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PAPER

Students' Alternative Conceptions and Teachers' Views on the Implementation of Pedagogical Strategies to Improve the Teaching of Chemical Bonding Concepts

Abdelouahed Lahlali(✉), Nadia Chafiq, Mohamed Radid, Azzeddine Atibi, Khadija El Kababi, Chaibia Srour, Kamal Moundy

Hassan II University, Casablanca, Morocco

abdelouahed.lahlali-etu@etu.univh2c.ma

ABSTRACT

The concept of chemical bonding is a crucial one in chemistry that occurs throughout the school curriculum and forms the basis of many topics in chemistry. Furthermore, learning about chemical bonding allows the learner to make predictions and provide explanations regarding the physical and chemical properties of substances. However, chemical bonding has been cited as one of the most difficult chemistry concepts for many secondary and higher education students to understand, and therefore, teachers can find it difficult to teach this concept due to the complexity of the underlying theory as well as the need to use abstract models to represent chemical bonds. The teaching methods used in the implementation of the concept can also be challenging. The aim of this study is to reveal the difficulties and alternative conceptions encountered by Moroccan secondary school students when learning concepts related to chemical bonding, the main causes of these difficulties, and the strategies used by teachers to help students overcome these obstacles. In this study, we conducted a survey of 57 Moroccan secondary school physical science teachers by means of a questionnaire. The questionnaire, consisting of three parts, was used to collect the data. Each part contains closed questions, open questions, and multiple-choice questions. The analysis of the results highlights the difficulties and alternative conceptions most frequently made by the students, namely: the octet rule, the geometry of molecules, and the polarity of molecules. Factors contributing to students' misconceptions include the nature of abstract concepts, the use of models, and the difficulty for teachers to explain certain concepts related to chemical bonding. The study also presents some suggestions for improving the teaching of chemical bonding, such as integrating information and communication technologies (ICT), diversifying the teaching tools used, and taking into account students' pre-existing conceptions. This can help teachers, curriculum developers, and textbook authors make the subject easier for students and address their misconceptions.

KEYWORDS

chemistry teaching, alternative conceptions, learning difficulties, chemical bonding

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1 INTRODUCTION

Chemistry is considered a fundamental science that depends on several fields of knowledge, such as health, biology, and geology … Therefore, an understanding of the basic concepts of chemistry is necessary, including chemical bonding and associated concepts such as the octet rule, ionic bonding, and molecular geometry… .

Chemical bonding is one of the key and fundamental concepts in chemistry [1–3]. It is a fundamental concept at the heart of the basic structural interface of chemistry, a key concept in explaining the cohesion of matter and molecular architecture, and it allows for the understanding of the structure and properties of chemical compounds.

However, assimilating this concept can be difficult for several reasons. Firstly, chemical bonds are microscopic phenomena that cannot be directly observed with the naked eye. Therefore, understanding them requires the use of theoretical models such as Lewis models, VSEPR (Valence Shell Electron Pairs Repulsion) models, or molecular orbital theory. These models are often abstract and can be difficult for students to visualize. Furthermore, the concept of chemical bonding is closely related to other concepts in chemistry such as the electronic structure of atoms, the polarity of molecules, and intermolecular forces.

Understanding these concepts is crucial to understanding the nature of chemical bonding, but they can also be difficult to assimilate. Thus, other studies explain the difficulty related to these concepts through the influence of school textbooks [4], the use of traditional pedagogy, and classroom practice by teachers [5]. Overall, the assimilation of the concept of chemical bonding and related concepts may be difficult to teach in the chemistry classroom [6,7] due to the abstract nature of the theoretical models used [4], the complexity of the connected concepts, and the multiplicity of models proposed.

Currently, many studies conducted in the Moroccan context (university cycle only) and even globally at all school and university levels have shown that most pupils and students find major difficulties in learning the concept of chemical bonding and related concepts. Indeed, research conducted by [4,8–11] revealed that students encounter difficulties in learning the concepts related to chemical bonding. Many students have a low level of progress in learning chemical bonding and do not possess the adequate understanding required for post-secondary education in chemistry courses.

Understanding the concept of chemical bonding is crucial for learning chemistry. Chemical bonding is the central concept of many other basic concepts in the chemistry program, but its complexity can cause difficulties for students. In view of these difficulties, the question arises as to how to facilitate the assimilation of the concept of chemical bonding and related concepts by chemistry students by identifying the best teaching strategies and the most effective pedagogical methods to improve the learning and understanding of these key concepts.

The study of pupils' alternative conceptions from the teachers' point of view in the scientific literature is poorly developed from a didactic point of view. Consequently, this research will focus on teachers' perspectives as key players in the teaching and learning process.

In this respect, the aim of this study is to identify the major difficulties and the most frequent alternative conceptions related to the learning of the concept of chemical bonding and related concepts among secondary school students from the teachers' point of view, including the origin of these difficulties and the strategies that teachers use to remedy them.

To this end, answers to the following questions were sought in this study:

- What are the most common alternative conceptions and difficulties of secondary school students regarding the concepts of chemical bonding?
- What are the factors responsible for the misperception of concepts related to chemical bonding?
- How can teachers adapt their teaching strategies to help students with different levels of understanding assimilate the concept of chemical bonding?

2 LITERATURE REVIEW

Pupils have persistent difficulties with some basic concepts in chemistry, such as the relationship between ionic and covalent bonds, and the geometry of molecules. Misconceptions are common and persist even after several years of teaching. Therefore, research in chemistry didactics has targeted these difficulties and the alternative conceptions of pupils and university students for several decades. The aim is to understand the origin and nature of these difficulties in the study context in order to propose solutions to overcome them.

Learning difficulties in chemistry: This is related to the student's relationship to knowledge and concerns the cognitive processes deployed by the student in learning, alternative conceptions, and epistemological barriers, as well as the language and abstraction of knowledge in science [12].

Learning difficulties in chemistry can have multiple causes, including the complexity of concepts, the need to use abstract models, the presence of alternative conceptions and difficulties in reasoning … These difficulties can lead to misconceptions and deficiencies that persist throughout the school curriculum.

