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# Discontinuity in the teaching of Lewis representation between secondary and higher education.

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## 5 ABSTRACT

This article focuses on the learning of the Lewis representation at the transition from high school to university, in France. Indeed, this notion is taught both in high school and in the first year of higher education but with different methods, which seems to hinder the learners. In this work, we observe 11th grade and higher education classes learning the Lewis representation to analyze the discrepancies in these two forms of learning which could be at the origin of performance differences. To complete these observations, we have developed assessments for learners to inform us about the effectiveness of different learning methods.

## KEYWORDS

High School / Introductory Chemistry, Lewis structure

## 15 BACKGROUND

The Lewis model<sup>1</sup> is an important topic for science students as it explains the formation of covalent bonds, understanding the relationships between the structure of an entity and its properties such as polarity. The problem is that this model remains quite opaque in terms of teaching. For Cooper<sup>2</sup>, the Lewis basis to build structure are omitted or too obscure, students and even teachers are confused as to how to construct correct Lewis structures:

*“However, despite nearly four decades of literature describing “improved” ways of teaching Lewis structures, the creation of valid representations remains an elusive objective for many chemistry students”*

*“[...]flaws and ambiguities in students' ability to create correct structures will inevitably produce obstacles when they need to interpret and apply these structural representations.”*

For over a decade, Cooper and Underwood<sup>3-8</sup> have studied the relationship between the Lewis structure and the physical and chemical properties of molecules such as geometry, polarity, boiling and melting points and reactivity (acidity and basicity). They and some other researchers show that students have difficulty making this relationship.<sup>9,10</sup> This difficulty echoes Johnstone's discussion of levels of knowledge,<sup>11,12</sup> namely the difficulty for learners to move between a structural representation and a molecular representation. The difficulty increases with the size of the structure, but even structures with a single carbon are problematic for students if they have no clue as to the structure of the molecule. Another difficulty for the learners is that they cannot find the correct sequence of atoms in the molecule. Cooper et al.<sup>2</sup> also showed that students thought that the most stable Lewis structures should be symmetric. Several authors point out that textbooks do not provide a guide for constructing Lewis structures.<sup>2,13</sup>

For decades, different methods for constructing Lewis structures have been proposed in the literature. They are usually based on drawings where the valence electrons are represented by dots and where the octet rule allows to complete this shell to saturation (8 electrons)<sup>2,13-22</sup>. The problem is that it is difficult to have a harmonization of methods since the way in which students are taught to

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draw Lewis structures, will vary from one chemistry course to another. The procedures often contain several steps. A typical one is to count the total number of valence electrons for all atoms in the molecule (consider possible charges). This number is divided by two and gives the total number of available electron pairs. Using an assumed or known atom connectivity, electron pairs are placed  
45 between and on atoms starting with atoms with one connection in an effort to give each hydrogen an electron count of two and all non-hydrogen atoms an octet.<sup>15,16,21,22</sup> Other researchers describe a method focusing on each atom of the molecule, first writing the Lewis structure of each atom of the molecule and then connecting them to obtain the Lewis structure of the molecule.<sup>17,20</sup>

Concerning the French instructions, the 11th grade program on the Lewis representation  
50 allows to model matter at the microscopic level and to predict the geometry of molecules. The program defines some mono or polyatomic molecules or ions that pupils should be able to write in Lewis. Lewis representation is based on the octet (or duet) rule. The electronegativity is then introduced in order to determine the polar nature of a bond, and from its geometry the polar or apolar nature of the molecule.

Concerning the higher education, Bachelor of Chemistry, Faculty of Sciences of the University  
55 of Montpellier, the first semester is devoted to the Lewis model and to the geometry of molecules using the VSEPR model. The second semester focuses on the determination of the electronic structure of atoms and molecules using simple approaches such as Slater's model or the orbital approach.

We note that the first-year undergraduate program repeats the high school program with  
60 regard to the Lewis representation, also relying on the octet rule (duet). The program goes further by introducing the mesomeric forms. The geometry follows from the Lewis model by introducing the VSEPR model. In this paper, we focus on the teaching of the Lewis structures themselves (the one used in secondary school and the one used in higher education) and the resulting geometry but not on the structure/property relationships.

## RESEARCH AIMS

We have noticed that students are confused in higher education during the course on Lewis  
structures. It seems that, although students have already encountered this notion, they have  
70 difficulties in higher education. We have noted that the approach to teaching this notion in higher education is different from that used in secondary education. For this reason, we explored the notion of the Lewis representation at the high school/university transition, to look at the differences of teaching that may exist between the two orders of education. In this article, we describe both methods and we want to highlight the differences between these two types of teaching, based on observations made in class. Do not these differences, which create a discontinuity of this teaching, lead to  
75 difficulties for learners? And if so, how can they be remedied? To do this, we also rely on the analysis of assessments that we have developed.

