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Difficult concepts in chemistry as seen by Moroccan high school students: A survey in the Fez-Meknes region

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ABSTRACT

This quantitative study investigates the conceptual difficulties in chemistry education among second-year baccalaureate students in Morocco's Fez-Meknes region, focusing on identifying difficult concepts and comparing perceptions between different groups. We administered a reliable questionnaire (Cronbach's alpha =0.86) to 250 students and 13 teachers across four urban and rural high schools, evaluating the perceived difficulty of 26 chemistry concepts on a four-point Likert scale. Results revealed that students identified nine concepts as particularly challenging (mean score >2.5), including chemical kinetics (temporal monitoring by conductometry and pressure measurement), density and mass density, electrochemistry (spontaneous transformations and batteries), organic chemistry nomenclature, and chemical transformations. Statistical analysis showed significant differences between teachers' and students' perceptions (p=0.007) with teachers identifying 12 difficult concepts compared to students' nine, and consistently rating concepts as more difficult. The school environment had a significant impact (p=0.045) with rural students identifying 11 difficult concepts versus 9 for urban students and reporting higher difficulty levels while we found no significant gender-related differences (p=0.814). Based on these findings, we recommend adapting teaching approaches with active and contextualized methods, enhancing teacher training programs, and encouraging collaboration between educational stakeholders to make chemistry learning more accessible and effective, particularly for students in rural areas.

Contribution/Originality: This study identifies specific conceptual barriers in chemistry for Moroccan high school students in the Fez-Meknes region, revealing teacher-student perception discrepancies and the significant impact of rural/urban environments, thus providing an empirical foundation for contextualized teaching approaches.

1. INTRODUCTION

Although fundamental, the teaching of chemistry faces significant learning difficulties among students concerning several key concepts (Coll & Treagust, 2001; Gabel, 1999; Taber, 2013). The abstract nature and the complexity of concepts, such as the structure of matter, chemical bonds, stoichiometry or acid-base reactions make understanding them arduous for many learners (Sevian & Talanquer, 2014; Treagust & Chittleborough, 2001). More specifically, mastering high-level intellectual skills, such as symbolic representation, mental visualization and causal reasoning about microscopic transformations seems complex for students to acquire (Johnstone, 2000; Stieff, 2011).

These obstacles find their epistemological roots in the highly specific nature of the chemical discipline (Gabel, 1999; Taber, 2013). On the one hand, the direct inaccessibility of the microscopic level makes it difficult to conceptualize the invisible entities and mechanisms governing chemical transformations (Johnstone, 1991; Stieff, 2011). On the other hand, chemistry requires mastering several modes of representation (symbolic, schematic, and algorithmic) and going back and forth between them (Russell et al., 1997). In addition, qualitative reasoning about chemical phenomena requires the simultaneous integration of multiple interdependent concepts (Boujaoude & Barakat, 2000; Sevian & Talanquer, 2014).

When difficulties arise with certain key concepts, such as atomic structure or chemical bonds, they are likely to have a negative impact on the assimilation of more complex notions that build on these foundations (Levy Nahum, Mamlok-Naaman, Hofstein, & Taber, 2010; Luxford & Bretz, 2014; Taber, 2001; Zoller, 1990). The result is gaps in the construction of chemical knowledge leading to limited overall learning performance in this discipline (Stieff & Uttal, 2015).

Yet mastery of the fundamental concepts of chemistry is essential not only for further study of this subject but also for understanding many phenomena in related scientific fields, such as biology, geology or physics (Taber, 2002; Talanquer, 2011). Indeed, chemistry is often regarded as a central discipline as it provides the basis for understanding many biological, geological and physical processes. For example, chemical reactions are at the heart of the functioning of living organisms, the formation of rocks and minerals and many physical phenomena, such as combustion or electrical conductivity.

These difficulties can be explained by students' lack of motivation and interest in chemistry, which is seen as complex, abstract and far removed from their interests (Osborne, Simon, & Collins, 2003; Salta & Tzougraki, 2004). The outdated image of the discipline and uninviting teaching methods are also blamed (Holbrook, 2005; Johnstone, 2010). The result is an alarming drop by several students pursuing higher education in chemistry in many countries (Breuer, 2002; Eilks & Hofstein, 2015). This decline by several chemistry students is of particular concern in many countries. In the US, for example, the number of undergraduate degrees in chemistry decreased by 5% between 2012 and 2016 from 16,939 to 16,076 (National Center for Education Statistics, 2018). In the UK, the number of students enrolled in chemistry at university decreased by 21% between 2014 and 2019 from 21,755 to 17,140 (Higher Education Statistics Agency, 2020). In France, the number of students in the first year of a chemistry degree decreased by 7.5% between 2011 and 2016, from 5,712 to 5,282 (Ministry of Higher Education Research and Innovation, 2018).