Alternative conceptions: A great deal of didactic research has shown that certain students' responses, which are generally described as "errors", are derived from a personal mode of reasoning and explanatory system, which presents a perfect and structured logic for them. This prompts didactic researchers to take an interest in and give major importance to what is called conception. Conceptions are students' internal representations of a concept, usually in science [13]. Some authors call them preconceptions, prescientific conceptions, misconceptions, primitive, naive, alternative, intuitive, erroneous, inappropriate, spontaneous, or unexpected conceptions. In English literature, the term misconception is preferred [14].

The alternative conceptual framework may have its origins in concepts learned in class, but about which students have drawn conclusions or developed explanations that are not consistent with scientific theory [15,16]. The identification of pupils' conceptions about a given concept, and moreover the identification of the origin of these conceptions or representations, could however prove very useful in constructing teaching sessions. Indeed, in light of these conceptions, the knowledge constructed by the pupils could sometimes turn out to be obstacles that hinder the learning of new notions. Among the alternative conceptions listed in the scientific literature, we will discuss those related to the concepts of chemical bonding and associated concepts.

Examples of alternative conceptions or misconceptions regarding chemical bonding: Research in literature has shown that students have difficulties with this concept, regardless of their learning context. Multiple sources, such as studies and textbooks, have identified various examples of misconceptions and alternative conceptions of chemical bonding. The following table (Table 1) presents common misconceptions regarding chemical bonding.

Table 1. Examples of common misconceptions regarding chemical bonding

Examples of Common Misconceptions	Relevant Sources
Think of a covalent bond as the equal sharing of electron pairs	[1, 17]
The student reduced the definition of the concept of chemical bond to the covalent bond	[9]
The concept of polarity and the geometry of molecules are challenging to comprehend	[17, 18, 20, 29]
Limit the type of bond to two: covalent and ionic	[17, 33]
Students believed ionic bonding was a sharing of electrons	[20, 22, 28, 30, 31]
Confusing intramolecular bonding with intermolecular bonding	[19, 24, 27]
Thinking that all the atoms in a molecule must obey the octet rule	[1, 10, 17, 23, 29, 33]
Confusing covalent and ionic bonds	[11, 19–21, 23–29, 32–33]

3 METHODOLOGY

3.1 Characteristics of the sample

The target respondents of this study were teachers in a single provincial directorate of the Regional Academy of Education and Training Casablanca-Settat region of Morocco, from the discipline of Physics and Chemistry, practicing in schools in urban areas. A total of 57 teachers from a total population of 70 participated in the questionnaire survey, and the participation rate is around 81%. The sample was selected in a simple random manner and comprised 46 men (81%) and 11 women (19%).

The following table (Table 2) presents the characteristics of the respondents. The first section of the table concerns the age of the respondents in the study, with the majority of respondents being between 31 and 40 years old (52.63%), 22.81% being under 30 years old, 15.79% being between 41 and 50 years old, and only 8.77% being over 51 years old.

Table 2. Characteristics of the participant (n = 57)

Attributes	Characteristics	Number	Percentage (%)
Age class	Under 30 years old	13	22.81%
	31 to 40 years old	30	52.63%
	41 to 50 years old	9	15.79%
	Over 51 years old	5	8.77%
Seniority	Less than 5 years	13	22.81%
	Between 5 and 10 years	19	33.33%
	Between 10 and 15 years	15	26.32%
	More than 15 years	10	17.54%
Level of study	Bachelor's degree	16	28.07%
	Master	31	54.38%
	Doctorate	10	17.54%
Professional training	Yes	48	84%
	No	9	16%
Specialty of study	Physics	29	51%
	Chemistry	28	49%

The second section of the table provides information on the professional experience of the teachers, where the majority of the respondents (33.33%) have been in the profession for between 5 and 10 years, followed by those with between 10 and 15 years (26.32%) and those with less than 5 years (22.81%), while teachers with more than 15 years of experience represent only 17.54% of the respondents (Table 2).

The third section of the table provides information on the educational backgrounds of the respondents. The majority have a master's degree (54.38%), followed by those with a bachelor's degree (28.07%) and those with a PhD (17.54%) (Table 2).

The fourth section of the table provides information on professional training, where the vast majority (84%) have received professional training in training centers, while a minority of teachers work directly without prior training (16%). Finally, the last section of the table provides data on the respondents' field of study. There is an almost equal distribution between physics and chemistry, with slightly more respondents having a specialty in physics (51%) (Table 2).

3.2 Measurement instrument

This research is conducted using a quantitative approach. To address the research questions, we employed an anonymous electronic questionnaire consisting of three distinct sections.

In the first part, entitled "Identification of difficulties and alternative conceptions", which aimed at identifying the different difficulties and alternative conceptions encountered by students regarding the concept of chemical bonding and related concepts from the teachers' perspective, we have included two questions: The first open-ended question collected different difficulties and alternative conceptions related to the concept of chemical bonding and related concepts and categorized them. The second question proposed a list of concepts related to chemical bonding, and we asked participants to select the concept(s) that seemed difficult to teach.

In the second part, entitled "Factors Responsible for the Misperception of Concepts", which aimed to determine the origin of the misperception of concepts related to chemical bonding, we proposed an evaluation of the factors influencing students' perception of the concepts relating to chemical bonding. This evaluation was carried out using a five-point Likert scale, ranging from "strongly agree", marked 5, to "strongly disagree", marked 1. In addition to this, we included multiple-choice questions (MCQs) to examine teacher-related factors such as the didactic tools and methods used to teach chemical bonding concepts and the methods used to diagnose difficulties and misconceptions.

In the third part, entitled "Solutions Proposed by Teachers to Remedy Difficulties and Alternative Conceptions", which aimed to collect proposals for solutions to difficulties related to the concept of chemical bonding and other associated concepts, we presented suggestions to overcome learning difficulties associated with the concept of chemical bonding and other related concepts. This assessment was carried out using a five-point Likert scale, ranging from "strongly agree" rated 5 to "strongly disagree" rated 1. In addition, we asked participants to suggest other solutions.

Ethical considerations: All respondents understood that participating in this study was voluntary, and they could decide to withdraw at any time. Furthermore, teachers were informed that their responses would only be used for a research study and that their identities would not be revealed.

Validation of the tool: The questionnaire was first checked and approved by four experts in the field of chemistry and education: two Moroccan university teachers at a public university in Morocco, a physics and chemistry inspector and an associate professor with 21 years of experience in teaching chemistry.