## METHODOLOGY

Our study focused mainly on the teaching of the Lewis model: we look at this teaching in high  
80 school (in 11th grade) and in the first year of university (see SI for description of the textbook of 11th grade class and description of the lecture course at university).

The two classes (with two teachers Mrs. X and Mrs. Y) observed in 11th grade include  
85 respectively 33 and 36 pupils, they are divided into half-groups during our observations. Pupils are around 16 years old. The classes belong to a good standard public high school in Montpellier. We filmed the session on Lewis representation and the geometry of molecules in the 4 half-groups. Authorizations to film had been requested from the parents (since the pupils are minors).

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We also collected the course from an 11th grade class from another high school in the same city of equivalent level, where the teacher used the same method as in higher education (36 pupils) (see SI). We are only using the results of the assessments in this class for comparison purposes (not for the qualitative study).

Our study at the university consisted first of all in analyzing the chemistry course offered in the amphitheatre to the entire class of first-year (around one hundred students). We then restricted our observation to a tutorial group that included about 20 students to whom we asked permission to film them. This group was filmed on the two tutorials dedicated to the representation of Lewis.

All videos were transcribed, which allowed us to study the verbatims to illustrate the analysis (qualitative part).

The transcripts were analyzed by identifying different categories in relation to our research questions:

Concerning the students, the categories are:

- problems with the octet rule (incorrect number of bonds for example): learners misapply the octet rule: for them, the number of valence electrons corresponds to the number of bonds.
- geometry problems: they don't take all pairs into account, resulting in incorrect geometry.
- omission of lone pairs
- problem with the choice of central atom: they think, for example, that the first atom in the molecule's formula is the one in the center.

Concerning the teachers, the categories are:

- repetition of some points in the method (number of bonds made by each atom, four for carbon, three for nitrogen, two for oxygen and one for hydrogen)

For both of them:

- materialistic view: for example, learners or teachers use terms referring to people when they talk about atoms (want, need...).

The categories correspond to points that pose problems for the students or points that the teachers come back to very often, each point appearing at least 3 times in the session, so they constitute a category. We list the sentences that correspond to these categories and use them to support our research hypotheses.

We developed assessments to analyze the construction of the notion of the Lewis model in high school and college students, and in order to compare the two teachings. To guarantee the validity of the assessments, pupils (at the same level of education) not involved in this research tested them to ensure that the questions were understandable and unambiguous. Teachers' consent is also required for these assessments.

We present the evaluations here, giving some of the information expected from the questions to answer our research question. First, the definition of the covalent bond (Q1) is asked. Since the Lewis model involves lone pairs, we ask for their definition (Q2). The third question is: "*Among the following Lewis structures, indicate which are incorrect and justify*". The three structures are not Lewis representations because they do not follow the octet rule or the lone pairs do not appear. We have considered as correct answers those accompanied by a valid justification. Question 4 shows that the Lewis representation does not directly inform about the geometry, both representations are correct. The question 5 wants to show that the representations of the molecules are models and that consequently they have limits, thus the lone pairs are not represented, that the geometry is not given as well as the polarity of the bonds or angles.

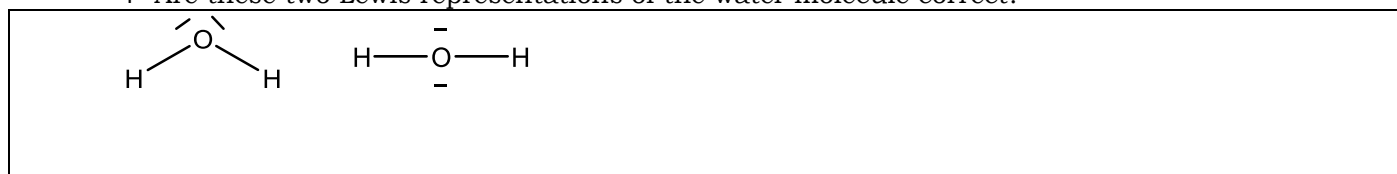
1-Give a definition of the covalent bond

2-What is a lone pair?

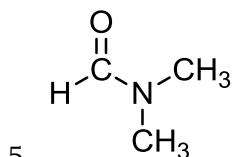
3- Among the following Lewis structures, indicate which are incorrect and justify.

Structure	Correct	Incorrect	Justification
$\begin{array}{c} \text{H} - \overset{\cdot\cdot}{\underset{\cdot\cdot}{\text{N}}} - \text{H} - \text{H} \end{array}$			
$\begin{array}{c} \text{O} \\ \parallel \\ \text{H} - \text{C} - \text{H} \end{array}$			
$\begin{array}{c} \text{H} \\   \\ \text{H} - \text{C} - \text{O} - \text{I} \\   \\ \cdot\cdot \end{array}$			

4- Are these two Lewis representations of the water molecule correct?



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5-

Are there any flaws or inaccuracies in the representation of the bond? If

so, which ones?

