

Misconceptions in Atomistics among Moroccan Upper Secondary Students: Diagnostic Assessment and Associations with Learning Practices

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ABSTRACT

Students' understanding of atomistic concepts remains a central challenge in chemistry education, specifically because it requires the articulation between macroscopic, submicroscopic, and symbolic representations. This study assessed Moroccan upper secondary students' understanding of atomistic concepts, combined with the investigation of learning practices associated with their scores. The instrument (32 items) showed satisfactory internal consistency, strong item discrimination, and appropriate range of item difficulty. Students' scores were moderate, with significant differences by grade level and academic track, digital tool, tutoring type, and self-assessment. Exploratory factor analysis suggested a three-dimensional construct involving structural representations and quantitative chemistry, ionic classification and nomenclature, and fundamental atomic concepts. The study findings support the use of diagnostic assessment to identify students' misconceptions about atomistic concepts.

KEY WORDS: Atomistic misconceptions, chemistry education, conceptual understanding, moroccan upper secondary education

INTRODUCTION

Atomistic concepts, as part of chemistry, constitute a fundamental basis for meaningful and effective scientific literacy, as they are the basis for the conceptual understanding of various scientific phenomena, not only chemical ones (Taber, 2003). Learning chemistry depends on the capacity to articulate the three interdependent levels of representation: The macroscopic (observable phenomena), the submicroscopic (atoms and molecules), and the symbolic with formulas, calculations, and equations (Johnstone, 1991; Talanquer, 2011). However, many students struggle to articulate amongst these three levels in the educational sitting, which can lead to cognitive overload and fragmented knowledge (Johnstone, 2000). In the school context, chemistry education often prioritizes the symbolic level at the expense of the submicroscopic level, which is essential to understand different chemical phenomena (Üce and Ceyhan, 2019). In Morocco, formal chemistry education begins in lower secondary school and continues in upper secondary school, following a spiral progression of chemical concepts. During upper secondary school, students begin with atomistic concepts in the 1st year; then, chemical concepts evolve toward quantitative chemical reactions with the introduction of transformations in solutions in the 2nd year. And then in the 3rd year of upper secondary

school, there is a theoretical and applied deepening, depending on the specialization, to cover chemical phenomena from a kinetic, energetic, and industrial point of view (Ministry of National Education, 2007).

Atomistic concepts are mostly prone to misconceptions in chemistry education (McAfee et al., 2025; Suparman et al., 2024). Although empirical research on atomistic misconceptions in education is abundant worldwide (Suparman et al., 2024), the research on misconceptions in chemistry education in the Moroccan context remains limited and scattered. In Moroccan educational system, misconceptions about chemical concepts result from a set of interdependent factors, including linear curriculum progression, the predominance of transmission-based approaches, uncommon experimental approaches, and learner disengagement (Mennani et al., 2023; Touli et al., 2014; Bouzit et al., 2023; Mardy et al., 2025; Boukayoua et al., 2021). The available studies about misconceptions identified among Moroccan upper secondary students, concern chemical concepts related to redox reactions and chemical bonding (Ferouni et al., 2012; Ouasri, 2017; Lahlali et al., 2023), with the misconceptions extending to a broader range of chemical concepts (Habibi et al., 2026). All identified chemical misconceptions are related to atomistic knowledge, such as atomic structure, electronic organization,

the stability of species, and interactions between particles. In this context, an investigation of atomistic misconceptions appears to be a priority to understand the learning difficulties in chemistry as well as other scientific school disciplines. The present study aims to assess upper secondary school students' understanding of atomistic concepts using a diagnostic instrument (questionnaire). The questionnaire was designed to examine students' level of understanding of atomistic concepts in relation to their learning practices like the use of generative artificial intelligence (GenAI). The instrument was validated by a panel of experts including four university professors and three upper secondary school teachers, for this diagnostic approach. This study plans to lay the foundation for the targeted didactic interventions for effective atomistics and chemistry education.

METHODOLOGY

This study adopts a quantitative approach to assessing upper secondary school students' understanding of atomistic concepts. This approach allows the identification of misconceptions and the analysis of links between learning practices and conceptual understanding of atomistics.

Population and Sampling

The target population consisted of upper secondary school students enrolled in science programs within the Moroccan education system, where French is the language of instruction for science. A total of 206 students participated in this study. The random sampling method was chosen to maximize learner participation in different regions of Morocco.

Instrument of the Study

The study data were collected using a diagnostic questionnaire designed specifically for this study, in accordance with the official Moroccan chemistry curriculum (Ministry of National Education, 2007). The questionnaire was divided into two sections:

- Demographic and contextual data: This section collected information on gender, grade level, and learning practices, including the use of digital tools and the use of academic support.
- Understanding of atomistic concepts: This section contained 32 questions (items) designed to assess students' understanding of atomic structure, isotopes, chemical bonds, physicochemical quantities, and transformations. The questions incorporated multiple-choice, true/false, categorization, and visual matching questions.

Validity and Reliability

The validity of the instrument's content was established by a panel of experts (four university professors and three upper secondary school teachers) who reviewed the items for clarity, scientific accuracy, and alignment with the chemistry curriculum. The instrument's internal consistency was assessed using Cronbach's alpha and McDonald's omega (Cronbach, 1951). The analysis revealed excellent reliability, with Cronbach's alpha and McDonald's omega values >0.70 , as shown in Table 1, the recommended threshold for

Table 1: Internal consistency reliability

Scale	Mean	SD	Cronbach's α	McDonald's ω
Scale	0.735	0.254	0.931	0.935

SD: Standard deviation

educational research instruments (Tavakol and Dennick, 2011). These values indicate that the instrument is a robust tool for diagnosing upper secondary students' understanding of atomistics.

Participation Procedure

The questionnaire was distributed online through Google Forms. Before full-scale distribution, a pilot study was conducted with a small group of students to validate the instrument's functionality. Participation was voluntary and anonymous. All participants were informed of the study's objective before data collection.