These conceptual barriers may vary according to individual learner characteristics. For example, differences between girls and boys have been reported in motivation and approaches to learning science (Eddy, Brownell, & Wenderoth, 2014; Potvin & Hasni, 2014). These differences can be influenced by gender stereotypes, teacher expectations, and socio-cultural norms (Carlone, 2004).

On the other hand, the socio-cultural environment as well as unequal access to educational resources depending on the school environment also play a key role in student success (Van de Werfhorst & Mijs, 2010). Education systems that promote greater equity can reduce inequalities in academic performance between students from different backgrounds (Van de Werfhorst & Mijs, 2010).

Students from lower socio-economic backgrounds may face more barriers to learning science due to limited access to educational resources, such as laboratory equipment, educational technologies and extra-curricular learning opportunities (Gorard & See, 2009). In addition, these students may have less access to successful science role models in their community which may influence their aspirations and their perception of the relevance of science to their future (Archer et al., 2010). Finally, students from disadvantaged backgrounds may also face additional challenges, such as increased family responsibilities, financial stress and a home environment less conducive to study, which may affect their engagement and success in science learning (Gorard & See, 2009).

Numerous studies highlight the difficulties faced by secondary school students in learning key chemistry concepts.

In Nigeria, research conducted by Uchegbu, Oguoma, Elenwoke, and Ogbuagu (2016) among 410 terminal scientific students identified mass-volume relationships and organic chemistry as the most problematic topics. The obstacles cited were the complexity of the calculations, the abstract nature of the concepts and the lack of adequate teaching resources.

Another Nigerian study of 95 SSII-level students (Agogo & Onda, 2014) revealed significant gaps in the periodic table, chemical reactions, mass-volume relationships and acid-base reactions.

At the level of Moroccan schools, teaching chemistry in high school focuses on total and reversible chemical reactions also known as "chemical equilibria" areas on which students show significant difficulties (Ouasri, 2017). Other work has highlighted specific obstacles in acid-base reactivity and spontaneous transformations in electrochemical cells (Ouasri, 2017).

In addition, another piece of research carried out with the same audience aimed to verify misconceptions relating to chemical transformations in general and more specifically mastery of the redox concept (Ferouni, Khyati, Talbi, El Jamali, & Radid, 2012). In the same study, concerning redox, difficulties included the correct writing of redox half-equations, the distinction between reactants and products, and the positioning of electrons in the presence of negative ions.

International assessments have consistently highlighted challenges in science education in Morocco. The Trends in International Mathematics and Science Study (TIMSS) 2015 survey showed Moroccan students scoring significantly below international averages (Provasnik et al., 2016) while recent Programme for International Student Assessment (PISA) 2022 data revealed that virtually no Moroccan students reached advanced proficiency levels in science compared to the Organisation for Economic Co-operation and Development (OECD) average of 7% (OECD, 2023). El Azhari, Bouderga, and Marzouki (2024) note that Morocco has established national evaluation programs, including the National Program for the Evaluation of Acquired Learning Outcomes (PNEA), to monitor student achievement and inform educational reforms. Despite these challenges, Morocco continues to engage with international benchmarking as evidenced by its participation in TIMSS 2023, reflecting the nation's commitment to improving mathematics and science curricula. In this context, the present research focuses on the learning difficulties perceived in chemistry by high school students in the 2nd year of their baccalaureate. Such identification of specific conceptual barriers may contribute to international efforts to understand how educational factors influence student performance in science (Laukaityte, Rolfsman, & Wiberg, 2024).

These results highlight the specific obstacles faced by learners in different geographical and cultural contexts, providing potential avenues for improving chemistry teaching at the secondary level.

Thus, it seems appropriate to investigate the learning difficulties perceived by the students themselves from the perspective of the gender and school environment. This study would identify the most problematic concepts from high school students' perspective. It would shed light on the key concepts to be reinforced as a priority to shed light on contextualized didactic avenues for more effective teaching of this discipline.

The objectives of the present study are as follows:

1) Identify concepts perceived as difficult by Moroccan students.
2) Determine whether there are differences between boys and girls in this perception.
3) Analyze whether school location influences the perception of difficulties.
4) Provide useful information for adapting teaching in Morocco.

1.1. Research Questions

This study attempted to provide answers to the following questions:

RQ 1: What are the main chemistry concepts perceived as difficult by Moroccan students in second- year baccalaureate classes?

RQ 2: Are there any discrepancies between teachers' and students' perceptions of these difficult concepts?

RQ 3: Does gender influence the perception of difficulties faced by students in learning these concepts?

RQ 4: Does the geographical location of the school have an effect on students' perception of difficult concepts?

