 107-127. https://doi.org/10.1023/A:1008671632536

Pazinato, M. S. (2016). Ligações Químicas: Investigação da construção do conhecimento no ensino médio[Chemical Bonds: Investigation of the construction of knowledge in secondary education]. *UFSM Digital Repository*. https://repositorio.ufsm.br/handle/1/3555

Pazinato, M. S., Bernardi, F. M., Miranda, A. C. G., & Braibante, M. E. F.(2021). Epistemological Profile of Chemical Bonding: Evaluation of Knowledge Construction in High School. *Journal of Chemical Education*, 171-246. https://doi.org/10.1021/acs.jchemed.0c00353

Santos, M. de C., Almeida, L. R., & Filho, P. F. S. (2020). O Ensino Contextualizado de Interações Intermoleculares a partir da Temática dos Adoçantes [The contextualized teaching of intermolecular interactions from the theme of sweeteners]. *Ciência & Educação, 26*(2), 20-38. https://doi.org/10.1590/1516-731320200028

Zabala, A. A (1998). *Educational practice: How to educate.* (5th ed.). Artmed. https://www.ifmg.edu.br/ribeiraodasneves/noticias/vem-ai-o-iii-ifmg-debate/zabala-a-pratica-educativa.pdf

Received: *February 11, 2022* Revised: *March 20, 2023* Accepted: *April 05, 2023*

Cite as: Miranda, A. C. G., & Pazinato, M. S. (2023). Contributions of Lakatosian theory to the evaluation of explanatory models of intermolecular forces made by upper-secondary students. *Problems of Education in the 21st Century*, *81*(2), 176-187. https://doi.org/10.33225/pec/23.81.176

Ana Carolina Gomes Miranda *(Corresponding author)*	PhD in Chemistry Teaching, Professor, Federal University of Ouro Preto, Rua Dom Veloso, 108. Bairro Cabeças, Ouro Preto, Minas Gerais, Brazil. E-mail: ana.miranda@ufop.edu.br ORCID: https://orcid.org/0000-0002-6675-6033
Maurícius Selvero Pazinato	PhD in Chemistry Teaching, Federal University of Rio Grande do Sul, Minas Gerais, Brazil. E-mail: mauriuspazinato@gmail.com ORCID: https://orcid.org/0000-0003-2440-7836