Misconceptions of undergraduate chemistry teachers about hybridisation

R. Hanson[7], A. Sam[8], & V. Antwi

Abstract

The research looked into the misconceptions held by prospective teachers about atomic orbitals and hybridization. A total of 88 undergraduate students were used in the study in the University of Education, Winneba, Ghana. The participants responded to multiple choice and constructed response questions on hybridization at the start of the research. They answered the same set of questions at the end of a three week treatment period. The responses were analyzed and response categories established on their misconceptions. The post-test was to assess their gain in conception at the end of the treatment period. Results indicated that pre-service teachers had gross misconceptions about atomic orbitals and hybridization. Suggestions have been made for more effective teaching approaches to ensure better understanding of the concept.

Keywords atomic orbitals, hybrid orbitals, hybridization

Introduction

Misconceptions are beliefs about events which do not conform to accepted scientific knowledge. These are formed when a learner's prior knowledge required for processing new information is not well articulated due to the poor bridging which results in confusion and poor reasoning. Students' prior knowledge is therefore a very important factor to successful learning. According to Hoz et al., (2001) since learners' knowledge is reconstructed during lessons, if one's prior knowledge is already erroneous, it would cause further faulty reasoning and a subsequent permanent wrong formation of concepts.

Misconceptions play a major role in learning chemistry than simply producing inadequate explanations to questions. Students either consciously or subconsciously construct their concepts as explanations for the behaviours, properties or theories they experience. They believe most of these explanations are correct because they make sense in terms of their understanding of the behavior of the world around them. Consequently if students encounter new information that contradicts their alternative conceptions it may be difficult for them to accept the new information because it seems wrong and unacceptable to them. The anomalies do not fit into their conceptual/cognitive structures. Under these conditions the new information may be ignored, rejected, disbelieved, deemed irrelevant to the current issue, held for consideration at a later time, reinterpreted in light of the student's current theories, or accepted with minor changes in the student's previously held concept.

[7] Hanson, R., lectures in the Chemistry Education Department, University Education, P.O.Box 25, Winneba – Ghana.

[8] Sam, A. & Antwi, V. lectures in the Physics Education Department, University Education, P.O.Box 25, Winneba – Ghana.

Theoretical framework

Chemistry basically deals with the nature and behaviour of atoms; how they bond together to form new species, the formulae and structure of the new species as well as the forces that hold them together.

Cros et al., (1988), Taber (1994), Harrison and Treagust (2000) have shown that students have difficulties understanding the structure of atoms and chemical bonding. Zoller(1990) and Taber (2000) have also studied students' difficulties in hybridization. Taber (2001) found that students assumed orbitals, shells and orbits to be one and the same. They could not distinguish between the terms atomic orbitals and molecular orbitals. Students talked about bonding electrons in hybrid orbitals of molecules and some other times, they discussed these bonding electrons as being in the s, p or d orbitals.

Zoller (1990) found that students exhibited these conceptual constraints due to poor understanding of basic pre-requisite concepts required for the hybridization topic. The meaning of the s, p, d, f, designations and their orbital directions are not well understood. Undergraduate students in the United States of America have been found to use the terms shell and orbital interchangeably (Nicoll, 2001).

The meanings of the "octet rule" and "stability" have been misconstrued by students. Robinson (1998) found that students use the octet rule as a basis for explaining chemical reactions and bonding instead of using it as a guide to identifying stable species.

Based upon the outlined framework, the following research questions were formulated for the study.

i) What conceptual learning difficulties do students encounter in learning about hybridization?

ii) How would conceptual-based teaching enhance students' understanding of the hybridization concept?

iii) Would students gain adequate conceptual understanding of hybridization through the use of a constructivist conceptual-based teaching method?

Method

Participants

The participants used for the research were in the second year of their chemistry education programme. This was a convenient sample (as one the researcher was teaching this class). Participants needed taught knowledge in Hybridization to understand bonding and shapes of some molecules. Bond formation of molecules in Hybridization state is a pre-requisite for a main course offered by second year students in Chemistry. Participants had already studied the hybridization concept in the first year first semester of their Chemistry Education. This concept is basically studied in the second year of their elective chemistry in the Senior High School (SHS).

Instruments

Validated diagnostic test items were administered to 88 participants. The test comprised eleven main questions. They were stratified such that there were subsidiary (follow-up) questions to the main ones. Each question attracted a mark and so a maximum of 20 marks could be scored by a student who had a sound conceptual understanding of hybridization. Misconception statements were identified and analyzed. Emphasis was placed on correcting participants' misconceptions during the treatment period.

Results

The first five items had two main objectives. They were meant to assess the participants' understanding and their misconceptions about atomic orbitals and hybridization. A sound knowledge of the concept of atomic orbitals is a pre-requisite for understanding the concept of hybridization. Items six to ten assessed the application of the hybridization concept in practical situations.

