Advance Organiser Based Anchored Instruction For Teaching Sigma (σ) And Pi (π) Bonds: An Orbital Overlap Analogy

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Abstract- *Advance organiser based anchored instruction strategy has been designed to teach the concept of orbital overlap analogy to the introductory chemistry students. In order to assimilate a better understanding of the nature of covalent bonding, an adequate knowledge of sigma and pi bonding is mandatory. Advance organiser based anchoring; a device of meaningful learning may be used as an icebreaker for students to understand the abstract notion of formation of covalent bonds in organic molecules. Here we have explored a novel pedagogical tool based on the principle of advance organiser and anchored instruction for meaningful learning of concept of sigma (σ) and pi (π) bonding in organic molecules, their mechanism of formation and calculation of number of bonds in an organic molecule.*

Keywords- Advance Organiser, Meaningful Learning, Anchored Instruction, Sigma and Pi bonding, Orbital Energy Overlap, High School/Introductory Chemistry

I. INTRODUCTION

The nature of covalent bonding in hydrocarbons especially in methane, ethane, ethylene and acetylene is a routine exercise in introductory organic chemistry textbooks.[1] The concept of atomic orbitals, orbital overlapping and orbital hybridisation are taught at the beginning of core organic chemistry curricula. A comprehensive idea about nature of sigma (σ) and pi (π) bonding have been discussed. According to the modern concept a covalent bond is formed by the overlapping of the atomic orbital. These orbital can overlap in various ways. There are primarily two ways of overlapping of *p* and *s* orbital. If the overlapping takes place end to end, the resultant covalent bond is called the sigma covalent bond. On the other hand, if the overlapping takes place side by side, it is called pi bond. Clearly, in the sigma bonding the overlapping takes place end to end and the electron density around the inter nuclear axis is more in addition to the bonded electrons being localized. Hence, the bond is stronger. In pi bonding, the overlapping takes place side by side and therefore the electron density is less in the internuclear axis. The shared electrons are not localized and they are loosely bonded with the nucleus and can move in the whole molecule. This is the cause of the phenomena of Resonance in some planar molecules like Benzene. There is a restriction of rotation of molecule around a pi bond which leads to the possibility of geometrical isomerism in the molecule. A pi bond is only formed after a sigma bond has already formed. The *s* orbital always forms the sigma bond but the *p* orbital can form sigma as well as pi bond. If one *p* and one *s* orbital overlap, they always form the sigma bond. If two *p* orbitals overlap, they can either form the pi bond or the sigma bond. If the overlapping takes place end to end they form sigma bond. If the overlapping takes place side by side they form the pi bonds. As the pi bonds are weak compared to a sigma bond so, the molecule containing the pi bonds are more reactive as the bond can be easily broken.[2] But it is matter of regret that majority of the students fail to comprehend such abstract concepts as orbitals cannot be directly observed. Again, shortcut and conceptual methodology concerning orbital overlap analogy has rarely been reported in literatyure.[3] In this investigation we tried to designed a pedagogical tool based on the principle of advance organiser and anchor instruction for meaningful learning of sigma and pi bonding on the part of the chemistry beginners.

II. AN OVERVIEW OF ADVANCE ORGANISER

Advance organisers are pedagogic devices that bridge the gap between what learners already know and what learners need to know (Ausubel 1968, 2000). They were first formally introduced by Ausubel in 1960 to test the hypothesis that learning of unfamiliar verbal material can be facilitated by the advance introduction of relevant subsuming concepts. Ausubel (1968) defined advance organizers as “appropriately relevant and inclusive introductory materials […] introduced in advance of learning […] and presented at a higher level of abstraction, generality, and inclusiveness” (Ausubel 1968, p.

148). According to Ausubel, learning is based upon the kinds of super ordinate, representational, and combinatorial processes that occur during the reception of information. An advance organiser is a tool or a mental learning aid that helps students "integrate new information with their existing knowledge, leading to 'meaningful learning' as opposed to rote memorization;" a means of preparing the learner's cognitive structure for the learning experience about to take place; a device for activating the relevant schema or conceptual patterns so that new information can be more readily "subsumed" into the learner's existing cognitive structures.[4] A block diagram of advance organiser is depicted in Figure 1.