This validation process resulted in the rewording of various items to make them more understandable to the respondents and more scientifically accurate. The experts considered the final version of the questionnaire to be valid. Before being used as a data collection instrument, it is important to note that the questionnaire was tested with 20 participants with characteristics similar to those of the study participants.

Data analysis process: The quantitative data gathered through questionnaires were analyzed using descriptive analysis (means and standard deviations) using SPSS 25 and Microsoft Office Excel 365. Concerning the open-ended questions in the questionnaire, content analysis was employed to code the answers into a meaningful set of categories.

The respondents' responses, assessed on a five-point Likert scale, are interpreted as follows (Table 3): The class interval is calculated by subtracting the maximum score with the minimum score and then dividing them with the number of scales; therefore, the class interval in this case is 0.8.

Table 3. Data interpretation

Point Value	Mean Range	Level of Agreement
1	1.00–1.79	Strongly disagree
2	1.80–2.59	Disagree
3	2.60–3.39	Slightly agree
4	3.40–4.19	Agree
5	4.20–5.00	Strongly agree

The table below (Table 4) shows the results of the Cronbach's Alpha reliability test on the questionnaire. The results show that the items are highly correlated as the Cronbach's Alpha values are quite higher than the value of 0.700 which is often considered highly correlated [34,35].

Table 4. Reliability statistics

Part	Number of Items	Cronbach's Alpha
Factors responsible for the misperception of concepts.	13	0.938
Solutions proposed by teachers to remedy difficulties and alternative conceptions.	10	0.955

4 RESULTS

4.1 Identification of difficulties and alternative conceptions with regard to chemical bonding and related concepts

The following table (Table 5) lists the different difficulties and the most frequent alternative conceptions identified by the teachers among the students about chemical bonding and related concepts, classified into eight sub-categories.

Table 5. List of difficulties and alternative conceptions identified by teachers with regard to students' concepts of chemical bonding

Category	Difficulties and Alternative Conceptions Identified among Students
Electronic structure and the octet rule	• The distribution of electrons on the electronic shells. • Non-observance of the octet rule for an element in a molecule. • Understanding the electronic structure and the outer shell.
The valence shell and valence electrons	• Confusion between the valence shell and valence electrons.
Covalent and ionic bonding	• Difficulty in distinguishing the different types of bonds. • Confusion of two concepts: ionic compounds and molecules. • Difficulty in distinguishing between a covalent bond and an ionic.
Electronegativity and polarity of a molecule	• The determination of the polarity of a molecule and the link to polar bonding. • The polarity of this molecule is determined solely by the differences in electronegativity between its atoms, without taking into account the molecular shape. • The difficulty in understanding the concept of electronegativity. • The location of partial charges in a molecule.
Isomerism	• The concepts of isomerism. • The structural representation of molecules and the confusion with the Lewis representation. • Confusion between structural formulae and the Lewis representation.
The geometry of the molecule	• The representation of the geometry of a molecule and the difficulty of representing it in 3D space.
Cram model	• The difficulty in realizing the Cram representation, as well as the representation of the bonds in this representation.
Lewis structure	• Failure to respect the number of bonds a chemical element can make in a molecule. • The organization of atoms in the representation of molecules. • The representation of some specific molecules. • The understanding of binding and non-binding doublets.

We note that several very common conceptual difficulties are detected by the present research, according to the teachers' statement. The categories of responses include such things as electronic structure and octet rules, valence shell and valence electrons, covalent bonding and ionic bonding, electronegativity and polarity of a molecule, isomerism, geometry of the molecule, the Cram model, and Lewis structure. This list clearly shows that understanding the concept of chemical bonding involves mastering several interrelated concepts and that the difficulties encountered by students can come from different sources (Table 5).

By comparing the above misconceptions, we can confirm that the concepts are chained and well structured. Moreover, if the student fails to master such concepts, it may induce difficulties; for example, to predict the polarity of molecules, it is necessary to know the geometry of the molecules and their electronegativity.

In addition, the following table (Table 6) presents the results allowing us to identify the concept(s) that seem to be difficult to teach from the teachers' point of view, and which allows us to measure the teachers' mastery of the concepts, as well as their impact on the teaching-learning process.

Table 6. A list of concepts that seem difficult to teach

Concepts	Number of Responses	Percentage%
Molecule geometry	29	50.9
Cram representation	24	42.1
The Polarity of a molecule	22	38.6
Isomerism	20	35.1
Electronegativity	19	33.33
Ionic bonding	17	29.8
Lewis structure	11	19.3
Polarized bonding	11	19.3
Duet rule	4	7
Octet rule	4	7
Electronic structure	4	7
Covalent bond	3	5.3
Valence shell	2	3.5
Valence electrons	2	3.5

The teachers interviewed identified some concepts as being more difficult to teach than others. According to their views, the geometry of a molecule (50.9%), the Cram representation (42.1%), the polarity of a molecule (38.6%), isomerism (35.1%), electronegativity (33.33%), and ionic bonding (29.8%) are among the most difficult concepts to teach, while other concepts seem to pose less difficulty. These results affirm the complexity of chemical bonding concepts in chemistry teaching and help to identify the concepts that teachers have difficulties with, which can help to improve the way these concepts are taught and understood by students (see Table 5).

In terms of identifying difficulties and alternative conceptions of students regarding concepts related to chemical bonding, it was found that the majority of teachers (82.5%) were able to identify difficulties and misconceptions of students, while 17.5% claimed not to have identified them. It is clear from the responses that some chemistry teachers are not aware of or do not address the misconceptions held by students, which can lead to the persistence of these misconceptions. Therefore, the results highlight the importance of addressing students' misconceptions in chemistry teaching in order to remedy them and ensure a deeper understanding of the concepts.

These results are serious warnings for chemistry teaching at the level of secondary education in Morocco. Teachers will certainly be concerned to overcome the difficulties of concepts that do not seem to be mastered by their students, but first of all, it is necessary to know the factors responsible for the misperception of concepts.

4.2 Factors responsible for the misperception of concepts related to chemical bonding

The table below (Table 7) presents the results of our study on the factors that cause students' misperceptions of chemical bonding concepts, categorized according to respondents. These results have been classified into different categories according to the respondents interviewed.