The following hypotheses are formulated:

H_{01}: There is no significant difference between teachers' and students' perceptions of difficult concepts.

H_{02}: There is no significant difference between girls' and boys' perceptions of difficult concepts.

H_{03}: School location has no significant influence on students' perception of difficult concepts.

2. RESEARCH METHOD AND PROCEDURE

2.1. Questionnaire Design

The study took place during the second academic session of 2021/2022. We set up an online focus group (Hinkes, 2021) bringing together two higher education teachers specializing in chemistry didactics (over 15 years' experience each) and six secondary school teachers (between 15 and 22-years' experience) to identify the chemistry notions and concepts posing learning difficulties for second-year baccalaureate students.

The asynchronous discussion took place on the Google Forms platform for 2 hours 30 minutes. It covered the entire second-year baccalaureate program. For each chapter, we asked participants the following question: "In your opinion, what concepts in this chapter seem difficult for students to grasp?" Participants responded freely, citing the concepts they considered problematic in their experience.

At the end of the discussion, we summarized the concepts cited by the group as a whole and identified those on which all participants agreed. 26 key concepts from the second-year chemistry curriculum were identified as potentially difficult for students to learn.

Based on these 26 concepts, the teachers in the focus group then collaboratively developed a detailed questionnaire to analyze students' cognitive barriers to each of the identified concepts.

This questionnaire, drawn up by experienced teachers is a validated tool for finely investigating learning difficulties with key chemistry concepts in high school.

The questionnaire consists of two sections which are as follows: A and B. Section A contained demographic information, such as region and gender while section B included 26 key concepts from the second-year baccalaureate chemistry syllabus.

The responses of thirty students who were not part of the main study were used to determine the reliability coefficient using Cronbach's alpha. According to the standard of Pallant (2005), Hogan (2007) and Nunnally (1978), a value of 0.86 was obtained and was deemed appropriate.

2.2. Study Population

The study involved 13 chemistry teachers and a sample of 250 high school students, divided between 130 girls and 120 boys from four high schools in the Fez-Meknes region of Morocco, selected using stratified cluster sampling. The research incorporated four educational institutions representing diverse regional contexts: two urban schools (Mohamed V High School in Meknes and Allal Al Fassi High School in Fez), complemented by two rural institutions (January 11 High School in Ain Taoujdate, El Hajeb province and Imam Chatibi High School in Ghafsai, Taounate province).

2.3. Data Collection

The questionnaire was distributed in paper form to all 250 students in the sample. The questionnaires were administered collectively in the classrooms under the supervision of the researchers and teachers and lasted around 60 minutes. The same questionnaire was distributed to the 13 chemistry teachers. The questionnaire used a four-point Likert scale: "not difficult" (ND) (1 point), "fairly difficult" (SD) (2 points), "difficult" (D) (3 points) and "very difficult" (VD) (4 points) to assess the perceived level of difficulty for each chemical concept.

2.4. Data Analysis

The questionnaire responses collected from the 250 students and 13 teachers were entered and processed using Statistical Package for Social Sciences (SPSS) version 25 software.

Descriptive statistics (means and standard deviations) were produced for each item corresponding to a chemical concept. Likert scale responses were averaged for each concept allowing us to determine the perceived level of difficulty for each notion.

A mean score of less than 2.5 was taken as an index of ease while a score of 2.5 or above was interpreted as a high level of difficulty. This limit was set a priori to discriminate concepts perceived as difficult from those perceived as affordable.

2.5. Ethical Considerations

This study was conducted under official authorization from the Regional Academy of Education and Training of Fez-Meknes, Morocco, granted on December 30, 2021 (Ref.No. S/4824/2021). This authorization issued within the framework of the Ibn Khaldoun research program funded by Morocco's National Center for Scientific and Technical Research (CNRST) remained valid throughout the 2021/2022 academic year and explicitly permitted conducting surveys with students regarding chemistry education challenges.

All research activities adhered to the ethical guidelines established by the Declaration of Helsinki. Before participation, students and teachers received comprehensive information regarding the study's objectives and methodological approach.

The questionnaire administration process maintained strict anonymity protocols with no identifying information collected or retained during data gathering or analysis phases. All statistical comparisons between demographic groups were conducted using aggregated data to prevent identification of specific individuals or institutions. We prioritized educational benefit while minimizing disruption to normal academic activities, ensuring that participants' educational rights and psychological well-being remained paramount considerations in the research design throughout the research implementation.

3. RESULTS

RQ1: Are there any discrepancies between teachers' and students' perceptions of these difficult concepts?

Table 1 presents a comparative analysis of the concepts perceived as difficult by second- year baccalaureate students (n=250) and their teachers (n=13). The level of difficulty was assessed for each of the 26 concepts in the chemistry syllabus on a 4-point Likert scale by calculating the mean of the responses for each concept.