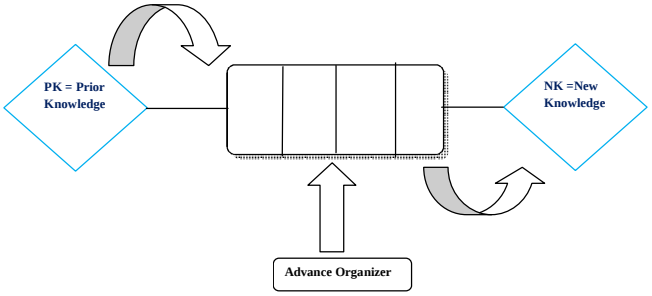

Figure 1. Block Diagram of Advance Organiser

III. SALIENT FEATURE OF ADVANCE ORGANISER

An advance organiser is an instructional unit that is used before direct instruction or before a new topic; this is sometimes called a hook, set induction, or anticipatory set. It possesses some features as stated below:

i. Advance organiser is introduced in advance of direct instruction,
ii. It is presented at a higher level of abstraction than the information presented later,
iii. It is designed to bridge the gap between what the learner already knows and what she/he needs to know.

IV. TYPES OF ADVANCE ORGANISER

Advance organisers can present themselves a plethora of ways as stated below.[5]

(a) Narrative: This type of advance organiser present new information on the format of a story. For example, a teacher will provide the main and important concepts of the lesson by telling a story that includes these concepts.
(b) Expository: This type of advance organiser is used to present new or detailed information as opposed to making connections with previously introduced information.
(c) Skimming: Skimming is when teacher provides the learners with the opportunity the skim over the information that is about to be introduced, focusing on highlighted information.
(d) Graphic Organisers: Graphic organisers are used as a method of presenting information in the visual realm. They are efficient because they highlight and focus on just the important aspects and they also show relationships between necessary information. Graphic organisers take on a plethora of avenues and looks, but two most utilised are Venn diagram and concept mapping.

V. A BRIEF OVERVIEW OF ANCHORED INSTRUCTION

Anchored Instruction is a technology centered learning approach, which falls under the social constructionism paradigm. It is a form of situated learning that emphasizes problem-solving within an integrated learning context, which can be examined from multiple perspectives. "In other words, the learning is contextualized to provide students with realistic roles that serve to enhance the learning process", (Fried, Zannini, Wheeler, Lee, & Cortez, 2005)[6]. During teaching, activities are designed or tied around an "anchor", such as an adventure or story, with a problem at the end that needs to be resolved. The connection made between the content and the authentic context is referred to as "anchoring". These models typically embed all the information needed for the problem to be solved, such data and hints. Anchored instruction is akin to Problem-based learning (P.B.L.) with the exception of its open-endedness.

Principles of Designing Anchored Instructions

The seven principles outlined, are used to govern the design of anchored instruction (Biswas, Goldman, & Bransford, 1997).

1. Generative Learning Format - An appropriate anchor should be selected for the instruction. This is usually a story that leads to a problem, which is of interest to the students. The end of the story needs to be generated by the learner, which is the solution to the problem. This method provides intrinsic motivation, through Active learning, because the students take ownership of the problem.
2. Video-Based Presentation Format - This format allows learner to understand the complex and intertwined problems better than a text or audio format. It solidifies what is taught in textbooks and

other literature through a dynamic, visual and spatial representation. The video medium gives life to the characters and depicts an authentic storyline. This format appeals to students who may have difficulty reading, or understanding written text and allows them to develop pattern recognition skills

3. Narrative Format - The video is narrated to give an account for the characters, the event, and subsequent events. The problem occurs naturally which give the students the impression they are resolving a real problem and not responding to a lecture on a video. The narrative format also makes it easier to embed information into the story.
4. Problem Complexity - The story or adventure used should have a high level of complexity to demand the full attention and stimulate the curiosity of the learner. The problems or issues should require several steps to be solved. This is based on the Anchored Interactive Learning Environment's (Ihlström & Westerlund, 2013) premise; learners must be trained to deal with complex problems that are more realistic.
5. Embedded Data Design - The story includes seamlessly embedded information that is needed to solve the issues. It should also include a great deal of extraneous information. When formatted in this manner, the learner would need to understand the question and determine what information is pertinent to answering the question. (Goldman, et al.; Sherwood, et al., 1995).
6. Opportunities for Transfer - Learners are able to transfer knowledge from one subject, example Geometry, to the topics in the same subject. This increases deep learning and skill transfer.
7. Links Across the Curriculum - In addition to containing all the necessary information, to solve the issue, the story may also introduce topics from other subjects, to provide a holistic learning approach.

