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Unearthing pre-tertiary students’ reasoning patterns about elements, mixtures and compounds

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Abstract
This study examined pre-tertiary students’ reasoning patterns about the structure of matter after they received concept-based instruction. The one-group, pre-test, post-test, and delayed-post-test design was employed to assess participants’ understanding before, immediately after, and weeks after the instruction, using particulate representations of matter on worksheets. A focus group interview was applied for corroboration. Data were analysed on the appropriateness of scientific reasoning. Findings showed that the concept-based instruction promoted the development of scientific understanding about the nature of matter, which hitherto was idiosyncratic. Authentic concepts must be introduced in engaging ways for long-lasting concretisation and application.

Keywords: conceptual understanding, compound, element, mixture, particulate matter, pre-tertiary

Introduction
Chemistry is regarded as a difficult subject by science students, teachers, researchers, and educators, due to the abstract nature of concepts, difficulty level of the scientific language, lack of computational skills, and students’ poor mental visualisation abilities (Ozmen, 2011). Another source of difficulty is the expected/required description of matter at three representational levels; only one of which can be readily observed and understood (Johnstone, 1993). The three levels are the macroscopic, sub microscopic (particulate), and symbolic representations. The sub microscopic level is often the most difficult reasoning level for students. Regardless these aforementioned difficulties, knowing about them is important for understanding chemical concepts. Thus, students must learn to connect concepts by using all three demonstrable levels. Though many studies have examined such level-type representations of matter in written (physical) and virtual forms, for especially preservice teachers (Haider, 1997; Valanides, 2000; Azizoglu, Alkan, & Geban, 2006; Tan & Taber, 2009), literature was not found on level-type representations for pre-tertiary students in the African sub-region, and Ghana in particular, at the time of this study.

Concepts such as electrons, protons, atoms, molecules, elements and compounds are difficult for students to understand due to their inability to mentally connect them with appropriate mental images, yet these concepts are important requisites to understanding the nature of matter. Students know that the particles that constitute matter are called atoms, from which elements, molecules and compounds originate. Nonetheless, they cannot somehow thoroughly comprehend the particularity of matter when this idea has to be applied in practical situations. Understanding the characteristics and particulate nature of matter are essential for learning advanced topics in chemistry (Yakmaci-Guzel & Adadan, 2013). It is being widely accepted now that the particulate nature of matter is a topic that learners have a number of alternative concepts about (Bilgin, Demircioglu Yurukel, & Yigit, 2017). They have a naive continuous matter outlook on the structure of matter as opposed to the scientifically accepted particulate model. They have primitive ideas about the nature of the spaces between particles, their behaviours in their different states, their sizes, as well as the changes in arrangements that result from phase changes (Ozmen, 2011). Understanding this concept is a bedrock for school science curricula all over the world. Like all other countries, the concept of matter is taught in early years in Ghana as well as in the senior secondary school, for reinforcement; yet students have difficulties in explaining and representing them correctly at the tertiary levels of education (Hanson, 2017). Hanson’s recent findings about tertiary students’ understanding of the concept of chemical bonding affirmed Ozmen’s findings about their naïve uncoordinated interpretations about matter. Hanson found that students’ failures to conceptualise the particulate nature of matter led to several misconceptions about its transformations and chemical bonding in particular. Such identified alternative conceptions, could play a role in designing instruction in teaching and learning, if authentic scientific concepts could be developed from them.

A simple and cost-effective instructional design that could be employed to enable students to form sound mental images of matter in the absence of modern technology could be through worksheets, though the importance of laboratory practical activities (the basic method for acquiring chemical knowledge) and technology cannot be denied. Worksheets have been known to help to translate abstract ideas into seemingly concrete ones so that through them students were able to express their understanding about chemical phenomena (Hanson, 2017; Celikler, 2010). Carefully designed engaging worksheets allow for hands- and minds-on activities that support learning. They also motivate students through collaborative and supportive discussions, thus fulfilling desired curriculum requirements (Hake, 1998). This study therefore used a simple, yet effective enhanced strategy to improve students’ understanding of chemical concepts at these three representational levels before they moved on to higher tertiary learning.
Purpose
Although many international studies about students’ understanding of matter have been carried out using open-ended questionnaires, interviews, and paper-pencil tests, research related to the said concept was almost non-existent for Ghana, where conceptual studies are a beginning trend. The purpose of this study, therefore, was to examine the demonstration of conceptual changes in pre-tertiary students’ understanding about the nature/structure of different forms of matter (with respect to their physical and chemical compositions) before, after, and weeks after they received instruction through hands-on worksheet activities. Achievement of the study’s purpose was guided by the following research questions:

1. What conceptions about the nature of matter would pre-tertiary chemistry students demonstrate before instruction?
2. What would be the basis of their classification of matter into desired groups before and after instruction, using worksheets?
3. How would their scientifically inappropriate reasoning patterns change from pre-, through post-, to delayed assessments?

The questions suggested the use of a mixed approach method from a quantitative perspective in data analyses to assess change in performance and a qualitative perspective aimed at understanding the changes in students’ initial inappropriate and uncoordinated scientific explanations.

Method
Concepts such as elements and their symbols, compounds and their formulas, representative structure of atoms, electron configuration, chemical bonding, and chemical reactions are taught at basic secondary school and so this was a basis upon which the study was structured. This was a one-group, quasi-experimental design with a pre-, post-, and delayed-test research. This design was chosen among other quasi-experiments because in this, after completing an assignment of interest, the level of the quasi-independent variable can be ascertained. Besides, it is better than the posttest only design, as the level of dependent variable can be factored in- before and after manipulation, and thus, increase one’s confidence that observed changes are due to the introduction of a desired factor. Furthermore, threats to internal validation, such as maturation, instrument decay, and regression were of little effect in this study, due to the short duration of the study. The participants consisted of a sample of 50 students who were at the end of their second year in a three-year pre-tertiary programme. These participants had learned information about students’ reasoning patterns about matter. This was to enable all students to benefit conceptually and cognitively, through visualisation, comprehension and the development of process skills. It was also to avoid threats to internal validation, such as selection, maturation and variability in interactive effect biases. Worksheets were adopted from Taber’s (2002) book on chemical misconception – prevention, diagnosis and cure.

Results and discussion
The results of students’ performance in the pre-, post-, and delayed-tests on identification of substances are presented in Table 1. Items 1 to 3 required students to define the terms element, compound and mixture, while items 4 to 9 required them to identify diagrammatic models of matter using their definitions of elements, mixtures and compounds.

Table 1: A presentation of students’ comparative tallied performances in the pre-, post- and delayed-tests (N=50)

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-correct</th>
<th>Pre-wrong</th>
<th>Post-correct</th>
<th>Post-wrong</th>
<th>Changed-correct</th>
<th>Delayed correct</th>
<th>Delayed change</th>
<th>Delayed wrong</th>
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<tr>
<td>1</td>
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<td>44</td>
<td>15</td>
<td>35</td>
<td>9</td>
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<td>19</td>
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<td>31</td>
<td>35</td>
<td>15</td>
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<td>11</td>
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<td>2</td>
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<td>25</td>
<td>25</td>
<td>16</td>
<td>19</td>
<td>-6</td>
<td>31</td>
</tr>
</tbody>
</table>

Pre-correct: Students who got items in the pre-test correct
Post-wrong: Students who got items in the pre-test wrong
Delayed-correct: Numbers of students who got items in the delayed-test correct
Delayed change: Difference between post correct and delayed correct

From Table 1, the results in the pre-test are tilted towards the attainment of low scores, while the post-test results are almost tilted towards the achievement of higher marks; a positive shift to show improvement in students’ performance after the treatment. Inferential statistical analysis of test scores gave a p-value of 0.00 at a 95% confidence level; an indication that the
concept-based instruction caused an improvement in the way students reasoned about elements, mixtures and compounds. The highest improved performances, shown as changed wrong scores, were observed with items 2 and 3 (that required the definitions of compounds and mixtures respectively), while the least changed performances were observed with items 1 and 7 (definition of an element and identification of a mixture of benzene and methane). In the delayed test, only item 3 indicated an improvement of an upward average gain of one correct response-over that from the post-test. For item 7 there was no change in students’ responses as numbers remained the same. In all the other items, there were losses in numbers of correct, coordinated responses about students’ interpretations of matter from a low of 2 to a high of 8.