For the students, 9 concepts obtained an average score higher than 2.5 and were therefore perceived as difficult. These were concepts relating to chemical kinetics (conductimetry and pressure measurement), density and mass density, electrochemistry (spontaneous transformations and batteries), nomenclature in organic chemistry and chemical transformations (forced/spontaneous).

Table 1. Mean and standard deviation of the level of difficulty of chemistry concepts

Themes or concepts	Students			Teachers		
	Mean	Standard deviation	N	Mean	Standard deviation	N
1) Descriptive table of evolution	1.224	0.558	250	1.461	0.519	13
2) The volumetric reaction rate	1.712	0.800	250	3.154	1.143	13
3) Determine the value of the maximum advancement $x\ max$ and final xf.	1.388	0.715	250	2.154	1.068	13
4) Factors influencing the volumetric reaction rate.	1.696	0.819	250	1.692	0.947	13
5) Legend the diagram of the experimental titration setup.	1.784	0.865	250	1.385	0.870	13
6) Density and mass density	2.636	1.068	250	2.692	0.855	13
7) Determination of the reaction quotient **Qr.**	1.440	0.749	250	2.154	0.689	13
8) Mole and molar quantity	1.728	0.785	250	2.077	0.954	13
9) Identifying the reactants and products of a transformation and writing a balance equation.	1.424	0.736	250	1.923	1.038	13
10) Temporal monitoring of a chemical transformation by conductometry.	2.608	1.067	250	3.769	0.599	13
11) Temporal monitoring of a chemical transformation by a pressure meter.	2.648	.984	250	3.615	0.650	13
12) Predominance domain and distribution diagram.	2.648	1.121	250	2.923	0.862	13
13) Acid and base titration	1.704	0.841	250	2.308	0.75	13
14) Titration by conductometric monitoring.	2.616	1.070	250	3.461	0.660	13
15) Determination of the half-reaction time.	1.592	.865	250	2.077	1.256	13
16) Determination of the final advancement rate τ.	1.524	0.817	250	2.154	1.143	13
17) Equation of the ideal gas law: pV= nRT.	2.316	1.026	250	2.231	0.599	13
18) Understanding the relationship between the provided solute molar concentration (denoted as C) and the effective molar concentration of the dissolved species (denoted as [X]).	2.312	1.005	250	2.538	1.050	13
19) Write the half-equation associated with the two acid/base couples and deduce the overall reaction equation.	1.412	0.751	250	1.923	0.954	13
20) Write the half-equation associated with the two oxidant/ reductant couples and deduce the overall reaction equation.	1.476	0.756	250	2.769	1.013	13
21) Predict the direction of spontaneous evolution of a chemical system.	1.732	0.880	250	1.846	0.801	13
22) Get to know the difference between Qr, K, K_e and KA.	2.192	1.092	250	2.615	0.768	13
23) Calculate conductivity and conductance	2.740	1.014	250	3.461	0.660	13
24) Nomenclature of organic compounds	2.732	.963	250	3.077	0.759	13
25 Spontaneous transformations in pile	2.620	1.077	250	2.538	0.776	13
26)Transformation forces	2.804	1.085	250	3.077	0.759	13

The teachers identified 12 concepts as difficult with an average score of over 2.5. These included the 9 concepts cited by the students as well as 3 additional concepts: the volumetric reaction rate, the relationship between the molar concentration of the solute and the effective molar concentration of the dissolved species, and writing the balanced equation for a redox reaction.

RQ 2: Does gender influence the perception of difficulties encountered by students in learning these concepts?