VI. ROLE OF LEARNERS AND FACILITATORS IN ANCHORED INSTRUCTION

Anchored instruction highlights the use of Instructional technology. Teachers are moved from the source of information to a coach. It is widely used at primary levels, and is applied to Mathematics, Reading and Language skills.

Anchored instruction, promotes active learning, by motivating and challenging learners. The story or anchor contains embedded data along with other extraneous information; it is the learner's responsibility to decipher, extract and organize pertinent information. The problem that needs to be solved often requires the learner to take multiple steps, by generating a man smaller question, which ought to support and guide their thinking. Small groups of learners are the appropriate size for this type of instruction. Members of the group often provide multiple opinions, thus having multiple solutions to the problem. Students are responsible for establishing their learning goals.

The facilitators are responsible for providing the anchor, the problem statement and embedded data in the story. Anchored stories also contain hints that act as instructional scaffolding to resolve problems. Scaffolding provides a temporary framework to support learning. The facilitator coaches and guides the learners through the learning process. They assist students to establish their own learning goals and accept that they are no longer the major source of knowledge.

Benefits of Anchored Instructions

The advantages of anchored instructions are;

1) To help students develop useful knowledge rather than inert knowledge.
2) Emphasis is on the importance of creating an anchor or focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems.
3) Major goal: enable students to notice critical features of problem situations and to experience the changes in their perception and understanding of the anchor as they view the situation from new points of view.
4) Begins with a focal event or problem situation that provides an anchor for students' perceptions and comprehension.
5) Ideally the anchor will be intrinsically interesting [always hard to find something appealing to everyone. Teachable Agents tap the universally motivating force behind social interaction and adoption/ownership, allowing the choice of content to be less consequential].
6) Effective anchors should also help students notice the features of problem situations that make particular actions relevant; relevant features of the problem that they are trying to solve. [How? format/layout features? prompts?]
7) Individual word problems need to be incorporated into a larger context that provides richer experiences with problem solving.

VII. PROPOSED METHODOLOGY

The proposed methodology comprises of three steps. In step 1, a narrative organiser may be demonstrated in front of the students in order to discuss the preliminary idea about sigma and pi bonds in organic molecules. Step 2 presents an anchor 'shake for sigma and pray for pi' to clarify the mechanistic pathway of formation of sigma and pi bonds. In the third step a trick can be used for determining number of sigma and pi bonds in a covalent molecule. The entire methodology is presented in the subsequent sections.

Step 1: Presentation of narrative organiser

At first an advance organiser in the form a story may be presented to the students. The story contains four characters namely (a) 'Sig' (b) sig's mother named 'ma' and (c) Sig's twin bhai's (brothers) named 'Pi'. 'Sig' lived in a city with a singly occupied bed for maintaining lively hood. There was no interaction with his mother for a longer period of time. One day, his mother met 'Sig'. As there was only a single bed, 'Sig' requested her mother to occupy this single bed left 'Sig'outside the room. As 'Sig' offered the single bed to 'ma' lead to a combination sigma. After few days, one of the twin's bhai (brother) 'pi' came to meet 'Sig'. 'Sig' arranged a vertically aligned hanging bed just over the existing bed for accommodation. It resulted a 'double bed' combination, one for 'sigma' and other for 'pi'. After another few days remaining bhai (brother) 'pi' came to 'Sig's house. 'Sig' then placed a third vertically aligned hanging bed in the similar fashion to accommodate remaining 'pi'. This analogy may be used during consideration of orbital overlapping between covalent atoms. Sharing of one electron pair between two atoms results one covalent single bond named sigma (σ) bond. When covalently bonded atoms contain double bond, there is one sigma (σ) bond and other is pi (π) bond. In triple bonded atoms, one is sigma bond and remaining two are pi bonds.
The narrative organiser described here may be best depicted in Figure 2.