Statistical Analysis

Statistical analysis was performed using JAMOV software (version 2.7.5). Descriptive statistics (frequencies, means, and standard deviations [SD]) were calculated to summarize the demographic data and questionnaire scores. Inferential statistics were conducted to examine group differences and relationships among the study variables.

Independent-samples t-tests and one-way analysis of variance (ANOVA) were used to test differences in students' scores according to gender, grade level, and academic track. A two-way ANOVA was performed to investigate potential interactions between gender and self-assessment levels. Multiple linear regression analysis was used to examine the relationship between students' learning practices and their scores on the atomistic concepts assessment. Finally, an exploratory factor analysis (EFA) was conducted to reveal the underlying dimensions of the conceptual framework of the study instrument.

FINDINGS

Item Difficulty Analysis of the Instrument

The quality of the study instrument was evaluated by analyzing the difficulty index (P) and the discrimination index (d) for the 32 items. The difficulty index represents the proportion of correct answers for an item; the higher its value, the easier the item is. As for the discrimination index, it measures an item's ability to distinguish high-performing students from low-performing ones. The difficulty and discrimination indices were formed according to the criteria proposed by Boateng et al. (2018). The classification of items by difficulty index is outlined in Table 2, which reveals an uneven distribution of difficulty levels, with most items falling within the easy and moderate categories. Half of the items ($n = 16$; 50%) were classified as easy while 12 items (37.5%) fell into the moderate, and only four items (12.5%) as difficult. This distribution suggests that the instrument is generally accessible to students, with limited number of difficult items to challenge students in understanding specific atomistic concepts.

The instrument demonstrates strong discriminatory power, based on the discrimination index, as shown in Table 3. Most items ($n = 30$; 93.75%) showed excellent discrimination, while the 2 remaining items (6.25%) were classified as having good discrimination. No item showed poor discrimination. These results indicate that the instrument items were able to differentiate effectively different levels of atomistic concepts understanding.

Misconceptions Related to Atomistic Concepts among the Study Population

To identify misconceptions hindering students' conceptual understanding of atomistic concepts, an analysis was performed of items classified as difficult, based on a difficulty index below 0.30 ($p < 0.30$). This analysis included Q1, Q16, Q17, Q28, Q29, and Q32. The misconceptions deduced from students' incorrect answers are elaborated in Table 4.

Demographic Characteristics of the Study Population

The study population consisted of 206 upper secondary school students, including 113 females (54.9%) and 93 males (45.1%). Demographic characteristics by grade levels and academic track are presented in Table 5.

Table 2: Difficulty index

Items ($n=32$)	p-value	Interpretation
4	<0.30	Difficult item
12	0.30–0.70	Moderate item
16	>0.70	Easy item

Table 3: Discrimination index

Items ($n=32$)	p-value	Interpretation
0	<0.15	Low discrimination
2	0.15–0.25	Good discrimination
30	>0.25	Excellent discrimination

Table 4: List of identified atomistic misconceptions among study students ($n=206$)

Items	Target concept	Expected answer	Frequent incorrect answer(s)*	Interpretation
Q1	Definition of chemical species	A pure substance made up of identical chemical entities	An isolated molecule (40.29%); a set of identical or different atoms (16%)	Difficulty distinguishing between the microscopic level (entity) and the macroscopic level (species).
Q16	Calculation of molar concentration	0.34 mol/L	No response (47.08%); unit or conversion errors (13.6%)	Difficulty applying unit conversions (mg to g or cm^3 to L) and calculating molar concentration.
Q17	Amount of substance of an ideal gas	0.2 mol	No response (52.42%); amount of substance constant (0.1 mol) (13.6%)	Difficulty related to applying the relation between amount of substance, concentration, and volume.
Q28	Lewis structure representation (for HCl)	.. H—Cl:	No response (51.94%); non-bonding doublets (15.04%)	Difficulty accounting for all valence electrons and applying the duet/octet rule in Lewis's structure representation.
Q29	Lewis structure representation (for H_2O)	.. H—O—H	No response (53.88%); Lewis structure with absent oxygen lone pairs (15.04%)	Difficulty distinguishing bonding electron pairs from non-bonding valence electron pairs.
Q32	Most stable structure for the oxygen element	O^{2-}	O_2 (40.77%); no response (30.58%)	Confusion between the molecular stability of oxygen in its natural diatomic form (O_2) and the electronic stability achieved by the oxide ion (O^{2-}) through a complete octet.

*Frequency represents the percentage of the total student population selecting this specific incorrect answer

Students' Learning Practices

Most students (92.2%) reported using digital tools to learn chemistry, with YouTube being the most frequently used resource (90.8%). Social media platforms were used by 18.4% of students, while GenAI tools were used by only 8.7%. Regarding tutoring, 22.3% of students reported that they regularly take private lessons, whereas 61.7% reported them occasionally. Individual study was the dominant learning mode for students (69.3%).

Scores on the Atomistic Concepts Assessment

The students' understanding of atomistic concepts was evaluated based on a possible total score of 32. Before inferential analysis, scores distribution was checked therefore descriptive statistics, and normality indicators are presented in Table 6. The histogram and Q-Q plots in Figure 1, with skewness (-0.36) and kurtosis (-0.10) values within the acceptable range of ± 1 , indicated that the data distribution was approximately normal and acceptable for inferential analyses.

Performance Levels on the Atomistic Concepts Assessment

To provide a pedagogical interpretation of the students' results, scores were classified into three performance levels as outline in Table 7: Low, moderate, and high.

Gender Differences in Atomistic Concepts Assessment Scores

To examine whether students' scores differed according to gender, an independent samples t-test was performed. The analysis revealed no statistically significant difference between female ($M = 19.7$, $SD = 7.20$) and male students ($M = 20.2$, $SD = 7.18$); $t(204) = -0.557$, $p = 0.578$. Furthermore, since the effect size was negligible (Cohen's $d = -0.0779$), gender was not meaningfully associated with students' performance in the study sample.