Table 2. The impact of students' gender on their perception of chemical concepts

Themes or concepts	Females			Males		
	Mean	Standard deviation	N	Mean	Standard deviation	N
1) Descriptive table of evolution.	1.131	0.381	130	1.325	0.688	120
2) The volumetric reaction rate.	1.654	0.701	130	1.775	0.893	120
3) Determine the value of the maximum advancement $x\ max$ and final xf.	1.292	0.577	130	1.492	0.830	120
4) Factors influencing the volumetric reaction rate.	1.592	0.794	130	1.808	0.833	120
5) Legend the diagram of the experimental titration setup.	1.677	0.837	130	1.900	0.883	120
6) Density and mass density.	2.485	1.080	130	2.583	1.134	120
7) Determination of the reaction quotient **Qr.**	1.285	0.546	130	1.608	0.891	120
8) Mole and molar quantity.	1.600	0.654	130	1.867	0.888	120
9) Identifying the reactants and products of a transformation and writing a balance equation.	1.354	0.669	130	1.500	0.799	120
10) Temporal monitoring of a chemical transformation by conductometry.	2.615	1.088	130	2.650	1.113	120
11) Temporal monitoring of a chemical transformation by a pressure meter.	2.577	0.963	130	2.883	1.022	120
12) Predominance domain and distribution diagram.	2.600	1.132	130	2.700	1.112	120
13) Acid-base titration	1.654	0.823	130	1.758	.860	120
14) Titration by conductometric monitoring.	2.561	1.085	130	2.717	1.131	120
15) Determination of the half-reaction time.	1.531	0.828	130	1.683	0.916	120
16) Determination of the final advancement rate τ	1.400	0.743	130	1.675	0.881	120
17) Equation of the ideal gas law: pV= nRT.	1.985	0.862	130	2.525	1.130	120
18) Understanding the relationship between the provided solute molar concentration (denoted as C) and the effective molar concentration of the dissolved species (denoted as [X]).	1.969	0.797	130	2.608	1.110	120
19) Write the half-equation associated with the two acid/base couples and deduce the overall reaction equation.	1.261	0.578	130	1.583	0.885	120
20) Write the half-equation associated with the two oxidant/reductant couples and deduce the overall reaction equation.	1.300	0.618	130	1.667	0.843	120
21) Predict the direction of spontaneous evolution of a chemical system.	1.577	0.766	130	1.908	0.970	120
22) Get to know the difference between Q_r, K, K_e and K_A.	1.777	0.891	130	2.542	1.180	120
23) Calculate conductivity and conductance.	2.577	1.018	130	2.883	1.146	120
24) Nomenclature of organic compounds	2.615	.910	130	2.942	1.031	120
25 Spontaneous transformations in piles	2.523	1.051	130	2.742	1.213	120
26) Forced transformations (electrolysis)	2.708	1.089	130	2.825	1.113	120

Table 2 shows the influence of gender on perceived learning difficulties for the 26 concepts in the chemistry curriculum. The data are presented separately for girls (n=130) and boys (n=120) with the means and standard deviations of the perceived difficulty scores for each concept, assessed on a 4-point Likert scale.

For girls, 9 concepts were cited as difficult with an average score of over 2.5. These were chemical kinetics (temporal monitoring of a chemical transformation by conductometry and a pressure meter), electrochemistry (spontaneous transformations (batteries)), conductimetry, the predominance domain and distribution diagram, organic nomenclature and chemical transformations (calculation of conductivity and conductance, forced transformations (electrolysis)).

For boys, 10 concepts were identified as difficult with an average score of over 2.5. We find the same 9 concepts as for the girls and one additional concept: the equation of the ideal gas law (pV = nRT).

These results show that the concepts perceived as the most problematic are broadly the same for girls and boys, with very similar average difficulty scores. Only the concept linked to the equation of state for perfect gases seems to pose more difficulties for boys than for girls.

Nevertheless, it is interesting to note that for certain concepts, such as organic nomenclature or spontaneous transformations in batteries, the standard deviations associated with the means are higher for boys than for girls.

This indicates greater variability in boys' responses with potentially more heterogeneous levels of perceived difficulty within this group.

RQ3: Does the school's geographical location have an effect on students' perception of difficult concepts?

Table 3. Influence of plant location on perception of chemical concepts

Themes or concepts	Urban environment			Rural environment		
	Mean	Standard deviation	N	Mean	Standard deviation	N
1) Descriptive table of evolution.	1.211	0.525	204	1.283	0.688	46
2) The volumetric reaction rate.	1.716	0.786	204	1.696	0.866	46
3) Determine the value of the maximum advancement x max and final xf.	1.368	0.700	204	1.478	0.781	46
4) Factors influencing the volumetric reaction rate.	1.618	0.807	204	2.043	0.788	46
5) Legend the diagram of the experimental titration setup.	1.676	0.838	204	2.261	0.828	46
6) Density and mass density.	2.490	1.098	204	2.717	1.129	46
7) Determination of the reaction quotient **Qr.**	1.348	0.644	204	1.848	1.0109	46
8) Mole and molar quantity.	1.647	0.745	204	2.087	0.865	46
9) Identifying the reactants and products of a transformation and writing a balance equation.	1.377	0.680	204	1.630	0.928	46
10) Temporal monitoring of a chemical transformation by conductometry.	2.554	1.084	204	2.978	1.105	46
11) Temporal monitoring of a chemical transformation by a pressure meter.	2.667	1.001	204	2.978	0.977	46
12) Predominance domain and distribution diagram.	2.578	1.122	204	2.956	1.074	46
13) Acid-base titration.	1.672	0.827	204	1.848	0.894	46
14) Titration by conductometric monitoring.	2.559	1.101	204	2.978	1.085	46
15) Determination of the half-reaction time.	1.569	0.842	204	1.761	0.993	46
16) Determination of the final advancement rate **τ.**	1.480	0.784	204	1.761	0.947	46
17) Equation of the ideal gas law: pV= nRT.	2.142	1.034	204	2.696	0.916	46
18) Understanding the relationship between the provided solute molar concentration (denoted as C) and the effective molar concentration of the dissolved species (denoted as [X]).	2.230	1.017	204	2.478	0.960	46
19) Write the half-equation associated with the two acid/base couples and deduce the overall reaction equation.	1.377	0.722	204	1.587	0.884	46
20) Write the half-equation associated with the two oxidant/reductant couples and deduce the overall reaction equation.	1.451	0.738	204	1.587	0.832	46
21) Predict the direction of spontaneous evolution of a chemical system.	1.647	0.820	204	2.130	1.046	46
22) Get to know the difference between Qr, K, K_e and K_A.	2.039	1.091	204	2.609	1.064	46
23) Calculate conductivity and conductance.	2.681	1.097	204	2.913	1.050	46
24) Nomenclature of organic compounds	2.740	.991	204	2.913	0.939	46
25 Spontaneous transformations in piles	2.524	1.151	204	3.087	0.939	46
26) Forced transformations (electrolysis)	2.672	1.125	204	3.174	0.877	46