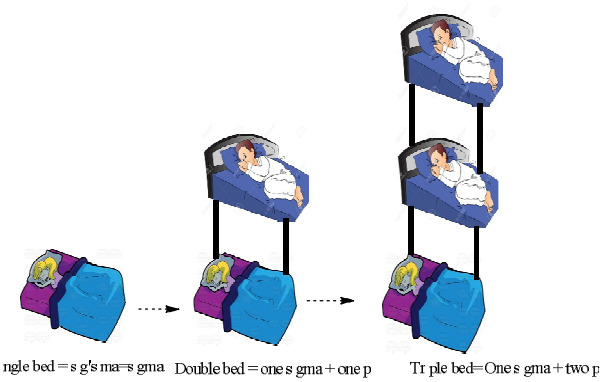

Figure 2. Advance organiser based narrative diagram for identifying σ and π bond

Step 2: Presentation of anchor 'shake for sigma and pray for pi'

In this step an anchor 'shake for sigma and pray for pi' is presented to the learners. It is our speculation that students already know the way of respecting, greeting or saluting others. In western culture, way of greetings is carried on through 'hand shake'. On the other hand, occidental culture exhibits 'prayer' or 'namaskar' or 'high five' in order to greet others. Handshake is an excellent analogy for σ bond formation. Hand shake indicates head-on or axial overlap of two hands forming a strong bond that is difficult to break. 'Pray' or 'namaskar' or 'high five' involves pressing both hands together. This is an analogy of sideways or lateral overlap resulting formation of π bond. Sideways overlap of two hands is easier to separate, thus, making a weaker bond. Praying is an identical analogy for unhybridized *p* orbital overlap in π bond formation. This proposed anchoring leads to a mnemonic 'shake for sigma and pray for pi' as a catch phrase to recall the different bond types and their attributes (Figure 3).

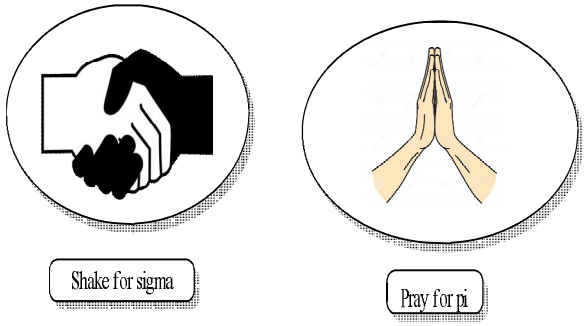

Figure 3. 'Shake for sigma and pray for pi' analogy based anchor

Step 3: In this step a trick equation is used to determine number of sigma bonds in an organic molecule. The number of sigma bonds present in an organic molecule is given by any one of the following equation: (1) Number of σ bonds = (n-1) where n is the total number of atoms in the molecule or (2) Number of σ bonds = (Number of carbon atoms) -1 + number of other atoms. The only limitations of the above euations are that they are not applicable for cyclic or ring compounds.

Example-1: Ethane molecule (C_2H_6)

From equation (1) number of σ bonds in the molecule = n-1 = (8-1) =7, from equation (2) number of σ bonds in the molecule = (Number of carbon atoms) -1 + number of other atoms = 2-1+6 = 7. From the structure of ethane molecule it is evident that number of σ bonds in the molecule is also 7.

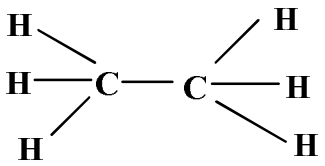

Figure 4. Structure of ethane molecule

Example-2: Prop-2-ene-1-oic acid ($C_3H_4O_2$)

Here, no of number of σ bonds in the molecule = n-1 = (9-1) =8; again from equation (2) number of σ bonds in the molecule = (Number of carbon atoms) -1 + number of other atoms = 3-1+6 = 8. From the structure of ethane molecule it is evident that number of σ bonds in the molecule is also 8.

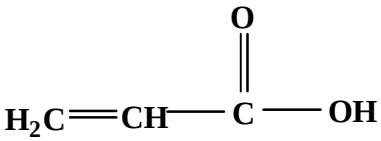

Figure 5. Structure of Prop-2-ene-1-oic acid molecule

Example-3: Naphthalene molecule ($C_{10}H_8$)

From equation (1) number of σ bonds in the molecule = n-1 = (18-1) =17, from equation (2) number of σ bonds in the molecule = (Number of carbon atoms) -1 + number of other atoms = 10-1+8 = 17. From the structure of napthalene molecule it is evident that number of σ bonds in the molecule is also 18. Hence the trick is not valid aromatic for ring compounds.