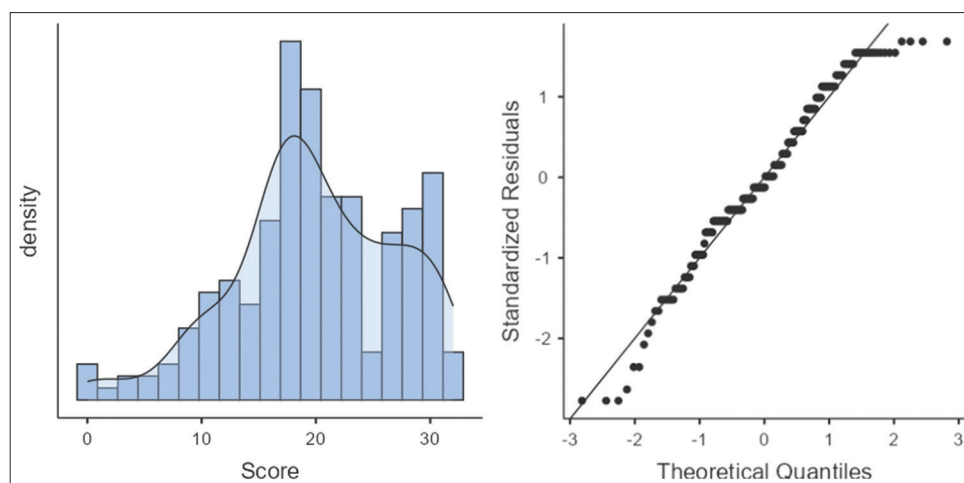


Figure 1: Distribution and Q-Q plot of atomistic concepts assessment scores

Table 5: Grade levels and academic track frequencies

Academic track and grade levels	n	Percentage
General science track (1 st year)	100	48.5
Experimental sciences track (2 nd year)	39	18.9
Mathematical sciences track (2 nd year)	10	4.9
Life and earth sciences track (3 rd year)	10	4.9
Mathematical sciences (a or b) track (3 rd year)	5	2.4
Physical sciences track (3 rd year)	42	20.4

Table 6: Descriptive statistics and normality indicators for the atomistics concepts assessment scores

Statistic	Score
N	206
Mean	19.9
Median	19.0
Mode	17.0
Standard deviation	7.18
Skewness	-0.366
Standard error skewness	0.169
Kurtosis	-0.0709
Standard error kurtosis	0.337
Shapiro-Wilk W	0.970
Shapiro-Wilk p	<0.001

Table 7: Students' performance levels

Performance level	Score range	n	Percentage
Low	0–15	50	24.3
Moderate	16–24	100	48.5
High	25–32	56	27.2

Differences in Scores by Grade Level and Academic Track

A one-way ANOVA was performed to examine whether students' scores differed according to grade level and academic track. The results indicated a statistically significant difference among groups, $F(5,200) = 4.68$, $p < 0.001$. This implies that

assessment scores varied significantly across grade levels and academic tracks.

Post hoc comparisons using the Games-Howell test (Table 8) revealed that students in the mathematical sciences track (2nd year) obtained significantly higher scores ($M = 28.7$, $SD = 4.03$) than students in the general sciences track ($M = 19.5$, $SD = 5.08$), students in the experimental sciences track ($M = 19.4$, $SD = 6.76$), and students in the physical sciences track ($M = 18.4$, $SD = 9.85$), with $p < 0.001$. Likewise, students in mathematical sciences A/B track scored significantly higher ($M = 26.4$, $SD = 9.29$) than students physical sciences track, $p = 0.020$. No statistically significant differences were observed among students in the general sciences, experimental sciences, life and earth sciences, and physical sciences tracks, $p > 0.05$.

Learning Practices and Atomistic Concepts Assessment Scores

To examine whether students' scores differed according to their use of digital learning tools, an independent samples t-test was conducted. The analysis indicated a statistically significant difference between students who reported using digital tools in their atomistic learning ($M = 20.4$, $SD = 6.88$) and those who reported relying on traditional methods ($M = 15.4$, $SD = 7.11$), $t(202) = -2.73$, $p = 0.007$. The effect size was moderate to large as indicated in Table 9. A Welch ANOVA was then conducted to determine whether students' scores differed based on the frequency of digital tools use. Welch's test was selected since the assumption of homogeneity of variances was not met, as indicated by Levene's test: $F(3,199) = 10.7$, $p < 0.001$. The analysis revealed a statistically significant difference among the frequency groups, Welch's $F(3,21,8) = 3.97$, $p = 0.021$. *Post hoc* Games-Howell comparisons indicated that students with moderate use of digital tools defined as 1–3 h per week, achieved significantly higher scores than students with low use (<1 h per week). However, no statistically significant difference was observed between students with moderate use and those with intensive use (more than 3 h per week).

Table 8: Games-Howell *post hoc* comparisons of scores by academic track

		General science track	Experimental sciences track	Mathematical sciences track	Life and earth sciences track	Mathematical sciences track (A/B)	Physical sciences track
General science track	Mean difference	-	0.155	-9.16	-0.460	-6.86	1.16
	p-value	-	1.000	<.001	1.000	0.618	0.978
Experimental sciences track	Mean difference		-	-9.32	-0.615	-7.02	1.00
	p-value		-	<.001	1.000	0.617	0.994
Mathematical sciences track	Mean difference			-	8.700	2.30	10.32
	p-value			-	0.111	0.992	<.001
Life and earth sciences track	Mean difference				-	-6.40	1.62
	p-value				-	0.787	0.995
Mathematical sciences track (A/B)	Mean difference					-	8.02
	p-value					-	0.528
Physical sciences track	Mean difference						-
	p-value						-

Table 9: Differences in scores according to learning practices

Learning practice	Groups	n	M	SD	Test	p	Effect size
Digital tools use	Users		20.4	6.88	t (202)=-2.73	0.007	Cohen's d=0.710
	Non-users		15.4	7.11			
Tutoring type	Private	68	22.9	7.65	Welch's t (115)=4.13	<0.001	Cohen's d=0.65
	Public	117	18.5	5.98			

SD: Standard deviation

Differences in scores according to tutoring type (private or public) were analyzed using an independent samples *t*-test. Due to the failure to meet the assumption of homogeneity of variances (Levene's test, $p < 0.05$) and the unequal group sizes, Welch's *t*-test was used. The results revealed a statistically significant difference between the two groups, $t(115) = 4.13$, $p < 0.001$. Students receiving private tutoring ($n = 68$) achieved significantly higher scores than those receiving public tutoring ($n = 117$). The effect size was moderate to large (Table 9).