A summary of participants' understanding as depicted through their responses is presented in a tabular form, item by item. The students' conceptions were put into three main categories (see Table 1).

i) Concepts that demonstrated sound and partially sound understanding (categorized as A)

ii) True misconceptions (categorized as B)

iii) No response to items (categorized as C) in tables 1 – 6.

The simple percentages observed in Table 1, indicate that more than half of the participants did not understand the meaning of the term, hybridization. Here, 72 of the participants (93.2%) failed to respond correctly to the set question or did not answer it at all.

Table 1 Summary of levels of understanding for the Hybridization

	Type of response	Number	Percentage
A	Sound understanding		
	• It is the mixing of two or more native orbitals to form hybrid orbitals	2	2.3
	• Mixing of atomic orbitals	4	4.5
B	Misconceptions • Mixing of two or more electrons • Mixing of atomic orbitals of different shapes • The pairing of more than one atom • Overlapping of atoms to form stable bonds • Mixing up of two or more atoms • Bonding of atomic orbitals to give rise to molecular orbitals • Overlapping of orbitals to form hybrid orbitals • Combination of two or more ionic substances • Mixture of atomic orbitals of two or more atoms • Combination of two or more orbitals to give a stable species	46	52.3
C	No response	26	40.9

Table 2 Summary of levels of understanding for why isolated atoms do not exist in hybridized states

	Type of response	Number	Percentage
A	Sound understanding		
	• Hybrid orbitals only exist when there is to be bonding or mixing of different orbitals for bonding	4	4.5
B	Misconceptions • There is no sharing of electrons • It is unstable • Difference in energy • It is single and there is no bond existing • Isolated atoms do not have bond with any other atoms • It must be stable at ground state • Because it can have more than one orbital • It does not mix with its own orbitals	38	43.2
C	No response	46	52.3

In Table 2, it is interesting to note that 46 students (more than half) out of the 88 did not respond to the item at all. Only four students had a fair conceptual view about why isolated items do not hybridize. Altogether, 95.5% of students had no or wrong conceptual beliefs as to why isolated atoms do not hybridize.

Table 3 Summary of concept of Atomic orbitals

	Type of response	Number	Percentage
A	Sound understanding		
	• Space around nucleus where there is a high probability of locating electrons	6	6.8
	• Where electrons can be located	10	11.4
B	Misconceptions • Orbitals used in bonding • Mixing of orbitals • Orbitals of the same energy • They are the number of shells • Sub shells where electrons exist • Orbitals of the same atom having different energy levels • Sub shells of a principal energy level which has the same energy • Shells made up of the same kind of atoms • Pathway that atoms travel • A hollow space; spaces in an element where atoms occupy • Orbitals which differ from one state to another	21	23.9
C	No response	24	57.9

Participants had a better idea of the concept of atomic orbitals. They scored a higher percentage of conceptual understanding here, even though it was abysmally low also; with only 16 participants (18.2) out of the 100% participants. Interestingly, the number or percentage of 'no response' was the second highest (57.9%).

Table 4 Summary of why atomic orbitals undergo hybridization

	Type of response	Number	Percentage
A	Sound understanding	0	0
B	Misconceptions • To obtain inert gas structure or octet rule • To form some bonds • They contain charged particles • Different orbitals have different energies • To give equal energy levels • To obtain overall stability • To form a single or multiple bond • To know their molecular structure • They undergo hybridization when they bond with other orbitals • To form pi and sigma bonds and their geometry • Different orbitals have different energy and shape	60	68.2
C	No response	28	31.8

In Table 4, no student had a conceptual understanding of why atomic orbitals undergo hybridization.

Table 5 Summary of responses for the Difference between hybrid orbital and pure atomic orbital

	Type of response	Number	Percentage
A	Sound understanding		
	• It has a character and energy different from the native atomic orbitals so it is more stable	5	5.7
	• They differ in size, shape and energy	4	4.5
B	Misconceptions	37	42.1
	• Hybrid orbitals obey the octet rule but atomic orbitals do not		
	• Hybrid orbital involves overlapping of orbitals while pure atomic orbitals do not		
	• Orientation of their shapes		
	• They contain overlap of two orbitals		
	• Because of their molecular structure		
C	No response	42	47.7

In Table 5, more than half of the participants had virtually no idea at all about the differences between hybrid and pure atomic orbitals. The results are similar tto those obtained for the meanings of 'hybridization' and 'atomic orbitals' This confirms the alternative conceptions that students hold on the terms 'hybridization' and 'atomic orbitals'.