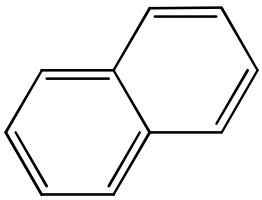

Figure 6. Structure of naphthalene molecule

Benefit to the students

The proposed methodology possesses some advantage over traditional class room instruction. These are listed as: (a) Use of narrative advance organiser will assist student to link new information with their prior knowledge which results meaningful learning of the content. (b) Use of 'handshake' and 'namaskar' or 'prayer' or 'high-five' as anchor is excellent analogies for explaining the mechanism of formation of σ and π bonds. (c) 'Handshake' analogy explains hand-on or axial overlap of two hands forming a strong bond that is difficult to break. On the other hand 'high-five' or 'namaskar' or 'prayer' explains the sideways or lateral overlap of two hands that are easier to separate, thus, making a weaker bond. Thus students easily understand that σ bonds are stronger than π bonds. (d) In classroom situation students may subsequently encouraged to meet their peers by shaking hands and 'high-fiving' or 'prayer' or 'namaskar', thereby making the demonstration more vivid and activity based learner centric learning. (e) Use of trick equation may help the students for calculation of number of σ bonds with minimum outlay of time.

VIII. IMPLEMENTATION OF THE PROPOSED METHOD

We have administered this proposed methodology upon thirty students of higher secondary (class XII, Pre-University) students (Science group, Chemistry major) of St. Pauls' Academy, Burdwan, West Bengal, India and evaluated the effectiveness of the strategy. For this purpose we selected sixty students and categorized them into two equivalent groups comprising thirty students in each group. The intervention was administered only on experimental group. The control group was taught by convention method following common text books. The equivalency of the groups has been determined on the basis of students' score in chemistry in their previous annual examination (class XI). For administration of advance organise based anchored strategy, a narrative (mentioned in the methodology part) was demonstrated to the students of the experimental group. It was observed that all the students were listening the story attentively. After that a student was requested to come on dais and the instructor performed a handshake with the volunteer. At the same time the instructor explained the mechanism of formation of σ bonds by way of head on overlap of atomic orbitals. This made the instruction more attractive. After that all the students were requested to meet with their peers by shaking hands and it was physically showed how much harder it is to break apart two hands that are placed in a way as if they are shaking. Thus they realised the strength of σ bonds. Then the instructor pressed his hands together and showed a style of 'namaskar' or 'prayer' or 'high-five'. This gave the idea of π bond formation through sideways or lateral overlap. Students also understood that it is easier to separate two hands hold together in a sideways manner. Thus the students were able to draw conclusion that 'shake' (handshake) results σ bonds and 'pray' (high-five/namaskar) results π bonds. Finally the proposed equation was used to calculate number of σ bonds present in an organic compound. The students of the control group were taught by traditional method following text book information. After completion of instructional procedure a teacher made achievement test (post test) was administered on the students of both the group. The results of both the groups are summarized in Table 1.

Table 1: Statistical result of post test

Group	N	Mean	SD	t_o	t_e at 0.05
Experimental	30	26.93	5.91	3.96	2.048
Control	30	20.67	5.01		

On analysis of the means of the two matched samples (experimental and control) the t-value (3.96 at 0.05 level at df = 29) exceeds the expected t-value (2.048 at 0.05 level at df = 29). The table 1 shows the post test mean scores produces a gain score of 6.26. This implies that the treatment had a positive effect on the students to achieve better score for the selected unit.

IX. CONCLUSIONS

Use of advance organiser based anchored instruction as a pedagogical tool for grasping the idea of orbital analogy is a novel strategy for introductory chemistry learners. The use of hands to define orbital overlap is a captivating approach to teaching bonding in organic compounds. It is an activity based learner centric pedagogical tool as they remain involved in the learning process. Use of narrative organiser and mnemonic like 'shake for sigma and pray for pi' makes the abstract notion of orbital analogy into a vivid demonstration. This strategy may be imparted without any external equipment and can be employed in any class venue.

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