Table 7. Factors responsible for the misperception of concepts related to chemical bonding

Factors	Items	Mean	Standard Deviation	Level of Agreement
Of didactic origin	The nature of abstract concepts.	3.05	1.540	slightly agree
	Concepts poorly adapted in the program: internal didactic transposition.	2.82	1.364	slightly agree
	Use of the textbook.	2.60	1.307	slightly agree
	Use of models (Lewis).	2.56	1.414	Disagree
Of pedagogical origin	The conditions of overcrowded classrooms.	3.39	1.656	slightly agree
	Absence of laboratory.	3.23	1.637	slightly agree
	Lack of teaching materials.	3.18	1.501	slightly agree
	Time spent on the chemistry program.	2.84	1.486	slightly agree
Student-related factors	Presence of representations (conceptions) among students.	3.07	1.321	slightly agree
	The influence of the language of instruction (language barrier).	3.09	1.491	slightly agree
	Pupils' orientation.	3.02	1.302	slightly agree
Teacher-related factors	Traditional teaching (absence of active pedagogies).	2.86	1.381	slightly agree
	Lack of training in science didactics.	2.72	1.278	slightly agree

The analysis of these results allowed us to distinguish four main sub-categories of factors that are responsible for this poor perception of chemical bonding concepts.

The first factor concerns difficulties of didactic origin, in which we find the nature of abstract concepts (3.05), concepts poorly adapted in the curriculum (2.82), the use of the textbook (2.60) and the use of models (2.56) (Table 7). The second factor is pedagogical in origin, such as overcrowded class conditions (3.39), lack of laboratories (3.23), lack of teaching materials (3.18) in addition to the time devoted to the chemistry program (2.84). The third factor is student-related difficulties, in which we find the presence of student conceptions (3.07), the influence of the language of instruction (3.09) and students' orientation (3.02). The last factor is teacher-related difficulties, considered less important, such as traditional teaching (2.86) and a lack of training in science didactics (2.72). All these last items have an agreement level of "slightly agree" except for the item "Use of models (Lewis)" which is in "disagree".

Other teacher-related factors: The table below (Table 8) shows the didactic tools used by teachers to teach concepts related to chemical bonding, as well as the number of respondents for each tool. The results show that the majority of teachers prefer the use of information and communication technologies (ICTs), such as animations and simulations, as well as molecular models (colored balls and rods). However, some teachers continue to use tools such as the blackboard and the textbook. It is important to note that the use of inappropriate teaching aids can cause difficulties for students.

Table 8. Didactic tools used by teachers to teach concepts related to chemical bonding

Didactic Tools	Percentage
Table	50.87%
Textbook	17.54%
Animations, simulations	66.67%
Molecular models (colored balls, rods for associating the balls)	57.94%

Table 9 presents the pedagogies used by teachers to teach the concepts related to chemical bonding. The results of the responses indicate that 49.1% of the teachers surveyed opt for a problem-solving method as a pedagogy for constructing the concept of chemical bonding and related concepts. However, 35.1% prefer the investigation method, and only 17.5% of the teachers prefer project-based pedagogy. Finally, almost a quarter of the respondents preferred to use the traditional method. These results highlight the diversity of pedagogies adopted by teachers to teach the concept of chemical bonding and related concepts. The presence of teachers using the traditional method may lead to misconceptions among students.

Table 9. Methods used by teachers when teaching concepts related to chemical bonding

Methods Used	Percentage
Problem solving	49.1%
Investigative pedagogy	35.1%
The traditional method	22.8%
Project-based teaching	17.5%

Table 10 presents the tools used to diagnose difficulties and misconceptions among students. The analysis of the results shows that the majority of respondents consider that exercises, summative assessments and written tests are the most common tools used to detect difficulties and misconceptions among students. This lack of assessment practice can lead to problems for students who fail to correct their misconceptions and misrepresentations early in the learning process. These results also suggest that teachers are not sufficiently aware of the importance of exploiting students' representations in their teaching, which may limit the deep understanding of chemical bonding and other related concepts.

Table 10. Methods of diagnosing difficulties and misconceptions

	Very Rarely	Rarely	From Time to Time	Often	Very Often
Assessments at the beginning of the session	17.54%	15.78%	31.57%	17.54%	17.54%
Assessments during the session	7.01%	24.56%	31.48%	28.07%	10.52%
Assessments at the end of the session	10.52%	26.31%	22.80%	22.80%	17.54%
Exercises	3.50%	8.77%	26.31%	21.05%	40.35%
Written tests	8.77%	12.28%	31.48%	28.07%	21.05%
Oral tests	19.29%	19.29%	24.56%	21.05%	15.78%
Direct questions	12.28%	22.80%	26.31%	21.05%	17.54%
Dialogue	15.78%	24.56%	22.80%	17.54%	19.29%

Finally, the pedagogical choices adopted by teachers, the ways in which difficulties are identified, as well as the limited use of didactic tools can all contribute to difficulties in learning the concept of chemical bonding and related concepts, to misunderstandings for many students.

4.3 Teachers' proposed solutions to difficulties and alternative conceptions

Table 11 presents the analysis of the responses concerning the solutions proposed by the teachers to cope with the difficulties and alternative conceptions encountered in teaching-learning related to the concepts of chemical bonding.

Table 11. Solutions proposed by teachers to deal with difficulties in learning the concept of chemical bonding and other related concepts

Items	Mean	Standard Deviation	Level of Agreement
1. Integrate information and communication technologies (ICT) such as simulations, animations, and flash tools.	4.05	1.355	Agree
2. Assess pre-requisites before starting the course.	3.98	1.445	Agree
3. Diversify teaching aids.	3.95	1.329	Agree
4. Provide in-service training for teachers to keep up with the latest teaching methods.	3.91	1.418	Agree
5. Encourage exchanges and communication between teachers.	3.91	1.258	Agree
6. To carry out practical work.	3.84	1.399	Agree
7. Adopt active teaching methods.	3.84	1.424	Agree
8. Improve communication with students by providing regular feedback on their progress.	3.82	1.227	Agree
9. Take into account students' pre-existing conceptions.	3.79	1.292	Agree
10. Modify teaching content to make it more accessible and understandable to students.	3.00	1.570	Slightly agree

The analysis of the results of the solutions proposed by the teachers to cope with the difficulties of learning concepts related to chemical bonding revealed that out of the 10 items proposed in the questionnaire, only 5 were considered very important by the teachers. Firstly, teachers indicated that it was necessary to integrate information and communication technologies (ICT) such as simulations, animations, and flashes (4.05). In second place, teachers stressed the importance of assessing students' prior knowledge before starting the course (3.98), then diversifying the didactic tools used (3.95), offering in-service training to teachers so that they can keep abreast of the latest teaching methods (3.91), and finally encouraging exchanges and communication between teachers (Table 11). Secondary proposals include conducting practical work (3.84), adopting active pedagogies (3.84), improving communication with students by providing regular feedback on their progress (3.82), taking into account students' pre-existing conceptions (3.79), and finally modifying the content of teaching to make it more accessible and understandable for students (3.00) (Table 11).

