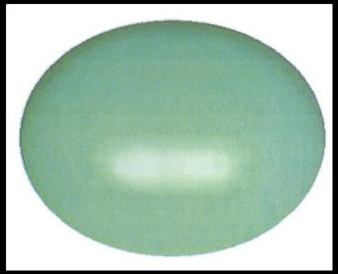
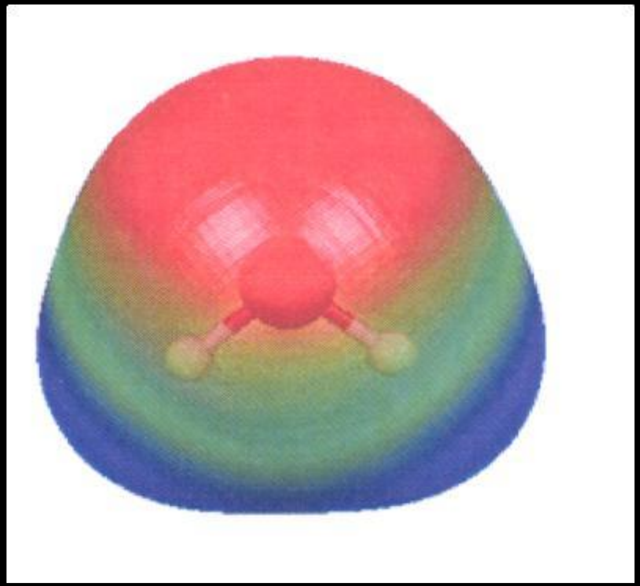
Using Static Colored Visual Representations of Chemical Bonding:

An Analysis of Students' Responses Using the SOLO Taxonomy





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VISUAL REPRESENTATIONS (VRs)

Physical models and images (visual representations) are vital to our understanding of chemistry.

both for learners and researchers.

In recent years, images, as a rule

colored images, have taken up more and more space in textbooks.

Technology, especially

personal computers and smart phones, has been increasingly important in enhancing both student interest

and learning

BUT …

The mere use of images and technology does not guarantee their effectiveness in promoting

learning.

- Learning outcomes appear to depend on both the quality and the pedagogic content of the images and also on how the images and the technology are used (National Research Council, 2012).

- Education research has definitively an important role to play here in assessing the outcomes and the effectiveness of these tools.

THE PRESENT STUDY

- The efficacy and problems associated with the use of static colored VRs of chemical structures and chemical bonding resulting from accurate quantum mechanical calculations are the subject of the present study, which involved a sample of 1st year, 2nd semester chemistry students, studying the elective course "Science Education" (N = 31).