Table 6 Summary of responses on Molecular orbital theory being a good model for explaining bonding in the NO molecule

	Type of response	Number	Percentage
A	Sound understanding	0	0
B	Misconceptions		
	• It is a covalent bond	10	11.4
C	**No response**	**78**	**88.6**

Table 6, exposed the participants' poor knowledge on 'Molecular orbital theory'. No student showed a partial or full sound understanding. The highest 'no response' to an item was recorded here. As many as 78 participants (88.6) failed to supply answers to the test item on whether the molecular orbital theory could adequately explain the kind of bonding in the NO molecule.

Table 7 Prediction of sulphur atoms in given sulphur molecules

Molecule	Type of hybridization	Correct	Wrong	No answer
SO_2	sp^2; bent	11	41	36
SO_3	Sp^2; trigonal planar	10	36	42
SO_4^{2-}	Sp^3;trigonal pyramidal	21	38	29
SO_3^{2-}	Sp^3; tetrahedral	8	29	51

Table 7, gives an overview of participants weak and alternative concepts of the types of hybridization that exists in the central atoms of given species. In all, the participants performed well on items 8 and 9 but poorly in items 19 and 11. Results of post test indicated tremendous progress in students' conceptual understanding of the topic Atomic orbitals and hybridization after the three-week treatment period. The results are shown in Table 8.

Table 8 Quantitative summary of improved conceptual understanding

Item No.	Percent of students with understanding Pre-test	Post-test	Changed score
1. The term *Hybridization*	6.8	57	50.2
2. Isolated atoms in unhybridized states	4.5	25.1	20.6
3. Concept of atomic orbital	18.2	54.7	36.5
4. Why atomic orbitals hybridize	0.0	42.2	42.2
5. Difference between hybrid and pure atomic orbitals	10.3	54.7	44.4
6. Effectiveness of Molecular orbital theory	0.0	27.4	27.4
7a. Hybridization of S in SO_2	12.8	41	28.2
7b. Hybridization of S in SO_3	11.4	31.9	20.5
7c. Hybridization of S in SO_4^{2-}	23.9	70.7	46.8
7d. Hybridization of S in SO_3^{2-}	9.1	45.6	36.5
8. Native atomic orbitals in sp^3	50.2	91.2	41
9. Relation between hybridization and geometric structure	47.9	88.9	41
10. Relation between hybridization and ionic bond	34.2	74.1	39.9
11. Relation between σ and Π	20.5	82.1	61.6

Discussion

A quick view of the pre-test showed that students hold misconceptions about hybridization. Tables 1-5 show very high percentages of "no responses' to questions posed to participants. Answers provided exposed their alternative concepts which were scientifically incorrect.

The atomic orbital concept is one of the most important pre-requisites for learning about hybridization. The six options which were deemed to be sound reasoning were only seemingly so. The terms orbitals, shells and orbits were used interchangeably.

Students portrayed their understanding of the solar system and Bohr models taught in Junior High School, (JHS).The sophisticated wave function explained in University chemistry was not able to eradicate their misconception.

In question 4, most students wrote that the idea of hybridization was to obey the octet rule. This is a wrong assertion which does not conform to valid scientific reasoning. The observation made in this research is in line with Taber's (1995) observation about the octet rule. He found that students used the octet rule as the basis of a principle to explain chemical reactions and bonding. This is the full shell explanatory principle (Taber, 1998). Some students also stated that electrons play a role in hybridization. They said "hybridization is a mixing up of electrons in atoms' Majority of the students showed absolutely no understanding of the concept under study as in all cases the 'no response' percentages were high for questions 1-5. Students could not distinguish between pure atomic and hybrid orbitals.

In question 7, majority of students who attempted the prediction of the hybridized states of sulphur atoms in given compounds performed poorly. No single student stated correctly the geometries of the given molecules. Four (4) out of the 88 students predicted the hybridized states of all the four molecules correctly. About 50 % (42 students) did not attempt the prediction. Interestingly, such students performed well on the application questions in (7-11). Question 10 however showed their non scientific and weak reasoning. There is absolutely no relationship between ionic bonds and hybridization. Hybridization is associated with covalency but students failed to realize this. Again, question 11 tested their knowledge on the covalency of sigma and pi bonds. Students chose the wrong option which said that they were certainly different kinds of bonds. They were not aware of the importance of hybridization in covalent bond formation (Nakiboglu, 2003).

The treatment phase concentrated on alleviating students' misconceptions. At the end of the three-week treatment period positive results were achieved. Significant positive changes were made in quite a number of issues. In question 1, 57 students were able to soundly explain the term hybridization. There was a 50 % marked improvement. The highest positive change was observed in question 11, where majority of the students (82.1 %) were able to understand, with sound explanation that sigma and pi bonds were covalent bonds. The least improvements were made in questions 2 and 7b. In question 2, only 25 % of participants (21 %) were able to explain why isolated atoms do not exist in hybridized states. Neither were they able to predict the hybridized state of sulphur in SO3. Generally, their conceptual understanding of pertinent issues in the topic improved drastically as can be observed from the changed scores in Table 9.