Other proposals suggested by respondents in an open-ended question to improve the teaching and learning of the concept of chemical bonding and other related concepts are grouped as follows (Table 12):

Table 12. Additional proposals suggested by respondents

Suggestions	Statement
At the Curriculum level	– Reword the part of the curriculum concerning chemical bonding concepts in the official instructions. – Expand the curriculum to include atoms with atomic numbers above 18. – Emphasize the use of the s, p, and d sublayers for electronic configuration rather than the K, L, M layers. – Allocate sufficient time for each concept to be taught.
In terms of Didactic tools	– Provide the necessary teaching materials to allow a concrete understanding of covalent bonding. – Use practical work and simulations to teach chemical bonding and the geometry of molecules. – Use appropriate simulations to enrich the teaching. – Make models of atoms available in the laboratory to enable a better understanding of covalent bonding. – Use the internet, multimedia room, and diagrams to facilitate teaching.
At the level of the didactic approach	– Work with a problem-based approach to correct misconceptions. – Encourage the investigative approach to enable students to search for the answer and information in order to avoid misconceptions. – Encourage student participation to carry out class projects related to the concept of chemical bonding.
Other suggestions	– Teach chemistry as a subject independent of physics, by chemistry specialists. – Reducing class size would allow better follow-up of students in difficulty. – Increasing the number of hours to allow more practical work to be done. – Accompanying students in difficulty. – Encourage dialogue to correct alternative conceptions.

5 DISCUSSION

Firstly, it should be recalled that the aim of this study is to explore the difficulties encountered by secondary school students in Morocco during the learning of concepts related to chemical bonding, as well as the origin of these difficulties and the strategies that teachers use to remedy them.

The results of the study highlighted the presence of difficulties and alternative conceptions among students concerning concepts related to chemical bonding. These difficulties, as perceived by teachers, can be attributed to a variety of factors such as didactic, pedagogical, and student-related factors. In addition, teachers themselves may contribute to the difficulties experienced by students. To address these learning challenges, effective strategies such as the use of information and communication technologies, the diversification of teaching tools, and the incorporation of molecular models should be included.

Concepts related to chemical bonding are key and fundamental concepts in chemistry education, indispensable for the understanding of almost all topics in chemistry [1,11]. Indeed, understanding the fundamental ideas of chemical bonding is essential for learning many concepts in chemistry, both at the secondary and higher education levels. However, these concepts are often regarded as abstract and remote from students' everyday experiences, which can lead to the emergence of alternative, erroneous conceptions, and misconceptions [8,18–19]. As a result, most students experience difficulties understanding chemical bonding and present various misconceptions about it [1,17,20–21].

The results of the study highlighted the presence of difficulties and alternative conceptions among students with regard to concepts related to chemical bonding. Teachers reported that many students had difficulties understanding the distribution of electrons on electron layers and the application of the octet rule, which is consistent with the findings of [22]. The study by Peterson et al. (1986) [23] also revealed that misconceptions about elemental stability and the octet rule are due to students' misinterpretations of these rules. In addition, students often confuse the valence layer with valence electrons, which has been reported in other studies such as those by [10,20,24].

In addition, students have difficulty distinguishing between a covalent bond and an ionic bond, as well as between ionic compounds and molecules. This is consistent with the findings [25]. In a study, Tan & Treagust (1999) [18] found that the majority of students (80.4%) thought that sodium chloride existed as molecules, suggesting that a high percentage of students do not understand the difference between the different bonds. These results are also consistent with other previous work, such as [1,6,17,19–22,26–28]. Nicoll [20] also investigated students' misconceptions about chemical bonding and revealed that students thought that ionic bonding was electron sharing, and this misconception is consistent with the findings of [29,30].

The results of the study indicated that the majority of students have misconceptions regarding the electronegativity and polarity of molecules. In particular, they have difficulty understanding the link between polar bonding and the polarity of a molecule. These results are in agreement with previous works such as those conducted [17,22,26,32]. In addition, some students find it difficult to associate the concept of polarity with electronegativity, as also found by [21,33]. Burrows and Mooring [36] stated that most students encounter difficulties in making meaningful associations between electronegativity and polar covalent bonding. Students also tend to think that the polarity of a molecule is determined solely by the differences in electronegativity between its atoms, without taking into account the molecular shape. These findings have also been supported by previous studies. With regard to the geometry of molecules, students have difficulties grasping the spatial representation of molecules and identifying their shape. These results are consistent with those of [20,28].

It is important to understand and identify the factors responsible for the misperception of concepts related to chemical bonding that often lead students to develop misconceptions. Several factors can explain this misunderstanding of these concepts, according to the teachers' views, including didactic factors, such as the abstract nature of the concepts, which appears to be a major obstacle. These results are consistent with previous studies conducted by [1,6,19]. Thus, the use of pedagogical models in chemistry teaching [1] and textbooks used by students may also be an explanatory factor [37,38].

On the other hand, there are other pedagogical factors, such as overcrowded classroom conditions, a lack of laboratory facilities, a lack of teaching materials, the amount of time devoted to the chemistry curriculum and other student-related factors, such as the presence of alternative representations or conceptions, the influence of the language of instruction as a linguistic barrier [39], and student orientation. It is therefore important to take these different factors into account in order to improve the teaching and understanding of concepts related to chemical bonding.

Our survey also reflects the fact that teachers can also be a source of difficulties for students. Their teaching style and use of traditional or simplistic pedagogical approaches are often ineffective in helping students fully understand abstract concepts [1,8]. Furthermore, the limited and insufficient use of didactic tools is not sufficient to improve students' understanding. This finding is supported by the results of previous research conducted by [40], as well as the lack of training in science didactics. This result can be explained by the presence of teachers in the sample who directly perform the work without prior professional training.