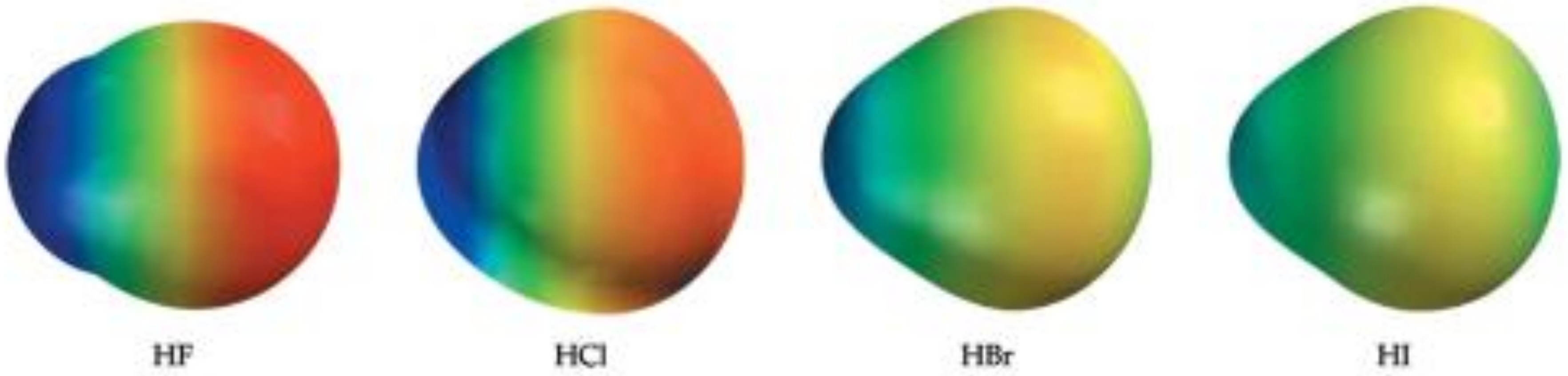


Figure 1: The electrostatic potential maps for the hydrogen halide molecules HF, HCl, HBr and HI, where the colors show differences in chemical bond polarity. The dipole moments μ (in D) are 1.86 for HF, 1.11 for HCl, 0.788 for HBr, and 0.382 for HI. The corresponding Pauling electronegativity differences are 1.78/0.96/0.76/0.46. Note that the shapes shown do not reproduce the relative actual molecular sizes: the gas phase bond lengths D(H–X) (in pm) are 91.7 for HF, 127.4 for HCl, 141.4 for HBr, and 160.9 for HI

- Jensen, J. H. (2010):

Molecular modeling basics.

Boca Raton, FL: CRC Press/Taylor & Francis.

RESEARCH QUESTION:

How do students interpret colored VRs when presented with them for the first time?

THE ANSWER TO THIS MAIN RESEARCH QUESTION

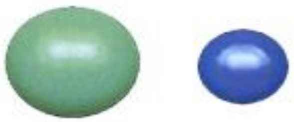
To what degree did the provided static colored VRs help the students to:

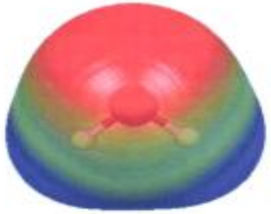
- RQ1: Deduce the type of bonding in various molecules?
- RQ2: Explain the variation of bond polarity in various molecules?
- RQ3: Exploit the difference in size between an atom and its corresponding ion?
- RQ4:Comprehend the concept of a continuum of bonding type and overcome the common misconception that bond polarity is only a feature of covalent bonds and not of ionic bonds?

Question D2. The following (electrostatic potential) maps are given:

Maps (a)
Theoretical (quantum mechanical) calculation of the geometry of the H atom (*left*) and the H_2 molecule (*right*)

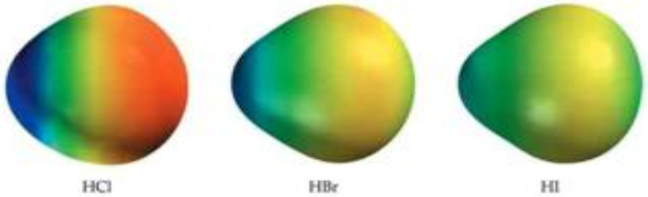
Maps (b)
Theoretical (quantum mechanical) calculation of the geometry of the lithium atom (Li) (*left*) and the lithium ion (Li^+) (*right*)



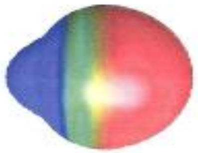


Maps (c)
The structure of the hydrogen molecule (H_2) (*above*) and the structure of the water molecule (H_2O) (*right*), as they are calculated quantum-mechanically.

Maps (d)
The structure of the hydrogen halide molecules HCl, HBr and HI.



Map (e)
Geometry of the system which consists of one lithium atom and one hydrogen atom (*lithium hydride*, Li-H) as it is calculated quantum-mechanically.



A color code scale for the *polarity of electrostatic potential* is also provided:

(+)  (−)

Figure 2: The electrostatic potential maps used in the main study, including a color code scale for the polarity of electrostatic potential.

SOLO TAXONOMY

- The SOLO Taxonomy (Structure of the Observed Learning Outcomes) (originally Biggs & Collis, 1982) can be used to categorize student responses to open-ended questions.
- SOLO illustrates the qualitative differences between student responses as it describes levels of understanding. It classifies outcomes in terms of their complexity, so that a judgement may be made on the quality of student responses to assessment tasks.