Differences in Scores According to Students' Self Assessment Level

To investigate whether students' scores varied according to their self-assessed level of understanding atomistic concepts, a one-way ANOVA was conducted. Since Levene's test revealed a violation of the assumption of homogeneity of variances ($F = 5.62$, $p < 0.001$), a Welch's ANOVA was used. This analysis showed a statistically significant difference in scores across self-assessment levels (Welch's $F = 53.6$, $p < 0.001$), indicating a strong positive correlation between students' perceived level of understanding and their scores on atomistic concepts assessment. Games-Howell *post hoc* comparisons showed significant differences between self-assessment groups (Table 10). Students identifying themselves as very good achieved significantly higher scores, compared to all other groups ($p < 0.001$). In the same way, the "good" group outperformed the "medium" and "weak" groups. The "I don't know" group presented scores statistically comparable to the

Table 10: Games-Howell *post hoc* comparisons of scores by self-assessment level

	Weak	Medium	Good	Very good	I don't know
Weak					
Mean difference	—	-5.50	-10.40	-16.15	-0.423
p-value	—	<0.001	<0.001	<0.001	1.000
Medium					
Mean difference		—	-4.90	-10.66	5.075
p-value		—	0.002	<0.001	0.347
Good					
Mean difference			—	-5.75	9.979
p-value			—	<0.001	0.054
Very good					
Mean difference				—	15.731
p-value				—	0.015
I don't know					
Mean difference					—
p-value					—

"weak" group, suggesting that uncertainty in self-assessment serves as a reliable indication for low understanding.

Predictors of Students' Understanding of Atomistic Concepts

A multiple linear regression was performed to examine the extent of which gender, grade level and academic track, self-assessment of atomistic concepts understanding, tutoring type, and digital tools usage predicted students' scores on the atomistic concepts assessment. Visual inspection of the

residual plots and the Shapiro-Wilk test revealed a deviation from normality ($W = 0.955$, $p < 0.001$); however, given the sample size ($N > 200$), the regression model was considered sufficiently robust to minor deviations from normality assumption (Lumley et al., 2002). The regression model was statistically significant and explained 35.1% of the variance in students' scores as confirmed in Table 11. The analysis was based on 182 valid cases (cases with missing values were excluded from the model).

The omnibus ANOVA results from the regression model revealed that self-assessment was a significant predictor of atomistic concepts assessment scores, $F = 7.96$, $p < 0.001$. Grade level and academic track were also significant predictors, $F = 2.78$, $p = 0.019$. In contrast, sex was not statistically significant, $F = 1.06$, $p = 0.305$. Tutoring type, $F = 3.18$, $p = 0.076$, and time spent using digital tools, $F = 2.47$, $p = 0.064$, did not reach the conventional threshold of statistical significance after controlling for the other predictors. Table 12 presents the regression coefficients for each predictor included in the regression model.

EFA

The suitability of the study data for EFA was evaluated using the Kaiser–Meyer–Olkin measure of sampling adequacy and Bartlett's test of sphericity (Watkins, 2018). The overall KMO value was .878, indicating that the correlation matrix was appropriate for factor extraction and that the sample displayed adequate common variance among items. Bartlett's test of sphericity was statistically significant, $\chi^2(496) = 3724$, $p < 0.001$, indicating that items were sufficiently correlated to be grouped for EFA. To determine the number of factors to retain, the scree plot was examined in conjunction with the Kaiser criterion (eigenvalues > 1). The scree plot suggested a three-factor solution, as indicated by the clear bend after the third factor, as shown in Figure 2.

An EFA was then conducted to examine the internal structure of the study instrument. Maximum likelihood extraction method combined with oblimin rotation was used, as the underlying conceptual dimensions were expected to be correlated. The analysis supported a three-factor model, as presented in Table 13.

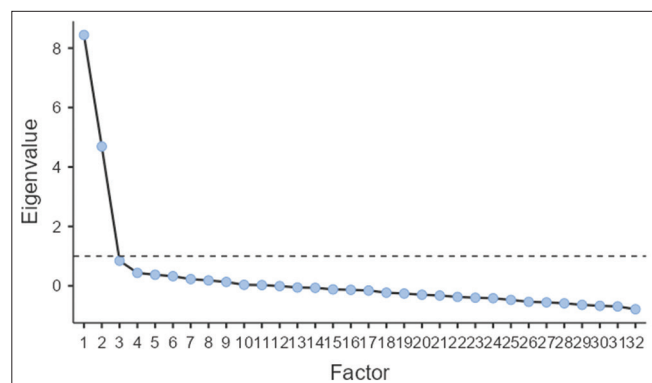


Figure 2: Scree plot of eigenvalues

The EFA suggested a three-factor structure indicating three dimensions of students' understanding of atomistic concepts.

Factor 1 was interpreted as a dimension related to structural representation and quantitative chemistry. It consisted of 13 items (Q1, Q4, Q12, Q14, Q16, Q17, Q22, Q24, Q27, Q28, Q29, Q31, and Q32), with item Q16 showing the strongest association with this factor (0.793).

Factor 2 was interpreted as a dimension related to ionic classification and nomenclature. It contained 7 items (Q6, Q9, Q19, Q20, Q21, Q23, and Q26) with a very strong association (ranging from 0.698 to 0.945).

Factor 3 was interpreted as a dimension related to fundamental atomic concepts. It included 10 questions (Q2, Q3, Q5, Q7, Q8, Q10, Q13, Q15, Q18, and Q30).

Items Q11 and Q25 did not display significant factor contributions (> 0.30) with any factor and displayed very high uniqueness values (> 0.90).