Participants' conceptual understanding was determined qualitatively through their expressions as well. At the beginning of the research students gave answers as has been depicted in Tables 1 – 8. However, with improvement in conceptual understanding, majority of the participants gave sound reasoning.

In response to the question, 'why do atomic orbitals undergo hybridization?' Students no longer relied strongly on the octet rule for answers. They responded more intelligently and soundly by saying that atoms need partially / half-filled orbitals in order to form bonds. Some atoms need to hybridize as they do not have adequate half-filled orbitals necessary for bond formation. They form proper orbitals necessary for bond formation; and they undergo hybridization so as to be in a form necessary for the geometric orientation required in the molecule to be formed.

In all of the answers above, students have shown a lot more maturity than before. Bonding is perceived in other terms other than the elementary octet rule.

Implications for instruction

The results indicate that students even at the university level have misconceptions about hybridization. Their concept of the pre-requisite knowledge in learning about hybridization is inadequate. They performed poorly in the conceptual questions administered. However, a deliberate use of conceptual teaching approach in line with the cognitive theory improved their conceptual understanding by 38 %.This answers the question as to whether the deliberate use of conceptual teaching would improve the understanding of the hybridization concept in students.

In the light of the above, the following educational practices are suggested:

1. Teachers must first find out about students' initial concepts about topics that they intend to teach. In this case, they will be able to plan along the students' misconceptions and help them to gain better conceptual understanding of chemical principles.
2. Emphasis should be placed on the differences between terms that are likely to interchanged by students and thereby create problems for themselves. In this instance, students interchanged terms such as orbits, shells, orbitals, sub-orbitals and energy levels.
3. The driving force which aids hybridization must be explained. This will enable students to understand why atoms undergo hybridization.
4. The octet rule must be explained in conjunction with other knowledge acquired in the study of ionic bonding. Its limitations as in molecules like BF_3, PCl_5 and XeF_6 must be emphasized (Nakiboglu, 2003).
5. Students see hybridization as analogous to the octet rule and rationalize and use the term-stable- as they do in the octet situation. As much as possible, the term stable, should be used with caution or avoided when teaching hybridization. One could say, a molecule is of a certain accepted geometry because the energy of the molecule is lowest in that configuration. Students in this case will appreciate bond formation in terms of energy rather than stability or the octet rule.
6. The shapes of hybrid orbitals and their orientation must be taught through conceptual methods and analogies.
7. The relationship between the type of hybridization of the central atom and its molecular geometry must be emphasized. The role of hybridization must be kept in perspective. It cannot be used to predict molecular shapes. It is a way of creating localized orbitals that produce the observed shapes of molecules (Clayden

et al., 2001). Many examples of covalency of hybrid orbitals in bond formation should be worked through with students so that they gain competency conceptually.

References

Clayden, J., Greeves, N., Warren, S., & Wothers, P. (2001). *Organic Chemistry.* New York: Oxford Univ Press.

Cros, D., Chastrette, M., & Fayol, M. (1988). Conceptions of second year university students of some fundamental notions in chemistry. *International Journal of Science Educ , 10*, 331-336.

Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education , 84*, 352-381.

Hoz, R., Bowman, D., & Kozminsky, E. (2001). The differential effects of prior knowledge on learning: A study of two consecutive courses in earth science. *International Science , 29*, 187-211.

Nakiboglu, C. (2003). Instructional misconceptions of Turkish prospective chemistry teachers about atomic orbitals and hybridization. *Chemistry Education: Research and Practice , 4* (2), 171-188.

Nicoll, E. (2001). A report of undergraduate bonding misconceptions. *International Journal of Science Education , 23*, 707-730.

Skelly, M. & Hall, D. (1993). The development and validation of a categirization of sources in chemistry. Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics. Ithaca, August.

Taber, K. S. (1998). An alternative conceptual framework from chemistry education. *International Journal of Science Education , 20*, 597-608.

Taber, K. S. (2001). Building the structural concepts of Chemistry: Some considerations from educational research. *Chemistry Education: Research and Practice in Europe , 2*, 123-158.

Taber, K. S. (1994). Misunderstanding the ionic bond. *Education in Chemistry , 31* (4), 100-103.

Taber, K. S. (1995). Prior learning as an epistemological block? The Octet rule-An example from Science Education. *European Conference on Educational Research.* University of Bath, September.

Tan, K. C. (1999). Evaluating students' understanding of chemical bonding. *School Science Review , 81* (294), 75-83.

Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry (general and inorganic). *Journal of Research in Science Teaching , 27*, 1053-1065.