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We also look at whether there is a discontinuity or rupture between the two levels of teaching. The Lewis representation is taught in 11th grade and in the first year of university. During the intermediate year, this notion is not reviewed, as the curriculum is very full in view of the "baccalaureate", and the teachers do not return to this theme and do not need to do so during the year. The major difference between these two populations is age: the students have done more chemistry and are more mature. For this reason and in spite of this, we have put forward the following hypotheses:

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- If the pupils and students give approximately the same correct answers (so  $\chi^2$  not significant), we can consider this to be continuity in teaching.

- On the other hand, if the results of the pupils and students are statistically different, we can speak of a rupture between the two levels of teaching.

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- If age is a factor in our study, all the 11th grade populations should be at a break with the university population.

## FINDINGS

Results and discussion: Reflecting on courses and tutorials in high school and university.

160 A description of what is taught during the session is given in SI-4 for both teaching levels (11th grade and university).

- In 11th grade

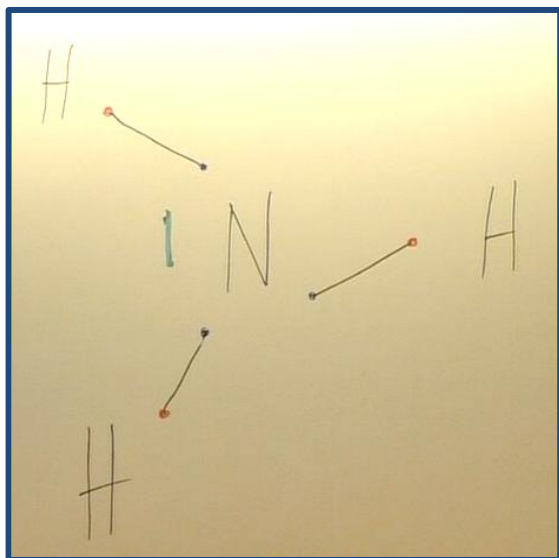
The Lewis representation is taught as follows (it can be noted that the texts are not precise, either in the school curricula or in the textbooks):

165 - Calculate the number of valence electrons of each atom in the molecule. Electrons are added in the case of anions and electrons are removed in the case of cations.

- Write each atom with their valence electrons around (dots)

- Connect the dots (electrons) of the atoms in order to make the bonds between atoms (respect the octet rule)

170 - Add the lone pair when necessary (Figure 1)



**Figure 1:** Lewis representation of  $\text{NH}_3$  molecule in 11th grade.

175 We have observed that the teachers of the high school insist on the fact that the Lewis structure must be established atom by atom, contrary to the method used in higher education, which is done on the molecule. This process is repeated several times (“*you do? atom by atom to find out how many bonds each atom has to make*”, “*you look for each atom how many bonds it needs and how many lone pairs it has*”).

180 Moreover, this method in which electrons are drawn by dots that must be connected to form bonds reinforces the materialist view of the bond<sup>23</sup>. Some students also use anthropological terms showing a personification of chemical concepts (*Pupil: “because they don’t need”*).<sup>24</sup> One of the two teachers also uses this kind of terms (“*the life of this molecule*”, “*it will try to have friends*”, “*the molecule what is its head?*”). All this leads to a misconception of the notions of bonding and more generally of chemistry.

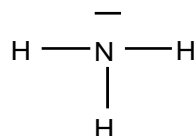
185 In addition, this method poses problems. Indeed, let us take the example of nitrogen. First of all, we quickly notice that the misconception “the atoms form as many covalent bonds as there are electrons on their valence shell” has been observed<sup>25</sup>, as illustrated by the following dialogue:

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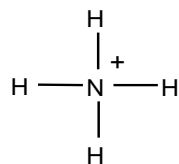
Teacher: So here how many bonds can nitrogen form to satisfy the octet rule, yes?

Pupil: 5

190 In the textbooks, it is explained that the nitrogen atom is located three columns before that of noble gases. It has 5 valence electrons and tends to acquire the electronic structure of the noble gas (neon) which has 8. It therefore puts three of its valence electrons in common with other atoms. It therefore forms three covalent bonds (electron pair). The two valence electrons remaining in nitrogen, and unshared, pair into a lone pair around the nitrogen atom.



But when we switch to the ammonium ion, we have to remove a valence electron to respect the charge of the ion. It is difficult to explain its Lewis representation on this same reasoning. Why is it an electron of the lone pair that is torn off to form the cation?



200 The case of sulfur (phosphorus...) which is not in the high school program but can be encountered in certain exercises and which does not always follow the octet rule since it belongs to the third period poses a problem for pupils if they always reason with this rule. Indeed, in an exercise given in 11th grade, the molecule of SO<sub>2</sub> is given and it is specified that its geometry is bent. The problem is, since sulfur no longer follows the octet rule, the pupils do not understand the geometry of this molecule. Here sulfur is surrounded by 10 electrons and not 8.