Table 11: Regression model fit predicting atomistic concepts assessment scores

Model	N	R	R ²	F	df1	df2	p
Regression model	182	0.592	0.351	6.45	14	167	<.001

Table 12: Regression coefficients predicting atomistic concepts assessment scores

Predictor	B	SE	t	p
Intercept	17.7055	3.472	5.0994	<0.001
Male versus female	0.9223	0.896	1.0293	0.305
Experimental sciences track versus general scientific track	0.2070	1.298	0.1595	0.873
Mathematical sciences track versus general scientific track	3.7206	2.353	1.5811	0.116
Life and earth sciences track versus general scientific track	0.9198	2.227	0.4130	0.680
Mathematical sciences A/B track versus general scientific track	-0.0847	4.265	-0.0199	0.984
Physical sciences track versus general scientific track	-3.2492	1.300	-2.4992	0.013
Medium self-assessment versus weak	1.7786	2.212	0.8040	0.423
Good self-assessment versus weak	7.1883	2.506	2.8683	0.005
Very good self-assessment versus weak	11.7201	3.252	3.6039	<0.001
"I don't know" self-assessment versus weak	-2.5126	3.721	-0.6752	0.500
Public tutoring versus private tutoring	-1.9134	1.073	-1.7825	0.076
<1 h/week digital use versus no use	0.7503	2.824	0.2657	0.791
1–3 h/week digital use versus no use	0.3746	2.923	0.1282	0.898
More than 3 h/week digital use versus no use	-5.1072	3.441	-1.4840	0.140

Intercept: Represents reference level, B: Unstandardized regression coefficient, SE: Standard error. Reference categories were female students, General scientific track, weak self-assessment, private tutoring, and no use of digital tools

Table 13: Pattern matrix from the exploratory factor analysis

Item	Factor 1	Factor 2	Factor 3	Uniqueness
Q1	0.705			0.485
Q2			0.500	0.587
T3	0.363		0.411	0.705
Q4	0.361			0.770
Q5		0.304	0.387	0.624
Q6		0.369	0.355	0.591
Q7			0.595	0.376
Q8			0.389	0.694
Q9		0.394	0.335	0.569
Q10			0.515	0.549
Q11				0.900
Q12	0.643			0.537
Q13		0.383	0.428	0.482
Q14	0.682			0.498
Q15			0.467	0.605
Q16	0.793			0.389
Q17	0.632			0.595
Q18			0.546	0.633
Q19		0.767		0.357
Q20		0.938		0.101
Q21		0.698		0.412
Q22	0.632			0.531
Q23		0.791		0.281
Q24	0.609	0.405		0.488
Q25				0.933
Q26		0.945		0.109
Q27	0.483			0.687
Q28	0.673			0.540
Q29	0.690			0.532
Q30	0.379		0.423	0.674
Q31	0.653			0.569
Q32	0.570			0.683

DISCUSSION

The Quality of the Instrument (Questionnaire)

The obtained Cronbach's alpha (0.931) and McDonald's omega (0.935) coefficients indicate satisfactory internal consistency (Taber, 2018), which supports its use as a diagnostic tool for students' conceptual difficulties in atomistics. The difficulty index analysis demonstrated that most items were easy (50%) or moderately difficult (37.5%), whereas only 12.5% were classified as difficult. This suggests that the instrument is generally accessible to upper secondary students while still including items requiring greater cognitive effort. However, the predominance of easy items should not be perceived as an intrinsic weakness. Item difficulty is affected not only by cognitive load but also by content, students' initial conceptions, and instructional context. The quality of an item depends also on its discriminatory power (Rezigalla, 2022). Most items (93.75%) showed excellent discrimination, while the remaining items showed good discrimination; no item had poor discrimination. Items with moderate difficulty can be the most effective at

differentiating students' proficiency levels (Sim & Rasiah, 2006; Rezigalla et al., 2024). Therefore, the questionnaire appears able to differentiate effectively between different levels of conceptual understanding of atomistic concepts. Overall, the instrument's value lies not merely in ranking students but in identifying the prevalence, nature, and degree of their conceptual understanding difficulties (Ma et al., 2025). These results support its use for guiding targeted pedagogical interventions aligned with learners' actual needs (Black and William, 2009).

Understanding Atomistic Concepts According to Grade Level and Academic Track

Students' understanding of atomistic concepts was generally moderate ($M = 19.91$), and it varied significantly according to grade level and academic track, as the ANOVA results revealed statistically significant differences between groups ($F [5,200] = 4.68$, $p < 0.001$). Mathematical sciences track students achieved the highest scores ($M = 28.7$), while physical sciences track students obtained the lowest scores ($M = 18.4$). These results are didactically significant because progression through school does not appear to ensure conceptual development. Although age, cognitive development, and grade level are generally associated with improved science performance (Peng and Kievit, 2020; Varma et al., 2023), the present findings suggest that grade progression alone is insufficient for consolidating atomistic concepts. The higher performance of students in the mathematical sciences track does not necessarily indicate more effective teaching of atomistic concepts in this track. However, it may reflect stronger proficiency in abstract and symbolic reasoning among students, which is fundamental for coordinating the three levels of chemical representation (Nickel et al., 2025). On the contrary, the lower scores of physical sciences track students raise curricular concerns, because chemistry is codominant in this track. This indicates that atomistic concepts are reused without sufficient consolidation of their submicroscopic meaning, leading to persistent conceptual difficulties (Becker et al., 2015).

The Misconceptions Identified among Students

The analysis of difficult items ($p < 0.40$) revealed six major misconceptions among upper secondary students that can be interpreted through two main dimensions: Confusion between the three levels of chemical representation and procedural weaknesses in using the symbolic level of chemistry. The six misconceptions concerned: macroscopic interpretation of atomistic phenomena, confusion between amount of substance and concentration, errors in unit conversion, procedural use of Lewis structures, misunderstanding of electronic stability, and confusion between molecular stability and ionic electronic configuration.

Responses to Q1 indicate confusion between the macroscopic and submicroscopic levels. Students are inclined to interpret chemical concepts through detectable features rather than submicroscopic explanations, which limits their understanding of atomistic concepts (Johnstone, 1991; Becker et al., 2015).