The responses from the students’ pre-test revealed many uncertainties and unscientific concepts about the nature of matter. Their reasons were not based on any scientific evidence or their own naïve descriptions of substances provided in items 1 to 3. Some of their foundations for their identified (classified) substances were not based on critical observations. They were conceptually wrong. Some of these naïve reasoning patterns are presented graphically as Figure 1.

Definitions were undefined. Most of them were conceptually wrong. Some of their popular or most presented wrong answers are shown per item.

1. Definition of an element:
   i. The smallest particle of an element which can exist independently. Eg, H₂
   ii. The smallest form of a pure substance which has been combined by a definite proportion by mass
   iii. Any substance which can be broken down by physical or chemical means
   iv. The smallest particle of an atom which exists chemically
   v. A pure substance which cannot be decomposed and undergoes chemical reaction
   vi. A compound that cannot be broken down into simpler units or form

2. Definition of a compound:
   i. A compound is a reaction between two or more substances to produce an entirely different substance with different properties. Alternatively, a compound is defined as a reaction.
   ii. A compound is the combination of elements
   iii. A property of a compound is misconstrued for a definition

3. Definition of a mixture:
   i. A mixture is the physical combination of two or more substances that can be separated by any means known

The definitions presented above connote various types of misconceptions, some of which are unscientific, non-factual, and teacher-made. Nevertheless, a thorough understanding of these concepts is required for the formation of a conceptual framework about the particulate nature of matter.

Figure 1: Samples of students’ worksheets that show their prior reasoning patterns

The students were required to further analyse models of substances with reasons, in a focus group interview (Appendix A) after the pre-test. Their identifications and assigned reasons for the models were similar to what they presented in their test- an affirmation of what they perceived about the different types of matter. Their arguments were erratic and not based on regular/defined patterns or basis. Their reasoning patterns could be said
to be illogical and incoherent. They often began and ended their arguments with:

'I know from the past ….' or 'I think that this diagram/model presents ….. (say mixture/element/compound) because……..eh……..mmmm……because………'.

Often, they responded that it was one of the substances in question, which 70% of the time, was wrong. Their best reason for choosing a chemical compound was that ‘there had been a chemical reaction’. Further probe on why they thought that some chemical reactions had taken place in the models that they were presented with, yielded no answers.

Figure 2: Samples of students’ worksheet showing a good presentation of reasoning skill

Series of class exercises were given to the students to study and choose from among those that were the same or different, and whether they were single substances, molecules, mixture or compound, with reasons. Sometimes they were required to discern between particles in different states for same substances; an example was a model of N₂ in the solid and again in the gaseous phases. Initially, most of their reasoning responses were distorted, as observed from their pre-intervention responses on their worksheets (see Figure 1). However, in the course of the intervention period, they improved on their reasoning answers. For example, they could now respond that some species were of, or from the same substance because they contained the same molecules. Another answer was, ‘they appeared different in arrangement because one represented a gas and had large spaces between its particles while the other was probably a solid because it had fewer or almost no spaces in between its particles’. The phrases after the word ‘because’ always projected and revealed how a student reasoned. The phrase after the word ‘because’ was the basis for an argument and expressed a reasoning structure. An example of a good reasoning pattern is depicted as Figure 2.

Discussion

Chemistry is a science of matter and its transformations. Thus, the particulate nature of matter is the heart of chemistry, as it touches on how its different transformations arise in a variety of substances. In this study, students’ knowledge about the concepts of basic substances had to be applied in making further distinctions, with reasons. In items 4 to 7, scores were analysed into four (4) categories based upon the criteria, ‘correct identification with correct interpretation’, ‘correct identification with wrong interpretation’, ‘wrong identification with correct interpretation’, and ‘wrong identification with wrong interpretation’. Items 4, 5, and 6, which represented a compound (CBr₄), an element (Xe), and an element (S), respectively were identified with a bit of ease. In the pre-test, 16 (32%), 19 (38%) and 11 (22%) students were able to correctly recognise the types of substances with correct supporting interpretations. About 60 to 70% of the students identified them correctly in the post-test, which was an improvement over the pre-test.