205 Another source of problem for high school pupils is the determination of the central atom. While in higher education it is clearly stated that it will be given if there is any ambiguity, high school students do not get a clear answer. It is explained to them during the courses that from the molecular formula, they can consider that the first atom of the formula is the central atom: if this works for certain molecules (CH<sub>4</sub>, CO<sub>2</sub> for example), it is not the same for others (e.g. H<sub>2</sub>O).

Pupil: it doesn't work if I say H<sub>2</sub>O

Teacher: it doesn't work, the third example is H<sub>2</sub>O and the one we name first is H. Is it in the center?

215 In fact, in 11th grade we try to surround each atom of a molecule with 8 dots representing electrons so that they respect the octet rule (2 for hydrogen). This chapter seems to be based on "by heart" learning rather than on reasoning. Indeed, in the textbook, a table summarizing the number of electron and lone pairs for each atom is given instead of a method to understand it (see SI). This process is also followed in class: for each atom, it is recalled several times during the session, the number of bonds that they can make several times in the four filmed sessions ("carbon makes 4 bonds, nitrogen makes three bonds, oxygen makes two bonds, hydrogen makes one bond"). However, the method in high school allows to calculate the number of bonds that an atom makes from its number of valence electrons. We have seen that this method can confuse the pupils, such as certain exercises in which sulfur is involved: in fact, the pupils do not understand why this atom does not respect the octet rule. Perhaps a little more precision on the role of a model and especially its limits would avoid this obstacle and this discontinuity with the higher education.

225 It seems that, even if this method seems simple, it annoys the pupils who at the end of the session do not all seem to have understood the process ("but madam, why H<sub>2</sub>O is not linear", "how do

we know that there are lone pairs in a molecule?”, “why are there 4 electron pairs here [speaking of one of the two carbon atoms in ethane]”). These remarks, at the end of the session, are worrying from the point of view of pupil understanding.

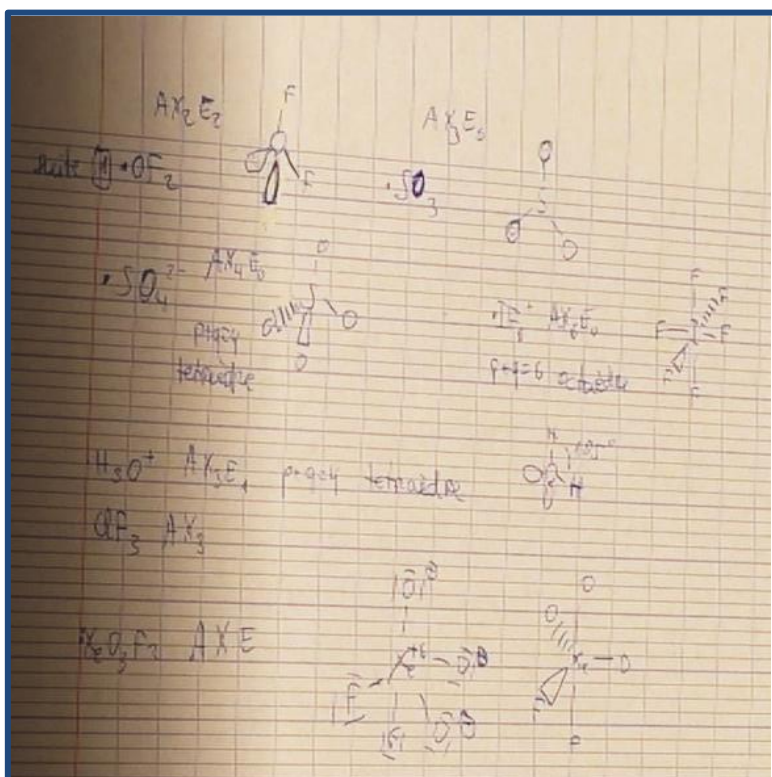
230 We have just seen that this method suffers from inaccuracies (determination of the central atom, no explanation of the limits of this model, materialist view) and consequently leads the pupils to misunderstandings. It can only be used for simple molecules.

- In bachelor’s degree

235 At university, the students have at their disposal a method that allows them to draw Lewis representations for any mono or polyatomic molecules or ions. Here a method is given in class and recalled in tutorial (SI).

At this level the role of a model has been more explicit than in high school. For the majority of students, this method is well assimilated as we observed during the tutorial sessions in first year of university. However, it is observed that it is misused or not used by some students.