Items Q16 and Q17 revealed learning obstacles with chemical quantities, particularly molar concentration and amount of substance. The high non-response rates (47.08% for Q16 and 52.42% for Q17) together with conversion errors (13.6% for both), suggest that these concepts remain largely procedural (Fang et al., 2014). Students therefore appear to struggle to connect mathematical operations with their underlying chemical meaning. Although molar concentration, amount of substance, and unit conversion are revisited across different educational levels, repeated exposure does not necessarily produce conceptual progression when these concepts are taught as isolated formulas rather than as interconnected quantities (Sevian and Talanquer, 2014). These difficulties may reflect failings in the progression of the spiral curriculum in the Moroccan context. Items Q28 and Q29, related to the Lewis structures of HCl and H₂O, showed similar difficulties. The high non-response rates, 51.94% and 53.88%, and representation errors, 15.04% for both items, suggest that students often apply Lewis structures as fixed procedures rather than as models based on electronic stability (Cooper et al., 2010; Tümay, 2016). Students may construct formally acceptable structures without interpreting the chemical information they contain (Cooper et al., 2012; Rotich et al., 2024). The teacher-centered instruction can also limit opportunities for students to construct and revise alternative representations. Thus, instruction should connect electron placement with bonding, formal charge, and electronic stability through explanation and learning tasks. Finally, Q32 revealed confusion about oxygen stability. While 30.58% did not respond, 40.77% selected O₂ rather than O²⁻ as the most stable structure, indicating difficulty distinguishing molecular stability from electronic configuration stability.

Overall, these findings support various actionable pedagogical and didactic recommendations for chemistry teachers. First, they should use diagnostic tasks at the beginning of each learning section to identify misconceptions and revisit atomistic concepts taught at earlier educational levels. In quantitative chemistry, students should articulate mathematical, symbolic, and submicroscopic representations before applying formulas. For Lewis structures, learning activities should focus on making students construct models rather than reproducing fixed procedures. Finally, peer interaction and formative feedback should be used to make students' reasoning visible and correct misconceptions during learning. However, the findings should be interpreted with caution considering the Moroccan educational context and sample characteristics. Hence, further research studies should be considered to improve our understanding of misconceptions related to chemistry.

Learning Practices and Atomistic Concepts Understanding

The results indicate that students' understanding of atomistic concepts is correlated with their learning practices. Students who used digital resources achieved higher scores than those relying only on traditional methods, suggesting that digital resources may support the articulation between symbolic representations and submicroscopic models. However, the strongest performance was associated with moderate use, 1–3 h per week, whereas

intensive use did not produce additional benefits. The type of digital resources also appears important. YouTube was the most frequently used tool, reported by 90.8% of students, reflecting strong reliance on video explanations and animations. Such resources can support learning when they explicitly connect the three chemical representation levels (Greeves and Oz, 2024; Herrington and Sweeder, 2025). Social networks were used by 18.4% of students; though, they may increase engagement, their scientific reliability and conceptual accuracy remain variable (Belova et al., 2022). The use of GenAI tools (such as ChatGPT) was reported by only 8.7% of students. Even though these tools can support explanation and individualized feedback, they are susceptible to hallucinations and reasoning errors (Morbisoni et al., 2025; Uçar et al., 2025). Consequently, students' productive use depends on their ability to confirm scientific accuracy and reconstruct generated responses rather than accept them uncritically (Valeri et al., 2025; Zhou, 2026).

Tutoring also seems associated with students' understanding. Students receiving private tutoring obtained higher scores than those receiving only public tutoring, possibly because private tutoring offers more personalized support with an adjusted learning pace. Thus, it can improve academic achievement (Nickow et al., 2024). However, this association should be considered cautiously, as tutoring was no longer statistically significant in the multiple regression model, $p = 0.076$. Its influence may overlap with other variables.

Overall, these findings in a didactic perspective suggest that learning atomistic concepts depends not only on access to additional resources but also on their use. Effective learning of atomistic concepts should include explicit articulation of macroscopic, submicroscopic, and symbolic representations to foster a conceptual understanding.

Association between Students' Self-Assessment and Atomistic Concepts Understanding

The results indicate a significant association between students' self-assessment and their scores in atomistic concepts. Students who perceived their level as "good" or "very good" achieved significantly higher scores than those who perceived themselves as "weak" or "I do not know." This suggests that understanding atomistic concepts depends on students' ability to evaluate their own learning, which is important because students with stronger metacognitive awareness (self-assessment) may be better at identifying inconsistencies in their reasoning and monitoring their understanding (Ohtani and Hisasaka, 2018; Tashiro et al., 2021). From a didactic perspective, these findings highlight the need to integrate metacognitive activities into atomistics learning, as it can improve self-efficacy and reduce cognitive load (Hartelt and Martens, 2024), thereby supporting a more durable understanding of atomistic concepts.

EFA: Dimensional Structure of Atomistic Concepts Understanding

The EFA provided evidence for the internal structure of the instrument used to assess Moroccan upper secondary students'

understanding of atomistic concepts. The sampling adequacy was satisfactory ($KMO = 0.878$ and Bartlett's test of sphericity was significant, $p < 0.001$), which confirms the suitability of the data for factor analysis and suggests that the questionnaire has a coherent latent structure (Knekt et al., 2019). The EFA identified three dimensions of atomistic concepts understanding: (1) structural representations and quantitative chemistry, (2) ionic classification and nomenclature, and (3) fundamental atomic concepts. This structure suggests that students' difficulties are not homogeneous but are mainly concentrated in dimensions requiring the coordination of several representational registers and levels of cognitive transfer. Thus, the three-factor solution provides an empirical contribution to Moroccan chemistry education, mostly because validated diagnostic instruments on atomistic concepts remain limited in this context (Ferouni et al., 2012; Ouasri, 2017; Lahlali et al., 2023). Beyond psychometric validation, the identified structure offers insight into the organization of students' conceptual understanding of atomistics in the Moroccan context that differ from the North American and European educational settings in which much of the reference literature has been produced (Suparman et al., 2024). However, items Q11 and Q25 showed high uniqueness values, >0.90 , and low factor loadings. This suggests that these items may assess peripheral aspects of the construct or may be insufficiently aligned with the main latent dimensions. Therefore, adjusting their conceptual focus could improve the coherence and internal validity of the instrument.