Most of the teachers interviewed do not value assessment and its roles in the training of students, such as diagnostic assessment to check prerequisites and formative assessment to monitor students' achievements. Over time, these assessment practices should be used with the aim of correcting misconceptions [1,41]. In addition, the study showed that teachers also face difficulties in teaching some basic concepts related to chemical bonding, which can lead to misconceptions among students. Indeed, the misconceptions that appear in teachers are also found in students [42].

It is recognized that students who do not master concepts related to chemical bonding during their high school years may struggle to understand them at a more advanced level [1,20,36]. Teachers therefore need to be aware of these difficulties among students.

Teachers have proposed effective strategies to address their students' alternative conceptions and learning difficulties. Firstly, the integration of information and communication technologies (ICT) such as simulations and animations can improve the quality of chemical bonding related educational content and help students overcome learning difficulties [37,43–47].

It is also recommended to assess the students' pre-knowledge before starting the course and to diversify the didactic tools [48]. including using molecular models for a better understanding of chemical bonding, according to [37,49]. Furthermore, teaching chemistry with active pedagogies is recommended, as stated by researchers [1,8,49], in order to avoid misconceptions. For this reason, teachers suggest in-service training to keep themselves updated with the latest teaching methods.

Reforms may be needed in the chemistry curriculum to facilitate the understanding of concepts related to chemical bonding at all levels. Our findings can be contextualized in the study; for example, according to [8] the best sequence for teaching bonding is to follow the following order: covalent bond, polar covalent bond, and ionic bond. Nicoll [20] suggests that teachers should emphasize transitions between the symbolic, the macroscopic, and the microscopic [11] through the adoption of a spiral curriculum covering the three years of upper secondary education.

Other results depend on the context of the study, such as reducing class size for better follow-up of struggling students, increasing the time allocated to practical work, teaching chemistry by chemistry specialists independently of physics, and supporting struggling students to cope with problems related to the teaching and learning of chemical bonding concepts.

Having considered all this information, it is crucial to create learning environments that incorporate appropriate pedagogical strategies and conceptual change techniques in order to address misconceptions and alternative conceptions related to the teaching and learning of the chemical bonding concept.

The study has some limitations that need to be mentioned. First of all, it is based only on teachers' opinions. Furthermore, it focuses only on teachers working in public schools. Finally, as the sample studied was very limited, consisting of only 57 teachers, it is clear that further research is needed to confirm the results and determine how teachers' practices regarding concepts related to chemical bonding impact students' understanding.

6 CONCLUSION AND PERSPECTIVES

From the results of our study, it appears that Moroccan students have difficulties assimilating the concept of chemical bonding and related concepts. These difficulties, as well as alternative conceptions, stem from several didactic, pedagogical, and student-related factors. Our results also highlight the fact that teachers can be a source of these difficulties, both in terms of the pedagogical methods used and assessment practices that do not sufficiently take modern assessment strategies into account, as well as the limited use of didactic tools. These results corroborate the findings of the existing literature on students' conceptions of chemical bonding.

Teachers should use computer simulations, animations, and molecular models to help students master the abstract concept of chemical bonding. In addition, learning environments based on active pedagogies, the use of appropriate teaching materials, and effective assessment strategies should be designed to address students' misconceptions about chemical bonding. It is recommended that in-depth studies be conducted by chemistry researchers to evaluate the effectiveness of these strategies.

In conclusion, it should be emphasized that multiple strategies are available to improve students' understanding of chemical bonding. In this context, teachers should be aware of the most common misconceptions and their levels, so that they can manage and apply new approaches in their teaching.

7 REFERENCES

[1] T. Levy Nahum, R. Mamlok-Naaman, A. Hofstein, and K. S. Taber, "Teaching and learning the concept of chemical bonding," Stud. Sci. Educ., vol. 46, no. 2, pp. 179–207, 2010. https://doi.org/10.1080/03057267.2010.504548

[2] T. Holme, C. Luxford, and K. Murphy, "Updating the general chemistry anchoring concepts content map," J. Chem. Educ., vol. 92, no. 6, pp. 1115–1116, 2015. https://doi.org/10.1021/ed500712k

[3] K. V. F. Fatokun, "Instructional misconceptions of prospective chemistry teachers in chemical bonding," Int. J. Sci. Technol. Educ. Res., vol. 7, no. 2, pp. 18–24, 2016. https://doi.org/10.5897/IJSTER2016.0357

[4] A. Bergqvist and S.-N. Chang Rundgren, "The influence of textbooks on teachers' knowledge of chemical bonding representations relative to students' difficulties understanding," Res. Sci. Technol. Educ., vol. 35, no. 2, pp. 215–237, 2017. https://doi.org/10.1080/02635143.2017.1295934

[5] J. Wiener, "Science teachers' conceptions of atomic models," European Journal of Mathematics and Science Education, vol. 1, no. 2, pp. 67–80, 2020. https://doi.org/10.12973/ejmse.1.2.67

[6] J. Joki and M. Aksela, "The challenges of learning and teaching chemical bonding at different school levels using electrostatic interactions instead of the octet rule as a teaching model," Chem. Educ. Res. Pr., vol. 19, no. 3, pp. 932–953, 2018. https://doi.org/10.1039/C8RP00110C

[7] M. Meltafina, W. Wiji, and S. Mulyani, "Misconceptions and threshold concepts in chemical bonding," J. Phys. Conf. Ser., vol. 1157, p. 042030, 2019. https://doi.org/10.1088/1742-6596/1157/4/042030

[8] H. S. Dhindsa and D. F. Treagust, "Prospective pedagogy for teaching chemical bonding for smart and sustainable learning," Chem. Educ. Res. Pr., vol. 15, no. 4, pp. 435–446, 2014. https://doi.org/10.1039/C4RP00059E

[9] A. Bouayad, F. Kaddari, M. Lachkar, and A. Elachqar, "Conceptions of the first-year license students on the concept 'chemical bond,'" J. Mod. Educ. Rev., vol. 5, no. 7, pp. 686–693, 2015. https://doi.org/10.15341/jmer(2155-7993)/07.05.2015/006

[10] E. Erman, "Factors contributing to students' misconceptions in learning covalent bonds: Factors contributing to students' misconceptions," J. Res. Sci. Teach., vol. 54, no. 4, pp. 520–537, 2017. https://doi.org/10.1002/tea.21375

[11] G. Tsaparlis, E. T. Pappa, and B. Byers, "Proposed pedagogies for teaching and learning chemical bonding in secondary education," Chem. Teach. Int., vol. 0, 2019. https://doi.org/10.1515/cti-2019-0002

[12] A. H. Simone, "Impact d'une formation collaborative donnée à des enseignants de chimie du secondaire sur l'enseignement et l'apprentissage du concept de mole," doctoral thesis, University of Montreal, 2019.