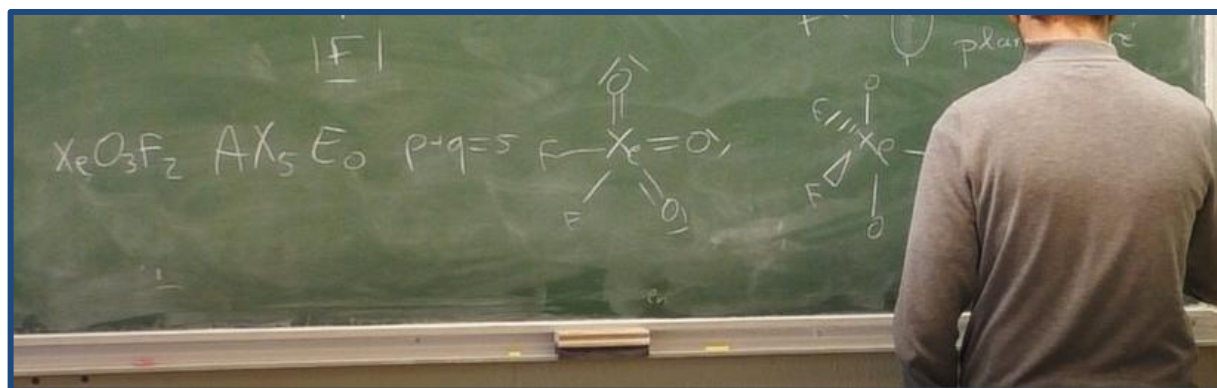
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**Figure 2:** Student worksheet: he does not calculate the total number of pairs.

245 Some students do not calculate the total number of pairs and find false molecules and they forget lone pairs (Figure 2). We observe that they do not use the rules learned in bachelor. Maybe it is because they learned another method in high school and find it hard to ignore it and use a new one? Especially since nothing has been explained about this change in strategy.





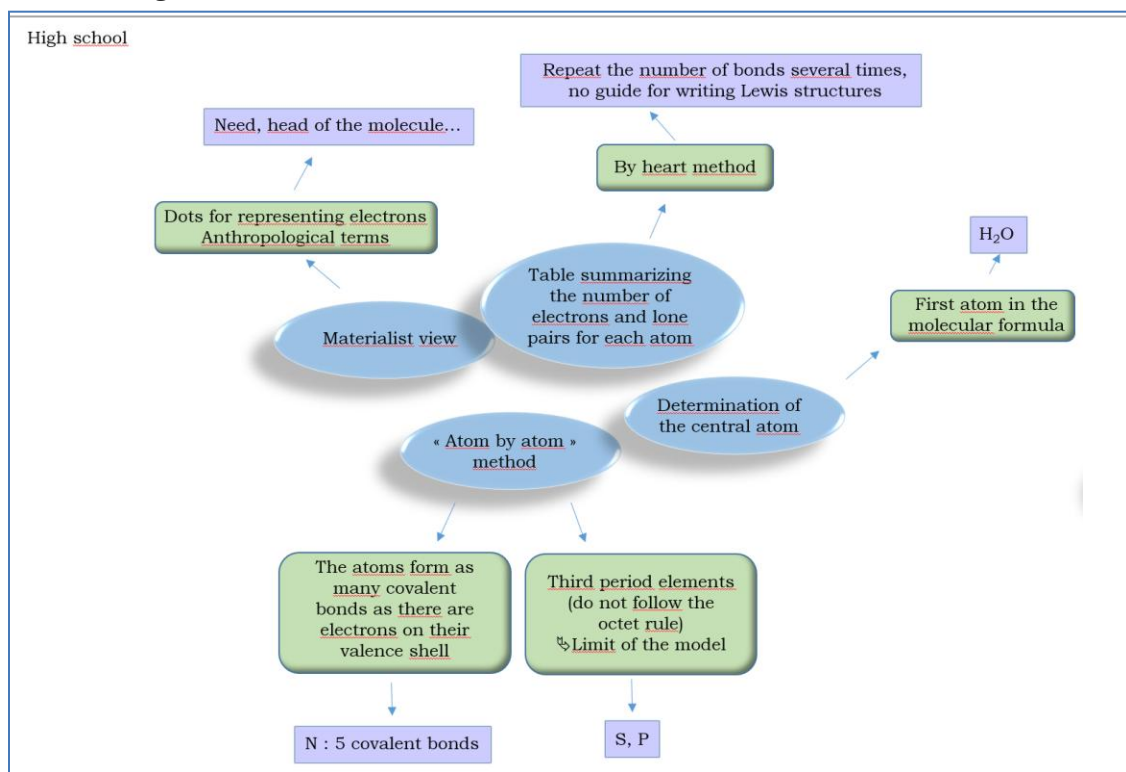
**Figure 3:** student who does not calculate the total number of pairs

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We see here that the student wanted to write the Lewis representation without calculating the number of pairs and therefore forgot the lone pair of fluorine (Figure 3). Of course, in the Bachelor's degree, it is explained to the students why from the third period the elements no longer follow the octet rule (existence of d orbitals).

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This figure 4 summarizes the differences outlines above between these two methods.