Table 3 analyses the effect of school location on perceived learning difficulties comparing the responses of students in urban (n=204) and rural (n=46) areas. The rates and standard deviations of the perceived difficulty scores are presented for each of the 26 concepts in the chemistry curriculum assessed on a 4-point Likert scale.

In the urban areas, 9 concepts were cited as difficult by the students with an average score of over 2.5. These were concepts relating to chemical kinetics (temporal monitoring of a chemical transformation by conductometry and a pressure meter), electrochemistry (spontaneous transformations in batteries, forced transformations and electrolysis)), conductimetry, organic nomenclature, density and mass density, and chemical transformations (calculating conductivity and conductance).

For students in rural areas, 11 concepts were identified as difficult with an average score of over 2.5. The 9 concepts mentioned for the urban students were also found as well as two additional concepts: kinetic factors and the equation of the ideal gas law (pV = nRT).

These results highlight significant differences in the perception of difficulties between urban and rural students. Not only did rural students identify a greater number of concepts as problematic but they also reported higher levels of perceived difficulty for several concepts common to both groups, such as conductimetry, spontaneous transformations in batteries or organic nomenclature.

The extent of the differences in averages between urban and rural students is particularly marked for certain concepts. For example, for spontaneous transformations in batteries, the average was 2.52 for urban students compared with 3.09 for rural students. Similarly, for the equation of state for perfect gases, the average was 2.14 for urban students compared with 2.70 for rural students. These differences suggest a significant effect of the school context on perceived learning difficulties.

Table 4. T-test for the significant difference between pupils' perceptions and teachers' opinions regarding difficult concepts

Status	N	Mean	Standard deviation	T-value	P-value
Teachers	13	2.503	0.663	-2.827	0.007
Students	250	2 .027	0 .544		

3.1. Hypothesis 1

Table 4 presents the results of a statistical test comparing the means of perception of the difficulty of chemical concepts between two groups: teachers and students. The null hypothesis H_{01} is that there is no significant difference in the identification of these obstacles between the two groups.

The results in Table 4 indicate a p-value of 0.007 for the statistical test between the mean responses of teachers and students. Since this p-value is below the conventional significance threshold of 0.05, the null hypothesis H_{01} is rejected.

We conclude that there is indeed a significant difference between teachers' and students' perceptions of the main difficult concepts in the chemistry syllabus.

This result suggests a discrepancy in the perception of conceptual obstacles between teachers and students. The teachers with their subject expertise and teaching experience seem to anticipate greater difficulties than those actually reported by the students. This may be explained by their in-depth knowledge of the subtleties and complexities of chemical concepts as well as their hindsight on the recurring obstacles encountered by learners over the years.

Table 5. T- test for the significant difference between girls and boys in their perception of difficult concepts

Gender	N	Mean	Standard deviation	T-value	P-value
Males	120	1.925	0.308	0.236	0.814
Females	130	1.896	0 .549		

3.2. Hypothesis 2

Table 5 presents the results of a statistical test evaluating whether there is a difference between two groups of students (boys and girls) in their perception of the difficulty of concepts. As the p-value obtained is above the 0.05 threshold ($p=0.814 > 0.05$), the null hypothesis H_{02} is accepted. There was no statistically significant difference between these two populations. In other words, the results in Table 5 suggest that there is no significant difference in the perception of conceptual difficulties in chemistry between girls and boys. Both groups seem to identify the same obstacles and attribute similar levels of difficulty to them. This finding is consistent with the observations in Table 2 which presented a detailed analysis of the difficulty scores per concept for girls and boys. In this table, we noted that the concepts perceived as the most problematic were broadly the same for both groups with very similar average scores.