[13] D. F. Treagust and R. Duit, "Conceptual change: A discussion of theoretical, methodological and practical challenges for science education," Cult. Stud. Sci. Educ., vol. 3, no. 2, pp. 297–328, 2008. https://doi.org/10.1007/s11422-008-9090-4

[14] J. Nussbaum and S. Novick, "Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy," Instr. Sci., vol. 11, no. 3, pp. 183–200, 1982. https://doi.org/10.1007/BF00414279

[15] C. Cormier, "Étude des conceptions alternatives et des processus de raisonnement des étudiants de chimie du niveau collégial sur la molécule, la polarité et les phénomènes macroscopiques," doctoral thesis, University of Montreal, 2014.

[16] I. Kaniawati, "Implementation of Interactive Conceptual Instruction (ICI) Learning Model Assisted by Computer Simulation: Impact of Students' Conceptual Changes on Force and Vibration," Int. J. Emerg. Technol. Learn., vol. 16, no. 22, pp. 167–188, 2021. https://doi.org/10.3991/ijet.v16i22.25465

[17] H. Özmen, "Some student misconceptions in chemistry: A literature review of chemical bonding," J. Sci. Educ. Technol., vol. 13, no. 2, pp. 147–159, 2004. https://doi.org/10.1023/B:JOST.0000031255.92943.6d

[18] D. K. C. Tan and D. F. Treagust, "Evaluating students' understanding of chemical bonding. School Science Review," vol. 81, no. 294, pp. 75–84, 1999.

[19] R. Vladušić, R. B. Bucat, and M. Ožić, "Understanding ionic bonding – a scan across the Croatian education system," Chem. Educ. Res. Pr., vol. 17, no. 4, pp. 685–699, 2016. https://doi.org/10.1039/C6RP00040A

[20] G. Nicoll, "A report of undergraduates' bonding misconceptions," Int. J. Sci. Educ., vol. 23, no. 7, pp. 707–730, 2001. https://doi.org/10.1080/09500690010025012

[21] P. Kumpha, P. Suwannoi, and D. F. Treagust, "Thai grade 10 students conceptual understanding of chemical bonding," Procedia Soc. Behav. Sci., vol. 143, pp. 657–662, 2014. https://doi.org/10.1016/j.sbspro.2014.07.458

[22] R. K. Coll and D. F. Treagust, "Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding," J. Res. Sci. Teach., vol. 40, no. 5, pp. 464–486, 2003. https://doi.org/10.1002/tea.10085

[23] R. Peterson, D. Treagust, and P. Garnett, "Identification of secondary students' misconceptions of covalent bonding and structure concepts using a diagnostic instrument," Res. Sci. Educ., vol. 16, no. 1, pp. 40–48, 1986. https://doi.org/10.1007/BF02356816

[24] K. S. Taber, "An alternative conceptual framework from chemistry education," Int. J. Sci. Educ., vol. 20, no. 5, pp. 597–608, 1998. https://doi.org/10.1080/0950069980200507

[25] H. K. Boo, "Students' understandings of chemical bonds and the energetics of chemical reactions," J. Res. Sci. Teach., vol. 35, no. 5, pp. 569–581, 1998. https://doi.org/10.1002/(SICI)1098-2736(199805)35:5<569::AID-TEA6>3.0.CO;2-N

[26] S. Ünal, B. Coştu, and A. Ayas, "Secondary school students' misconceptions of covalent bonding, " J. Turk. Sci. Educ., vol. 7, no. 2, pp. 3–29, 2010.

[27] M. Vrabec and M. Prokša, "Identifying misconceptions related to chemical bonding concepts in the Slovak school system using the bonding representations inventory as a diagnostic tool," J. Chem. Educ., vol. 93, no. 8, pp. 1364–1370, 2016. https://doi.org/10.1021/acs.jchemed.5b00953

[28] G. Tsaparlis, E. T. Pappa, and B. Byers, "Teaching and learning chemical bonding: Research-based evidence for misconceptions and conceptual difficulties experienced by students in upper secondary schools and the effect of an enriched text," Chem. Educ. Res. Pr., 2018. https://doi.org/10.1039/C8RP00035B

[29] R. K. Coll and N. Taylor, "Alternative conceptions of chemical bonding held by upper secondary and tertiary students," Res. Sci. Technol. Educ., vol. 19, no. 2, pp. 171–191, 2001. https://doi.org/10.1080/02635140120057713

[30] C. J. Luxford and S. L. Bretz, "Development of the bonding representations inventory to identify student misconceptions about covalent and ionic bonding representations," J. Chem. Educ., vol. 91, no. 3, pp. 312–320, 2014. https://doi.org/10.1021/ed400700q

[31] S. Ünal, M. Çalık, A. Ayas, and R. K. Coll, "A review of chemical bonding studies: Needs, aims, methods of exploring students' conceptions, general knowledge claims and students' alternative conceptions," Res. Sci. Technol. Educ., vol. 24, no. 2, pp. 141–172, 2006. https://doi.org/10.1080/02635140600811536

[32] K. Taber, "Constructivism as Educational Theory: Contingency in Learning, and Optimally guided Instruction," Nova Science Publishers Inc., pp. 39–61, 2011.

[33] K. Danckwardt-Lillieström, M. Andrée, and M. Enghag, "The drama of chemistry – supporting student explorations of electronegativity and chemical bonding through creative drama in upper secondary school," Int. J. Sci. Educ., vol. 42, no. 11, pp. 1862–1894, 2020. https://doi.org/10.1080/09500693.2020.1792578

[34] J. Pallant, "SPSS Survival Manual: A step by step guide to data analysis using IBM SPSS," (7e éd.), Routledge, 2020. https://doi.org/10.4324/9781003117452

[35] J. W. Creswell and D. J. Creswell, "Research design: Qualitative, quantitative, and mixed methods approaches," (5e éd.), SAGE Publications, Inc, 2018.