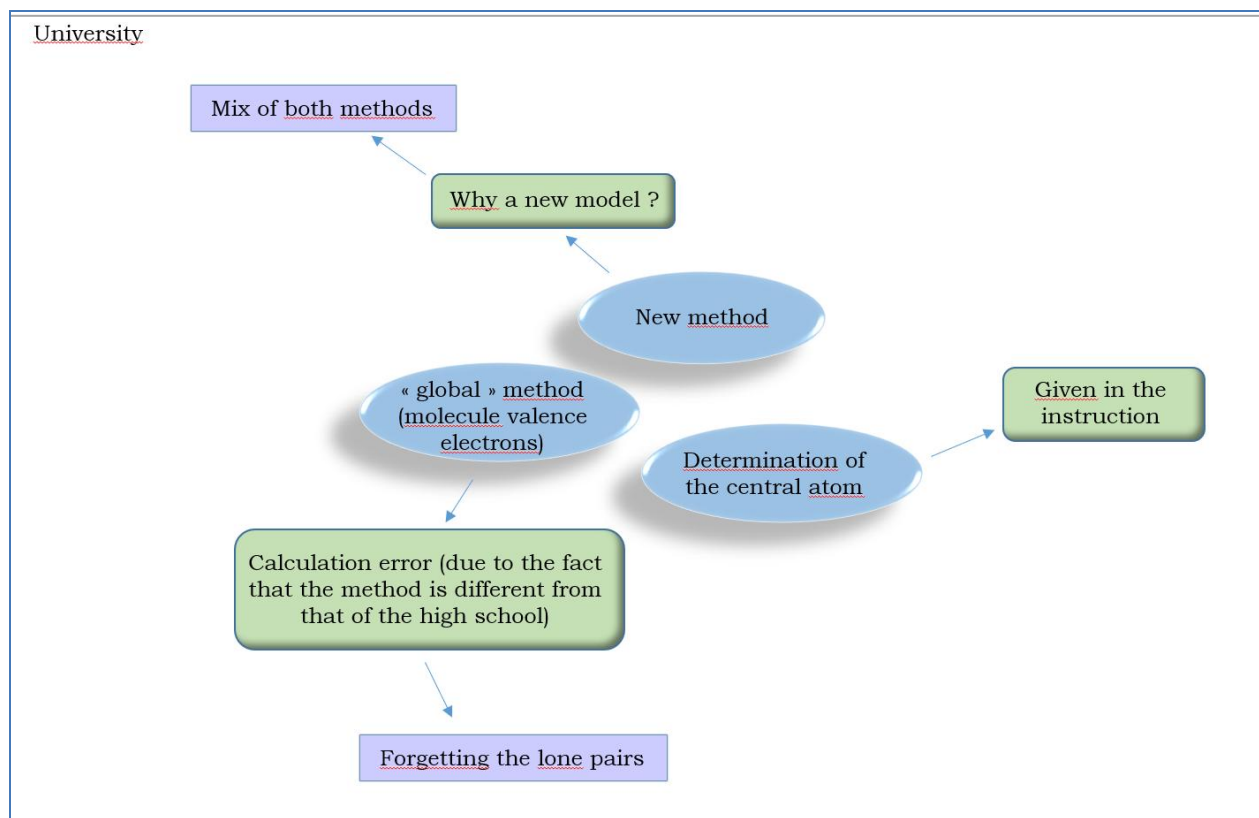


Figure 4: Summary of the characteristics and differences of the two methods

As a reminder, the "atom by atom" method leads pupils to make a number of inaccuracies, such as thinking that atoms form as many bonds as they have valence electrons, or that the elements of the third period can follow the octet rule. It is also learnt repeatedly and memorized without any thought. The pupils seem to be lost between not understanding which atom is at the center and the fact that this is a model and therefore does not apply to all the elements of the periodic table. High school pupils seem to cling to the table given in their textbook, where for the most commonly used atoms (H, C, N, O, Cl, ...) they are given the number of electron pairs and the number of lone pairs. One might expect university students to find it easy to represent molecules using the Lewis model, since they have already studied it and are more expert in chemistry than high school pupils. Despite this, some students are relatively lost, discovering a new method for a concept they have already encountered. They mix up the two methods, which leads them to forget things or make mistakes. This method, which focuses on the whole molecule, confuses the students. A clarification of the concept of the model could help to clarify some of the ambiguities but also perhaps a harmonization of methods.

- Assessments

The assessments were completed by pupils in 11th grade during a class, and first-year students in amphitheatre. The questions presented here focus on the Lewis representation (see methodology).

The assessments were given to the learners after the sequence on the Lewis model in both grades.