Table 6. T-test for significant difference in school location on pupils' perception of difficult concepts

Environment	N	Mean	Standard deviation	T-value	P-value
Urban	204	1.925	0.308	-2.060	0.045
Rural	46	1.896	0 .549		

3.3. Hypothesis 3

Table 6 presents the results of an independent samples t-test comparing the means of perception of conceptual difficulties in chemistry between students in urban (n=204) and rural (n=46) areas. The aim was to assess the influence of the school environment on the identification of conceptual obstacles.

The difference between the statistical means was significant ($p=0.045 < 0.05$), so the null hypothesis H_{03} was rejected. Students in rural areas perceived a significantly higher level of difficulty than those in urban areas.

This result confirms the findings of Table 3 which presented a detailed analysis of difficulty scores by concept for urban and rural students. In the above table, we noted that rural students identified a greater number of concepts as problematic and reported higher levels of perceived difficulty for several concepts common to both groups.

4. DISCUSSION

Learning high school chemistry presents many challenges for students, particularly in terms of understanding key concepts. The aim of this study was to identify the main conceptual obstacles perceived by Moroccan high school students in their learning of chemistry.

The results showed that several key concepts are considered particularly difficult by these learners. Firstly, concepts related to chemical kinetics, such as reaction time monitoring was considered to be very complex. These difficulties are consistent with the work of Gabel (1999) who highlight the major obstacles to the assimilation of kinetics concepts. Several studies carried out in different countries have made the same observation about gaps in these abstract concepts requiring the visualization of invisible microscopic transformations (Calik & Ayas, 2005; Pinarbasi, Sozbilir, & Canpolat, 2009).

In addition, electrochemistry (spontaneous reactions and batteries), density and specific gravity were perceived as difficult for students to master. These results corroborate previous studies by Boujaoude and Barakat (2000) and Sirhan (2007) which highlight the difficulty of integrating several interdependent concepts simultaneously.

Furthermore, organic chemistry nomenclature was identified as a major obstacle. The extent of this highly codified terminology and the effort required to memorise it probably explain this frequently encountered difficulty (Grove, Cooper, & Cox, 2012; Sirhan, 2007).

Moreover, mastering spontaneous or forced chemical transformations is a complex task for pupils. These results confirm the obstacles linked to the conceptualization of phenomena invisible at the microscopic level raised in numerous studies in chemistry didactics (Taber, 2001; Vosniadou, 2007).

These results converge with international studies on learning difficulties in chemistry (Coll & Treagust, 2001). They highlight the priority conceptual gaps that need to be targeted to improve the teaching of this subject in Morocco.

There are significant differences between teachers' and students' perceptions of the difficulty of chemical concepts. Teachers identified a systematically higher level of difficulty than students for concepts, such as molar concentrations or redox.

This discrepancy can be explained by the difference in teaching experience between teachers and students (Rollnick & Mavhunga, 2015; Yakmaci-Guzel & Adadan, 2013). Indeed, teachers armed with their teaching practice are better able to identify the recurring obstacles encountered by students and to anticipate potential difficulties (Kolomuç & Tekin, 2011). In addition, teachers have a finer understanding of chemical concepts, which sharpens their perception of the most complex aspects for learners due to their advanced scientific training (Jimoh, 2005; Okanlawon, 2010). These differences in perception between teachers and students are crucial to be taken into account to best adapt chemistry teaching and prevent learning difficulties.

These conceptual obstacles are likely to have a negative impact on students' motivation and commitment to this discipline which is perceived as complex and abstract, thus reinforcing their negative perception of chemistry (Bennett, Lubben, & Hogarth, 2007; Osborne et al., 2003). Indeed, the abstract nature of chemical concepts and the difficulties faced by students can lead to a decrease in their interest and motivation for the subject (Broman & Simon, 2015; Salta & Koulougliotis, 2020).

In addition, this research reveals a significant effect of rural or urban school environment on the perception of difficulties. This result underlines the importance of taking account of students' learning context in the didactic approach (Sarkar, Overton, Thompson, & Rayner, 2020). Differences in resources and infrastructure between rural and urban schools may influence students' learning of chemistry and perception of difficulties (Onwu & Randall, 2006; Otor & Achor, 2013).

Furthermore, no significant differences were found between girls and boys in the identification of barriers. This result suggests that conceptual difficulties in chemistry are independent of students' gender (Ezeudu & Obi-Theresa, 2013; Veloo, Lee, & Seung, 2015). Thus, these results make it possible to consider adapting the didactic approach to chemistry among all Moroccan high school students in the Fez-Meknes region regardless of gender.