SOLO TAXONOMY

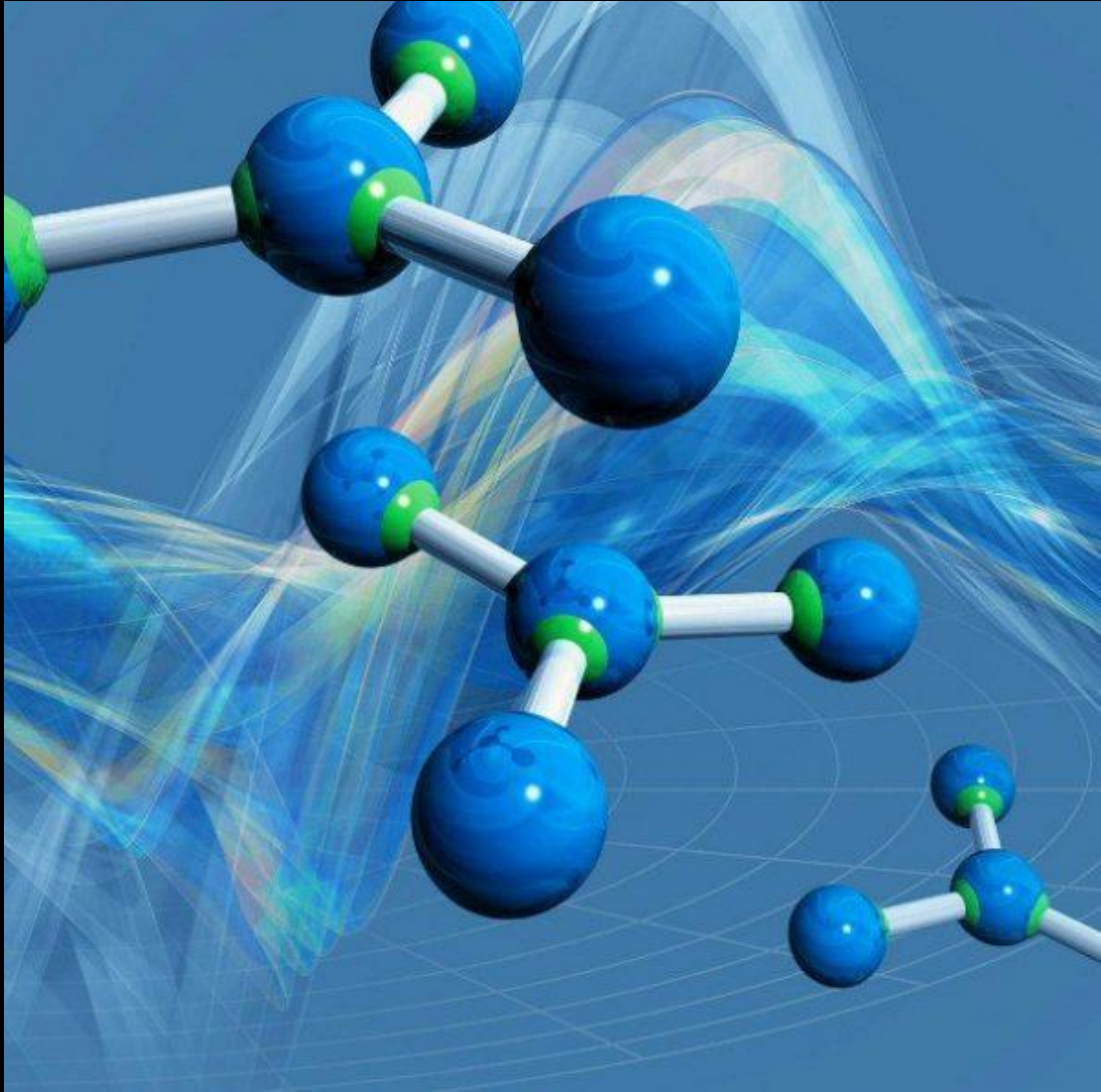
The SOLO taxonomy classifies understanding into five (5) levels:

1. Prestructural: at this level the learner is missing the point
2. Unistructural: a response based on a single point.
3. Multistructural: a response with multiple unrelated points.
4. Relational: points presented in a logically related answer.
5. Extended abstract: demonstrating an abstract and deep understanding.

CHEMICAL BONDING: EASY OR NOT?