**Table 1: Correct answers for both pupils of 11<sup>th</sup> Grade in % and (numbers of correct answers/total people).**

Question	Pupils of 11 <sup>th</sup> Grade	Pupils of 11 <sup>th</sup> Grade (same method as in university)	$\chi^2$
Q1	23.2% (19/82)	55.5% (20/36)	11.858

Q2	46.9% (38/82)	69.4% (25/36)	5.366
Q3a	81.7% (67/82)	91.7% (33/36)	1.918
Q3b	64.6% (53/82)	77.8% (28/36)	2.008
Q3c	85.4% (70/82)	91.7% (33/36)	0.895
Q4	59.8% (49/82)	72.2% (26/36)	1.678
Q5	57.3% (47/82)	69.4% (25/36)	1.547

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To begin with, we compare the results of the two different populations of 11th grade pupils (classes using the traditional high school method and those using the university method) (Table 1). A very small minority of high school classes use the university method. The percentages of success are better in the class using the university method. This method is based on a deeper understanding, as it is not based on memorized and repeated teaching. It uses a global method rather than an “atom by atom” method, which leads to errors or inaccuracies on larger molecules as previously mentioned. A closer look at these results shows that only the first two questions are statistically significant ( $\chi^2 > 3.841$ ); the others are not. The first two questions concern definitions that are not repeated as often in class as the other questions, which concern structures containing atoms that all the pupils often encounter and know by heart. Indeed, the most repeated points, according to the video analyses, concern the number of bonds that each element can make, also pointing to the number of lone pairs. The exercises are more traditional and repeated, so there is less difference between the two populations.

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But our aim in this article is not to compare these two methods in the year of 11th grade, when they were taught at high school, but rather over time. Our study seeks to understand why we observe certain difficulties among first-year students when learning the Lewis representation, even though the latter has already been studied in high school. This is why we are comparing these two populations of pupils with the university population. Of course, you have to bear in mind that these students are two years older, but that in 12th grade, the Lewis representation is not reviewed. The 12th grade curriculum is full in the run-up to the baccalaureate, so teachers have no time to go back over this chapter. We will take a closer look at the results by comparing the following populations: 11th grade pupils (classic method)/university and 11th grade pupils (university method)/university.

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**Table 2: Correct answers for both pupils and students in % and (numbers of correct answers/total people).**

Question	Pupils of 11 <sup>th</sup> Grade	Students of Bachelors	$\chi^2$
Q1	23.2% (19/82)	61.8% (55/89)	25.941
Q2	46.9% (38/82)	82% (73/89)	23.857
Q3a	81.7% (67/82)	92.1% (82/89)	4.139
Q3b	64.6% (53/82)	79.8% (71/89)	4.909
Q3c	85.4% (70/82)	95.5% (85/89)	5.174
Q4	59.8% (49/82)	75.3% (67/89)	4.715
Q5	57.3% (47/82)	88.8% (79/89)	21.766

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First of all, we compare students following the traditional secondary school method with university students. We note that the 11th grade students do not manage to give a definition of covalent bond, a notion which is however taken up during the course on the Lewis representation. Similarly, the notion of lone pairs, introduced during the study of the Lewis model, is not assimilated. On the proposed structures which do not correspond to Lewis structures, the students are less able to correct them. We notice that the least successful question is the one where the lone pairs of the oxygen are missing. Both representations of the water molecule are correct (Q4): half of the students are aware of it against three quarters of the students. Indeed, the Lewis model does not consider the geometry. The semistructural formula of question 5 has indeed inaccuracies since the lone pairs are not represented contrary to the Lewis model. We can note other inaccuracies, such as the geometry, the polarity of the bonds, the movement of the electrons which are not shown on this representation.<sup>26</sup> The difference of correct answers between the two populations is important. Note that these results are significant ( $\chi^2$  greater than 3.841) (Table 2).

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The two populations are two years apart. It should be noted that during the year that separates them, i.e., 12th grade, the program does not include these concepts. We cannot exclude the fact that students are more mature at university and therefore their results are better. However, according to our research hypotheses, the comparison between the two populations of 11th grade and university students using the same teaching method should enlighten us further. Maybe, the differences are too large to be attributed exclusively to age, especially since these concepts have not been revised in the meantime. On the other hand, the method used in higher education seems effective.

In high school, to build the Lewis representations, the method is done "atom by atom" since we calculate the number of valence electrons for each atom. We have observed, in class, that the teachers repeat this number several times during the session for the different elements. The textbooks present tables (see SI) summarizing the numbers of electron pairs and lone pairs for an element instead of presenting a method to calculate them and thus be able to build the Lewis structure. All this leads to a "by heart" teaching. At the university, the change of method, based on the global electron number of the molecule, leads to some errors in class (forgetting the lone pairs) but the method seems to lead to more solidly anchored notions according to the analyses of the assessments.

In Table 3, we compare the results of the assessment between the pupils who learn the "university" method and the students of bachelors.