[36] N. L. Burrows and S. R. Mooring, "Using concept mapping to uncover students' knowledge structures of chemical bonding concepts," Chem. Educ. Res. Pr., vol. 16, no. 1, pp. 53–66, 2015. https://doi.org/10.1039/C4RP00180J

[37] M. I. Stojanovska, B. T. Soptrajanov, and V. M. Petrusevski, "Addressing misconceptions about the particulate nature of matter among secondary-school and high-school students in the Republic of Macedonia," Creat. Educ., vol. 03, no. 05, pp. 619–631, 2012. https://doi.org/10.4236/ce.2012.35091

[38] A. Bergqvist, M. Drechsler, O. De Jong, and S.-N. C. Rundgren, "Representations of chemical bonding models in school textbooks – help or hindrance for understanding?" Chem. Educ. Res. Pr., vol. 14, no. 4, pp. 589–606, 2013. https://doi.org/10.1039/C3RP20159G

[39] M. Jarmouni, "L'apprentissage de la physique-chimie en première année d'université au Maroc : entre difficultés et solutions," Revue Marocaine de l'Évaluation et de la Recherche en Éducation, N°6. 2021.

[40] G. Tsaparlis and E. T. Pappa, "Types of intra-and intermolecular bonding: The case of general chemistry textbooks," Proceedings of the ESERA 2011 Conference, Lyon, France, 2012.

[41] C. Srour, A. Atibi, K. El Kababi, and M. Radid, "Assessment of learning and its practices in the secondary school through reforms of the Moroccan education system," Test Engineering and Management, vol. 7, no. 7, pp. 8654–8664, 2020.

[42] N. Palisoa, D. Tahya, and V. Kayadoe, "Students misconception identification of chemical candidates teachers using three tier test method in the basic concept of chemical bond," Edu Sciences, vol. 1, no. 1, pp. 37–43, 2020. https://doi.org/10.30598/edusciencesvol1iss1pp37-43

[43] H. Özmen, H. Demircioğlu, and G. Demircioğlu, "The effects of conceptual change texts accompanied with animations on overcoming 11th-grade students' alternative conceptions of chemical bonding," Comput. Educ., vol. 52, no. 3, pp. 681–695, 2009. https://doi.org/10.1016/j.compedu.2008.11.017

[44] M. Agarwal and S. Saha, "Learning chemistry through puzzle-based game: Atoms to Molecule," 9th International Conference on Emerging eLearning Technologies and Applications (ICETA), 2011. https://doi.org/10.1109/ICETA.2011.6112613
[45] I. Kaniawati, "An analysis of students' misconceptions on the implementation of active learning of optics and photonics approach assisted by computer simulation", Int. J. Emerg. Technol. Learn., vol. 15, no. 09, pp. 76–93, 2020. https://doi.org/10.3991/ijet.v15i09.12217
[46] K. Moundy, N. Chafiq, and M. Talbi, "Digital textbook and flipped classroom: Experimentation of the self-learning method based on the development of soft skills and disciplinary knowledge", Int. J. Emerg. Technol. Learn., vol. 17, no. 07, pp. 240–259, 2022. https://doi.org/10.3991/ijet.v17i07.28933
[47] A. Lahlali, N. Chafiq, M. Radid, and K. Moundy, "Teachers' attitudes towards integrating ICT in teaching chemistry in Morocco: Contribution, constraints and perspectives," Journal of Hunan University (Natural Sciences), vol. 59, no. 2, pp. 215–226, 2023. https://doi.org/10.55463/issn.1674-2974.50.2.23
[48] H. A. Marifa, M. A. Abukari, J. A. Samari, P. Dorsah, and F. Abudu, "Chemistry teachers' pedagogical content knowledge in teaching hybridization," Pedagog. Res., vol. 8, no. 3, p. em0162, 2023. https://doi.org/10.29333/pr/13168
[49] R. Kozma and J. Russell, "Students becoming chemists: Developing representational competence," in Visualization in Science Education, Dordrecht: Springer Netherlands, pp. 121–145, 2005. https://doi.org/10.1007/1-4020-3613-2_8

8 AUTHORS

Abdelouahed Lahlali is a PhD student at the Laboratory of Sciences and Technologies of Information and Education, Faculty of Sciences Ben M'Sick, Hassan II University, Casablanca, Morocco (email: abdelouahed.lahlali-etu@etu.univh2c.ma).

Nadia Chafiq is a PhD in Educational Technology. She is a Professor at Faculty of Sciences Ben M'Sick, and she is heading Laboratory of Sciences and Technologies of Information and Education, Hassan II University, Casablanca, Morocco (email: nadia.chafiq@etu.univh2c.ma).

Mohamed Radid is a PhD in Physical Chemistry. He is the Vice Dean of the Faculty of Sciences Ben M'Sick at Hassan II University, Casablanca, Morocco. He is a Member of the Observatory of Research in Didactics and University Pedagogy (ORDIPU) (email: mohamed.radid@univh2c.ma).

Azzeddine Atibi is a PhD in Physical Chemistry. He is a professor at the Regional Center for the Professions of Education and Training, Casablanca-Settat, Morocco (email: Atibi.azzeddine@outlook.com).

Khadija El Kababi is a PhD in Physical Chemistry. She is a professor at the Regional Center for Education and Training Professions. Casablanca-Settat. Morocco. She is the Provincial Director of the Ministry of National Education. She is a member of the Laboratory of Materials at the Faculty of Sciences Ben M'Sick, Hassan II University of Casablanca (email: elkababi@hotmail.fr).

Chaibia Srour is a PhD in engineering training and didactics of science and technology. She is a professor at Regional Center for the Professions of Education and Training, Casablanca-Settat, Morocco (email: najcha@gmail.com).

Kamal Moundy is a PhD in Educational Science and Technology at the Laboratory of Sciences and Technologies of Information and Education, Faculty of Sciences Ben M'Sick, Hassan II University, Casablanca, Morocco (email: kamal.moundy-etu@etu.univh2c.ma).