- Chemical bonding is a core concept in chemistry, which remains complex to teach and difficult to learn.

- Visual representations (VRs) of chemical structures have proved invaluable in aiding students in understanding this topic.



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Chemistry Education Research and Practice, 19(4), 1253–1269. (Plus Supplementary files).

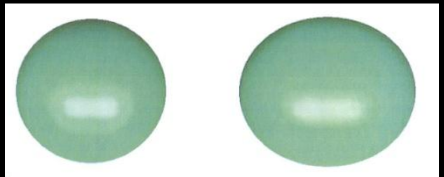
- Tsaparlis, G., Pappa, E. T., & Byers, B. (2020). Proposed pedagogies for teaching and learning chemical bonding in secondary education.

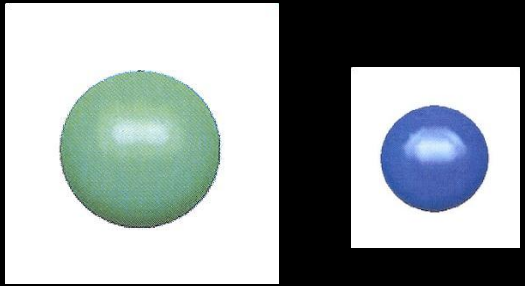
Chemistry Teacher International, 2(1), 20190002.

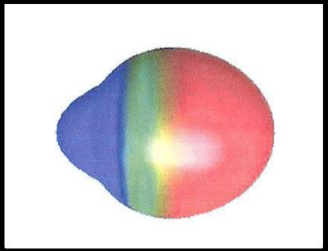
PART D2.a Compound lithium hydride is ionic (it is a solid, for which the melt is a conductor of electricity).

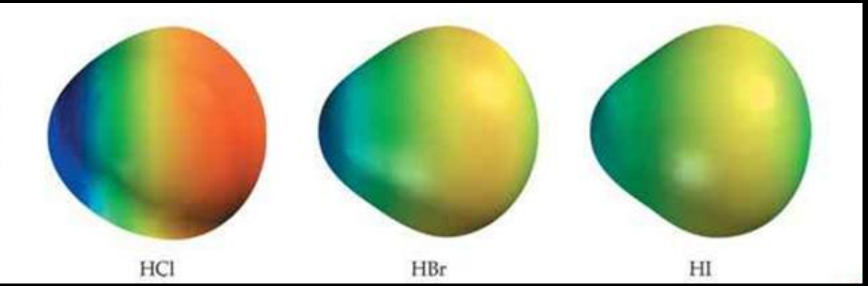
- Which are the cation and the anion in this compound?

- With the aid of: maps (a) (left), maps (b) and map (e), explain why this compound is ionic.



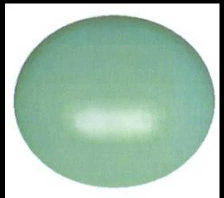


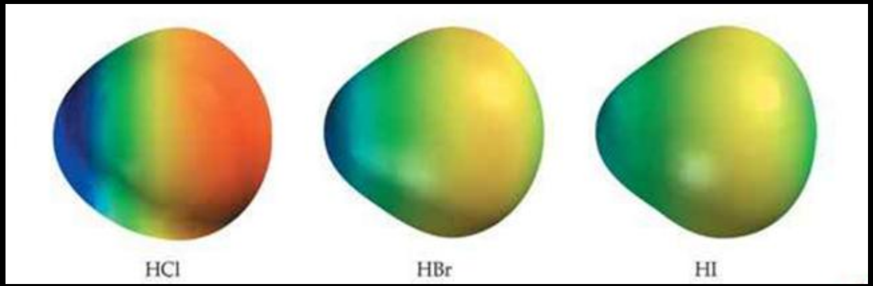


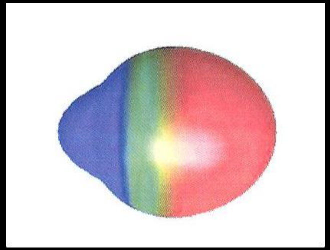


PART D2.b What do the color differences of the HCl, HBr and HI hydrogen halide molecules show?

PART D2.c Which of the structures of maps (c), (d) and (e) show a chemical bond polarity?