**Table 3: Correct answers for both pupils (of the 11th grade class that uses the same method as in university) and students in % and (numbers of correct answers/total people).**

Question	Pupils of 11 <sup>th</sup> Grade	Students of Bachelors	$\chi^2$
Q1	55.5% (20/36)	61.8% (55/89)	0.417
Q2	69.4% (25/36)	82% (73/89)	2.395
Q3a	91.7% (33/36)	92.1% (82/89)	0.007
Q3b	77.8% (28/36)	79.8% (71/89)	0.062
Q3c	91.7% (33/36)	95.5% (85/89)	0.714
Q4	72.2% (26/36)	75.3% (67/89)	0.126
Q5	69.4% (25/36)	88.8% (79/89)	6.845

The chi-square calculation (not significant) shows that there is no difference between the 11<sup>th</sup> grade pupils and the university students, except for question 5 ( $\chi^2$  significant). This question deals with geometry and polarity, which has not been covered much in high school, which explains why students perform better on this question. The pupils of this class seem to have understood Lewis' representation better than their peers at the other school. These results show that the method taught at the university can be used by 11th grade pupils. It seems that this method is more accessible than the one taught in secondary schools, which is less comprehensive and leads to some inaccuracies. If age were a factor, there would also be a difference between this 11th grade class and the students.

To sum up, among the two populations of high-school pupils, the one that obtains the best results is the one that has adopted the same method as in higher education, a method based on greater understanding and not on memorization. Furthermore, when we compare these two populations with those in higher education, we see that there is less difference in results between students and pupils using the same method as at university (hence a continuity in learning) than between pupils using a different method from higher education and students (hence a break in learning).

## CONCLUSION

As we said in the introduction, the Lewis model is a basic subject for learning chemistry. However, it is not so trivial for learners. There are various methods in the literature for constructing Lewis structures, which are not necessarily explicit in textbooks. We have shown that the reflection-based method is more effective and longer-lasting than the memorization-based method. Indeed, the observations and analyses carried out show that the method used in high school is based on "by heart" learning. Moreover, the method is not applicable to all elements without being able to explain it at this level of teaching (i.e. S, N). However, the method in higher education avoids these inaccuracies.

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Moreover, the students do not even have the advantage of having already studied it, since the method is different in higher education.

The definition of a model needs to be specified. Although in high school the Lewis model is in principle centered on the elements of the first two periods, it seems necessary to clarify that it cannot be applied for the whole periodic table, especially if examples are taken for elements that do not follow the octet rule. An effort should be made to define a model and its limits, in order to enlighten learners about the validity of these models and therefore the areas in which they are relevant.

It seems that it would be interesting to use the same method as in higher education in order to avoid this discontinuity of teaching, which leads students to write Lewis incorrect or incomplete Lewis representations, for example by forgetting lone pairs. We have shown that there is a discontinuity in the teaching of Lewis representation between high school and college. The method used is different and leads to learning by heart in 11th grade and to a misunderstanding of Bachelor's students who find themselves confronted with a new method on a subject they have already encountered. When it comes to the Lewis representation method they saw in high school, the students are not comfortable when they encounter it in college. We were able to see that the method used in the superior is quite possible in 11th grade and leads to very good results. We have shown that this method works in the high school. The advantage of using the same method in both levels of education, is that they will not be confronted with different instructions that were an obstacle; they will be able to enrich it with knowledge encountered during the Bachelor's degree. This would provide continuity in the learning process and avoid making it unnecessarily difficult for learners.

Although our results were obtained on a small population, they seem promising. Indeed, this method should be generalized to all high schools so that students do not have to relearn a new method for a subject they have already seen.

It would also be interesting to broaden and deepen this subject on the possibility that learning the same subject using different approaches poses a problem. To our knowledge, this problem of discontinuity when learning a concept in two different ways has not been evaluated. It would be interesting to cross-reference it with other similar studies, either on the same theme, or on another, or even on concepts belonging to a different disciplinary field. Our results seem to support this hypothesis but, this is a case study with all the limitations that entails.

#### Limitation of the study and implications

As is the case with case study, the small sample size limits the generalizability of the results. Nevertheless, the results are interesting and this study case has the potential to inform instruction and future research in this area. What this article shows is that it is necessary to harmonize teaching methods on this subject so as not to create discontinuity and misunderstanding. It seems that students' difficulties in constructing Lewis structures come from using several methods, not all of which are very explicit for learners. Although certain concepts take time to learn, such as property/structure relationships, we can see that in secondary school, using the university method, the Lewis model itself is relatively quickly constructed. What we recommend is the use of the method of the superior, which seems to be effective in the secondary level. Furthermore, this method causes less confusion among the learners (no by heart learning, choice of the central atom...). Finally, the molecules studied in high school should be simpler than those studied in college. The Lewis model is very rich since it allows to deduce relationships between the structure and properties of a molecule. This is why the study of the representation alone needs to be well understood and mastered by the students. This model needs to be well constructed by the learners, as it is the basis for many other concepts.

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## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. **ACS will fill this in.** 1. Description of the textbook (11<sup>th</sup> grade class),  
415 2. Description of the lecture course at university, 3. Description of the instruction given in 11<sup>th</sup> grade  
class for the Lewis representation, 4. Observations in class (4a Observations of teaching methods in  
11<sup>th</sup> grade, 4b Description of the tutorials (first year of the faculty of sciences in university)) (docx).

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