CONCLUSION

This study aimed to assess Moroccan upper secondary students' understanding of atomistic concepts, identify their main misconceptions, and examine the association between these understanding and particular learning practices. Based on a quantitative design involving 206 students and using inferential and exploratory factor analyses, this study provides empirical evidence on atomistic concepts understanding that remains insufficiently investigated in the Moroccan educational context. The findings show that students' understanding of atomistic concepts is generally moderate, as atomistics require the articulation of multiple levels of representation. The diagnostic instrument identified several misconceptions, particularly concerning the distinction between chemical species and entities, concentration and amount-of-substance calculations, Lewis structures, and electronic stability. These difficulties suggest that students' learning obstacles are not limited to isolated errors but reflect a fragmented understanding of atomic and chemical explanatory models.

The study findings suggest that understanding atomistic concepts is a multidimensional construct structured into three complementary dimensions: fundamental atomic concepts, ionic classification and nomenclature, and an integrative dimension combining structural representations and quantitative chemistry. Furthermore, students' scores were associated with several learning practices, including

moderate use of digital tools (videos, social media, and GenAI), tutoring, and, most importantly, self-assessment. However, this study has limitations. The study design does not allow causal relationships to be established between variables, and the sample size ($n = 206$), although acceptable for exploratory analysis, limits the confirmation of the proposed construct.

Overall, this study produces a dual contribution: It proposes a diagnostic tool adapted to the Moroccan educational context and provides an empirical model of students' understanding of atomistic concepts. Future longitudinal and intervention-based studies are needed to clarify the mechanisms underlying students' learning difficulties in atomistics.

ETHICS STATEMENT

This study was conducted in accordance with the ethical principles for educational research with questionnaire. Students' participation was voluntary, and they were informed about the purpose of the study. The questionnaire was anonymous, and students had the right to decline participation or leave items unanswered without penalty. No names, identification numbers, or personal information were collected. The data were analyzed and used exclusively for scientific research purposes.

REFERENCES

- Becker, N., Stanford, C., Towns, M., & Cole, R. (2015). Translating across macroscopic, submicroscopic, and symbolic levels: The role of instructor facilitation in an inquiry-oriented physical chemistry class. *Chemistry Education Research and Practice*, 16(4), 769-785.
- Belova, N., Krause, M., & Siemens, C. (2022). Students' strategies when dealing with science-based information in social media-a group discussion study. *Education Sciences*, 12(9), 603.
- Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment Evaluation and Accountability*, 21(1), 5-31.
- Boateng, G.O., Neilands, T.B., Frongillo, E.A., Melgar-Quinonez, H.R. & Young, S.L. (2018) Best practices for developing and validating scales for health, social, and behavioral research: A primer. *Frontiers in Public Health*, 6, 149.
- Boukayoua, Z., Kaddari, F., & Bennis, N. (2021). Students' interest in science learning and measurement practices: Questions for research in the Moroccan school context. *SHS Web of Conferences*, 119, 05006.
- Bouzit, S., Alami, A., Selmaoui, S., & Rakibi, Y. (2023). Scientific experiments in Moroccan high schools life science courses: Constraints and solutions. *European Journal of Educational Research*, 12(2), 957-966.
- Cooper, M.M., Grove, N., Underwood, S.M., Bunce, D.M., & Klymkowsky, M.W. (2010). Lost in Lewis structures: An investigation of student difficulties in developing representational competence. *Journal of Chemical Education*, 87(8), 869-874.
- Cooper, M.M., Underwood, S.M., & Hilley, C.Z. (2012). Development and validation of the implicit information from Lewis structures instrument (IILSI): Do students connect structures with properties? *Chemistry Education Research and Practice*, 13(3), 195-200.
- Cronbach, L.J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, 16(3), 297-334.
- Fang, S.C., Hart, C., & Clarke, D. (2014). Unpacking the meaning of the mole concept for secondary school teachers and students. *Journal of Chemical Education*, 91(3), 351-356.
- Ferouni, A., Khyati, A., Talbi, M., El Jamali, S., & Radid, M. (2012). Identification of a few difficulties in chemistry in Moroccan high school: Case of the redox. *Procedia - Social and Behavioral Sciences*, 46, 101-107.