PART D2.d State in which of the maps (a), (b), (c), (d) and (e), the structures demonstrate the continuity between the covalent and the ionic bond, and why?

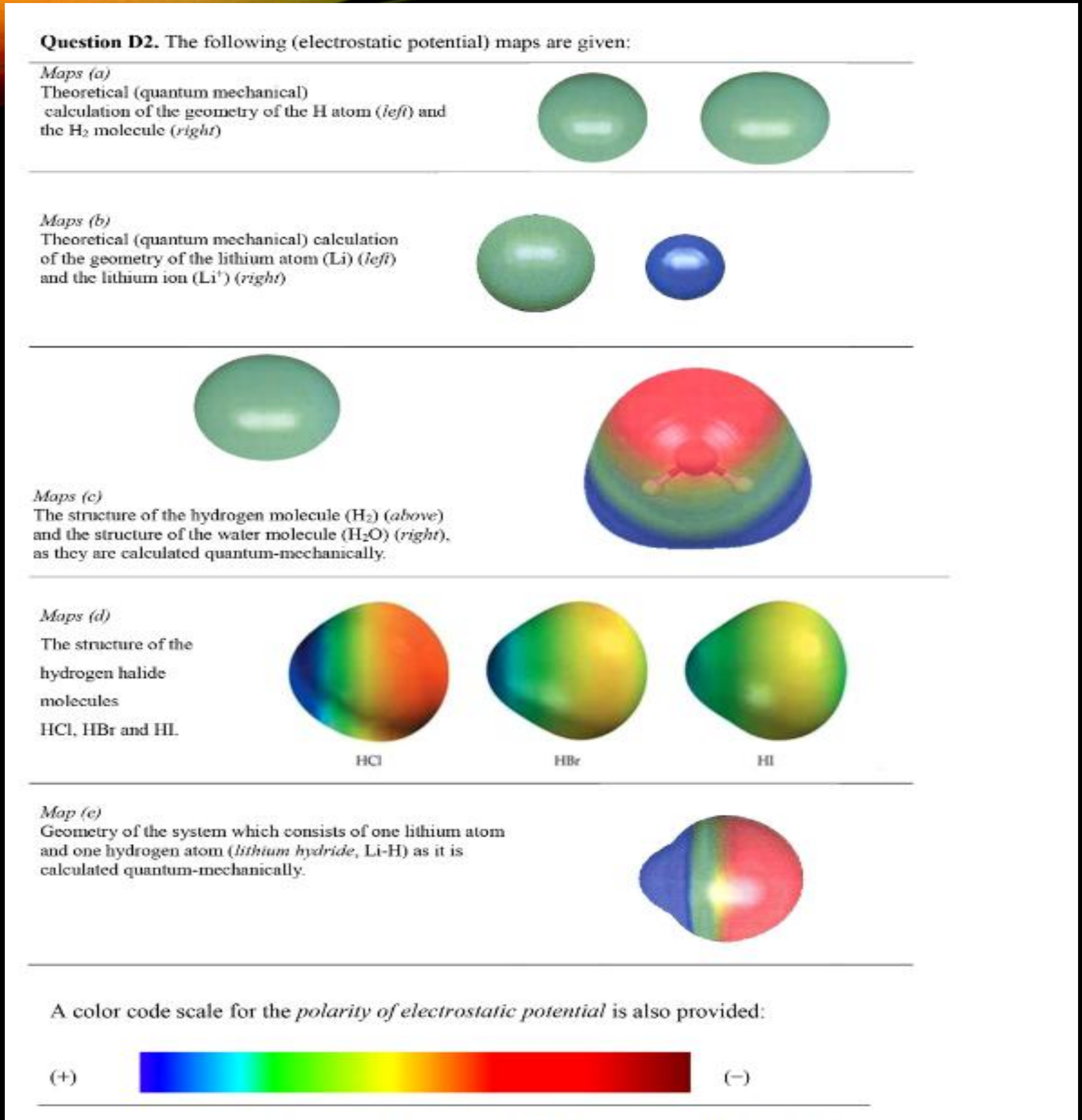
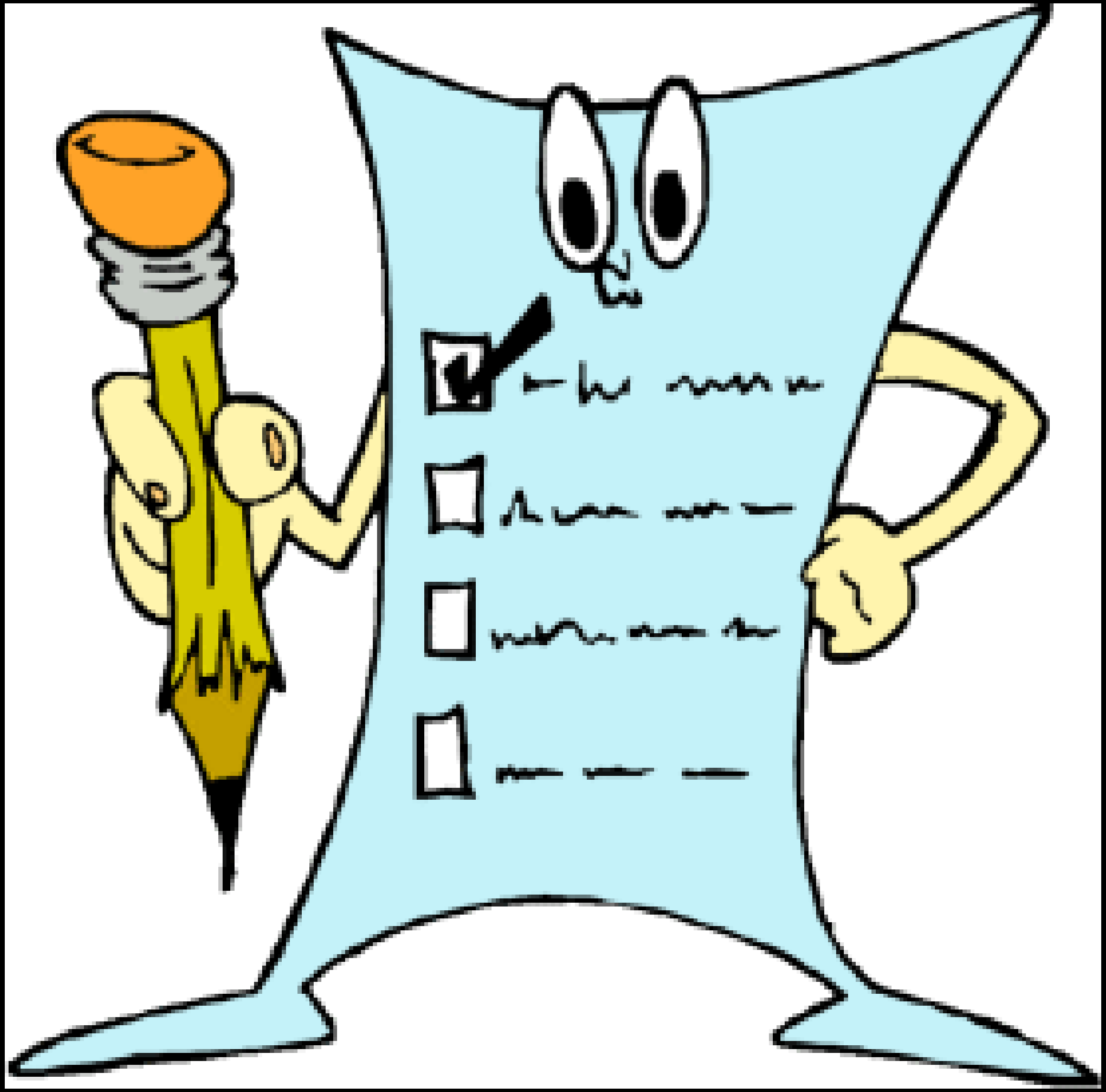