4.1. Recommendations

Several recommendations can be made to improve chemistry teaching and help students overcome the conceptual difficulties identified based on the results of this study and the existing literature.

1. Adapt teaching approaches by favoring active and contextualised methods that encourage student engagement and understanding of abstract concepts (Bennett et al., 2007; King, 2012). For example, teachers can use problem situations rooted in authentic contexts or collaborative projects enabling students to make sense of the concepts studied.
2. Use several teaching tools and aids, such as analogies, concrete models and interactive technologies, to help students visualize and better grasp complex chemical concepts (Harrison & Treagust, 2000; Prins, Bulte, & Pilot, 2016). For example, computer simulations and virtual experiments can allow students to manipulate molecular representations and observe the effects of different parameters on chemical reactions.
3. Take into account the local context and the resources available in each school to best adapt teaching strategies (Taconis, den Brok, & Pilot, 2016). For example, this may involve taking advantage of the natural or industrial resources present in the school's environment to contextualise learning, or developing partnerships with local actors (universities and businesses) to enrich students learning experiences.
4. Strengthen initial and in-service training for chemistry teachers, focusing on the conceptual difficulties identified and on innovative teaching approaches (Avalos, 2011; Darling-Hammond, Hyler, & Gardner, 2017). Specific training modules could be developed in partnership with universities and research institutes, to help teachers update their disciplinary and didactic knowledge.
5. Encourage collaboration between teachers, didactics researchers and curriculum developers to develop teaching resources tailored to the needs of students and the realities on the ground (Koehler & Mishra, 2009; Mooney Simmie, 2007). Such collaboration can focus in particular on the design of innovative teaching sequences incorporating the results of research into the didactics of chemistry.

By implementing these recommendations, it should be possible to reduce the conceptual difficulties faced by Moroccan students in chemistry and to improve their motivation and commitment to the subject. However, further research will be needed to assess the impact of these measures and to adjust strategies according to the results obtained.

4.2. Limitations and Prospects

Although this study sheds important light on the conceptual difficulties faced by Moroccan high school students in chemistry, it has certain limitations that should be taken into account.

Firstly, the data were collected using a questionnaire which may lead to certain biases. Students may have been influenced by social desirability in their responses. Individual interviews or classroom observations could help to triangulate the data and deepen understanding of the difficulties encountered.

Secondly, the study was carried out on a sample of 250 students and 13 teachers in the Fez-Meknes region. Although this sample is substantial, it is not necessarily representative of all Moroccan high school students and teachers. Further research would make it possible to confirm and generalize the results obtained on a larger scale and in other regions of Morocco.

Thirdly, this study focused on students' perceived conceptual difficulties but did not directly measure their impact on academic performance. Longitudinal studies combining measures of perceived difficulties and assessments of students' attainment could provide a better understanding of the relationships between these variables.

Despite these limitations, this study opens up several avenues for research and practice. In terms of research, it would be interesting to explore in greater detail the causes of the conceptual difficulties identified by examining, students' representations, their learning strategies or teachers' teaching practices. Comparative studies with other countries could also help to highlight the specific features of the Moroccan context.

In practical terms, the results of this study could be used to design and evaluate innovative teaching methods that specifically target the conceptual difficulties identified. Action research, involving teachers and researchers in a collaborative approach could be particularly relevant for developing and testing these systems in a real context.

Finally, this study invites a wider reflection on educational policies and teacher training in Morocco. How can school curricula and textbooks take better account of students' difficulties? How can teachers be trained in innovative teaching approaches tailored to the needs of students? These questions deserve to be explored in greater depth, involving the various actors in the education system (political decision-makers, inspectors, trainers, teachers, and researchers).

5. CONCLUSION

This study highlights the main conceptual obstacles faced by Moroccan secondary school students in learning chemistry in particular the complexity of concepts relating to chemical kinetics, electrochemistry, organic nomenclature and chemical transformations. The differences in perception between teachers and students and the influence of the school environment on the difficulties experienced are also highlighted.

These results provide an essential starting point for rethinking the teaching of chemistry in Morocco and developing teaching strategies tailored to students' needs. It would seem crucial to introduce innovative teaching approaches that encourage students to engage with and understand abstract concepts while taking account of local conditions and the resources available in each school.

This study opens up numerous prospects for improving the learning of chemistry in Morocco based on close collaboration between teachers, researchers and political decision-makers. It calls for continued efforts to gain a better understanding of students' difficulties and to develop effective teaching solutions to promote high-quality science education for all young Moroccans.

This work contributes to a global reflection on science teaching in Morocco and underlines the importance of placing students' needs and difficulties at the heart of educational concerns by taking concerted action and drawing on the results of research that it will be possible to make lasting progress in learning chemistry and, more broadly to equip the younger generations with the scientific skills they need to meet the challenges of today's world.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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