- Greeves, S., & Oz, M. (2024). YouTube in higher education: Comparing student and instructor perceptions and practices. *Frontiers in Education*, 8, 1330405.
- Habibi, I., Elachqar, A., & Kaddari, F. (2026). Difficult concepts in chemistry as seen by Moroccan high school students: A survey in the Fez-Meknes region. *International Journal of Education and Practice*, 14(2), 28-43.
- Hartelt, T., & Martens, H. (2024). Self-regulatory and metacognitive instruction regarding student conceptions: Influence on students' self-efficacy and cognitive load. *Frontiers in Psychology*, 15, 1450947.
- Herrington, D.G., & Sweeder, R.D. (2025). Is this a helpful YouTube video? A research-based framework for evaluating and developing conceptual chemistry instructional videos. *Journal of Chemical Education*, 102(2), 621-629.
- Johnstone, A.H. (1991). Why is science difficult to learn? Things are rarely what they seem. *Journal of Computer Assisted Learning*, 7(2), 75-83.
- Johnstone, A.H. (2000). Teaching of chemistry - logical or psychological? *Chemistry Education Research and Practice*, 1(1), 9-15.
- Knekta, E., Runyon, C., & Eddy, S. (2019). One size doesn't fit all: Using factor analysis to gather validity evidence when using surveys in your research. *CBE-Life Sciences Education*, 18(1), rm1.
- Lahlali, A., Chafiq, N., Radid, M., Atibi, A., El Kababi, K., Srouf, C., & Moundy, K. (2023). Students' alternative conceptions and teachers' views on the implementation of pedagogical strategies to improve the teaching of chemical bonding concepts. *International Journal of Engineering Pedagogy*, 13(6), 90-107.
- Lumley, T., Diehr, P., Emerson, S., & Chen, L. (2002). The importance of the normality assumption in large public health data sets. *Annual Review of Public Health*, 23, 151-169.
- Mardy, A., Alami, A., Khouna, J., & Aouine, Y. (2025). Identifying challenges in teaching chemistry among high and middle school physics and chemistry teachers in Morocco. *International Journal of Evaluation and Research in Education*, 13(4), 1230-1245.
- McAfee, S.C., Watts, F.M., & Rodriguez, J.M.G. (2025). A review of research on the teaching and learning of quantum mechanics. *Chemistry Education Research and Practice*, 26(3), 578-593.
- Mennani, M., Raouf, K., & Khyati, A. (2023). Epistemological and didactic difficulties of teaching chemistry in Moroccan high schools. *Journal of Educational and Social Research*, 13(3), 60-72.
- Ministry of National Education. (2007). *Programs and Teaching Guidelines for Physics and Chemistry in the Upper Secondary Cycle*. New Delhi: Ministry of National Education.
- Morbidoni, C., Mascitti, A., Sarra, A., Tonucci, L., & Coccia, F. (2026). Exploring the potential of using ChatGPT in chemistry education. *Journal of Chemical Education*, 103, 286-297.
- Nickel, S., Brockmüller, S., Boone, W.J., & Habig, S. (2025). Measuring representational competence - analyzes of dimensionality and the relationship to general content knowledge. *International Journal of Science Education*, 48, 2071-2095.
- Nickow, A., Oreopoulos, P., & Quan, V. (2024). The promise of tutoring for PreK-12 learning: A systematic review and meta-analysis of the experimental evidence. *American Educational Research Journal*, 61(1), 74-107.
- Ohtani, K., & Hisasaka, T. (2018). Beyond intelligence: A meta-analytic review of the relationship among metacognition, intelligence, and academic performance. *Metacognition Learning*, 13, 179-212.
- Ouasri, A. (2017). A study of Moroccan pupils' difficulties at second Baccalaureat year in solving chemistry problems relating to the reactivity of ethanoate ions and to copper-aluminium cells. *Chemistry Education Research and Practice*, 18, 737-748.
- Peng, P., & Kievit, R.A. (2020). The development of academic achievement and cognitive abilities: A bidirectional perspective. *Child Development Perspectives*, 14(1), 15-20.
- Reziggalla, A.A. (2022). Item analysis: Concept and application. In: Firstenberg, M.S., & Stawicki, S.P. (Eds.), *Medical Education for the 21st Century*. London: IntechOpen, pp. 1-16.
- Reziggalla, A.A., Eleragi, A.M.E.A., Elhussein, A.B., Alfaifi, J., Alghamdi, M.A., Al Ameer, A.Y., Yahia, A.I.O., Mohammed, O.A., & Adam, M.I.E. (2024). Item analysis: The impact of distractor efficiency on the difficulty index and discrimination power of multiple-choice items. *BMC Medical Education*, 24, 445.
- Rotich, F., Ward, L., Beck, C., & Popova, M. (2024). Attention is currency: How surface features of Lewis structures influence organic chemistry student reasoning about stability. *Chemistry Education Research and Practice*, 25(4), 1071-1089.
- Sevian, H., & Talanquer, V. (2014). Rethinking chemistry: A learning progression on chemical thinking. *Chemistry Education Research and Practice*, 15(1), 10-23.
- Suparman, A.R., Rohaeti, E., & Wening, S. (2024). Student misconception in chemistry: A systematic literature review. *Pegem Journal of Education and Instruction*, 14(2), 238-252.
- Taber, K.S. (2003). The Atom in the chemistry curriculum: Fundamental concept, teaching model or epistemological obstacle? *Foundations of Chemistry*, 5(1), 43-84.
- Taber, K.S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, 48(6), 1273-1296.
- Talanquer, V. (2011). Macro, Submicro, and symbolic: The many faces of the chemistry "triplet." *International Journal of Science Education*, 33(2), 179-195.
- Tashiro, J., Parga, D., Pollard, J., & Talanquer, V. (2021). Characterizing change in students' self-assessments of understanding when engaged in instructional activities. *Chemistry Education Research and Practice*, 22(3), 662-682.
- Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, 2, 53-55.
- Touli, E.H., Talbi, M., Moutaabbid, M., & Radid, M. (2014). The teaching-training of chemistry in Moroccan high schools: Obstacles and areas for improvement. *Procedia - Social and Behavioral Sciences*, 116, 373-376.
- Tümay, H. (2016). Reconsidering learning difficulties and misconceptions in chemistry: Emergence in chemistry and its implications for chemical education. *Chemistry Education Research and Practice*, 17(2), 229-245.
- Uçar, S.Ş., Lopez-Gazpio, I., & Lopez-Gazpio, J. (2025). Evaluating and challenging the reasoning capabilities of generative artificial intelligence for technology-assisted chemistry education. *Education and Information Technologies*, 30, 11463-11482.
- Üce, M., & Ceyhan, İ. (2019). Misconception in chemistry education and practices to eliminate them: Literature analysis. *Journal of Education and Training Studies*, 7(3), 202.
- Valeri, F., Nilsson, P., & Cederqvist, A.M. (2025). Exploring students' experience of ChatGPT in STEM education. *Computers and Education: Artificial Intelligence*, 8, 100360.
- Varma, K., Van Boekel, M., Aylward, G., & Varma, S. (2023). Executive function predictors of science achievement in middle-school students. *Frontiers in Psychology*, 14, 1197002.
- Watkins, M.W. (2018). Exploratory factor analysis: A guide to best practice. *Journal of Black Psychology*, 44(3), 219-246.
- Zhou, C. (2026). From initial trust to critical reconstruction: Upper secondary students' engagement with generative AI in science learning. *Frontiers in Psychology*, 17, 1830646.