Figure 2: The electrostatic potential maps used in the main study, including a color code scale for the polarity of electrostatic potential.

CONTRIBUTION OF THE COLORED VISUAL REPRESENTATIONS TO UNDERSTANDING

- PART D.2e asked students to refer to two features of the colored VRs that helped them to understand chemical bonding and a mean mark of 82.7% was obtained on this part.



RESULTS

- **The mean mark obtained by the 31 students on question D2 was 57.9% (s.d. 18.1%), reflecting a moderate performance.**

- **Regarding the whole section D, there were seven students (22.6% of all students) who achieved a mark >70% (with student #18 achieving the highest mark 77.4%).**

EXAMPLE STUDENT ANSWERS

PART D2.a Compound lithium hydride is ionic (it is a solid, for which the melt is a conductor of electricity).

- Which are the cation and the anion in this compound?

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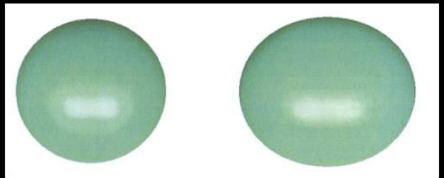

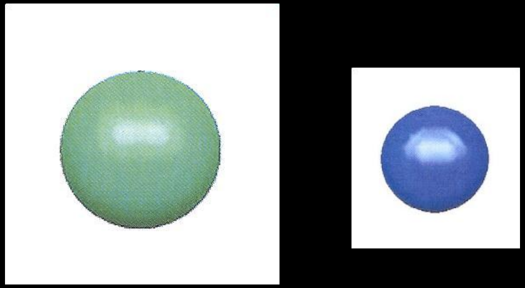

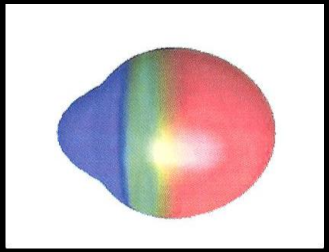

STUDENT #23:

- "Li lies lower (than H) in the periodic table, so it is less electronegative, therefore H has a larger tendency to attract electrons. Consequently, H is the anion and Li is the cation. From maps (b) it is seen that the Li cation is smaller since it loses one electron, and its color is blue…and acquires a positive charge. On the other hand, H, which acquires a negative charge, becomes red. Therefore, with the formation of ionic bond between them, the representation in map (e) results"

- STUDENT #3:

“Li^+, H^-. Ionic is the compound in map (e) because, as we see from the colors, the compound contains one blue color (the cation) and one red color (the anion)”.

- STUDENT #1:

- “From the colors [the color scale] for electronegativity, we see blue and red colors in Li–H, which means that there is a large difference in electronegativity, therefore the bond is much polarized, so that the elementary charges become nearly unity and we have an ionic compound (Besides, Li is a metal, so it does not make covalent bonds)”

- It is noteworthy that 10 students did not refer to the color coding for bond polarity at all, but instead used various arguments concerning the “mechanism” for ionic bond formation (the “history conjecture”, including anthropomorphic elements) (Taber, 2013):

- STUDENT #26:

- “It is about an ionic compound because as Li has one electron, which is…donated to H, which has already one electron and wants to fill a He noble-gas structure. In map (e) we see that the bond is ionic because of the polarity difference, which is considerable”.

CONCLUSIONS

Although the situation with respect to polar and nonpolar covalent bonding appeared satisfactory, difficulties were encountered with concepts related to ionic bonding.

Most students did not employ multistructural thinking (in the sense of the SOLO) when providing explanations about variations of bond polarity, rather they restricted themselves to consideration of only a single factor, aspect or feature.

LIMITATION

A substantial limitation of this study was that the students had not encountered the quantum-mechanical colored VRs prior to the examination. Although the students were certainly able to work with the EP maps, it was not clear whether they were actually using the colored VRs to inform their understanding, or, whether they were instead resorting to previous knowledge and other heuristics to map onto the VRs.

Further, students found difficulty in employing multi-structural thinking or simply did not feel a need to do so, and restricted themselves instead to considering only a single factor, aspect or feature. So it is not really clear to what extent the VRs helped these students to make the required deductions.

… CONCLUSIONS

Many students were clearly impressed by the information provided by the colored quantum mechanical VRs and their features.

Finally, our students' lack of previous experience with these VRs makes us believe that with exposure to these VRs and the method of constructing them, the students will become familiar and comfortable with their various features and uses.

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Using electrostatic potential maps as visual representations to promote better understanding of chemical bonding

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