Items 7, 8 and 9 were the most difficult substances for students to identify in both the pre- and post-tests. Only 4%, 8% and 18% of the students made correct identifications with tangible reasons. In the post-test only 22%, 30% and 50% of the sample made correct reasoned choices. Students had difficulty accepting that substances such as C₆H₆ and CH₄ were presented as individual entities, but as a ‘unit’ in one diagrammatic presentation, and that they all together formed a mixture, while HOCl was a compound; and that the mix of Kr and Ne gases were also not chemically combined and so formed a mixture, unlike particles in the HOCl entity, where H, O, and Cl were chemically combined. They also assumed that if particles were bonded, as in a chemical reaction or a definite compound, then there should be structures with definite lines as Taber (2002) also observed in a similar study. In the pre-test, reasons for choices made were expected from students. These reasons were expected to be based on whether only one type of atom or molecule was observed and if a compound had more than one type of atomic core. Item 7 appeared to be the most difficult substance to be identified in the entire exercise. Students were able to identify both benzene and methane in one of the diagrams but could not somehow perceive them as being a mixture even though they had different cores and were not combined at all in any way. Their knowledge about C₆H₆ as one compound and CH₄ also being another compound might have thrown them out of perspective in their analysis. Their main problem was with substance identification. They could not decipher
particles which were atoms, elements or molecules and whether these were interacting as units or individual components. Some of their answers to item 7 were:

i. It is a compound because the constituents are combined

ii. It is a compound. The diagram contains atoms that come together to form a compound.

iii. It is a compound. The elements in the diagram cannot be combined by physical means because they cannot be separated.

This is enough to say that a ‘mix’ of the different cores or entities was not considered. The individual units of compounds were considered instead. Some of these answers came from students who had given excellent and illustrative definitions for ‘elements’, ‘mixture’ and ‘compounds’ in items 1 to 3. The implication here is that students can learn certain definitions and principles by rote but fail to put them into application when confronted with real practical situations. It also suggests that the true meanings of the definitions or principles are conceptually not understood well enough for its application or translation into reality. The HOCl compound was said to be an ‘element’ because ‘the substances in the diagram cannot be split up by any known means’. Another student said that it could not be simplified any further. This student might have been thinking of molecular and empirical formula and exhibiting a conceptual misunderstanding. The student was clearly implying a compound from his partially ‘could be’ correct answer, if he had chosen ‘compound’ and improved on his interpretation. Several common alternative conceptions were prevalent. They also sometimes over exaggerated the application of knowledge such that they became misconceptions.

In the interview session it was clear that students were unable to distinguish between types of substances as the term ‘core’ was not used. They could not tell if species were existing as unit entities with single cores or as combined unit species with different cores. Their arguments and reasoning patterns were contorted. Sometimes, they looked at a diagram and said that the types of ‘molecules’ were the same but it was a mixture when it should have been a single substance, in truth. At other times, the same group identified different molecules (cores) but concluded that the presentation was that of a single substance. The probable answers for identifying ‘different molecules’ could have been mixtures or molecules of compounds. If they were uncombined atoms or molecules, then a single substance or a molecule of an element were the appropriate answers. For such reasons, remediation was provided through class exercises for four weeks of one-hour hands-on activities and discussions during each session.

In the class exercises similarities and differences among sets of substances were sometimes required. At other times, students only had to label very similar substances as being either a single substance matter or a mixture. Teaching the distinction between pure substances and mixtures enabled students to distinguish between single substances that were elements and those that were compounds. Thus, their understanding about the benzene-methane mixture improved. In their post-test, no reasons were required. In the delayed test, reasons were again required. A lot of coherence was observed in the post-test but not so much in the delayed test, which was surprising. This could imply that some of our students lapse back into their own naïve conceptions even after reconstruction is deliberately attempted. In such instances, familiar, but correct conceptual examples have to be worked on repeatedly with students through practical exercises for deeper reinforcement before new and distinguishing examples are introduced (Hanson, 2017).

By the end of the intervention sessions, students were able to identify single substances that were composed of different atoms but existed as entities or ‘whole units’. Some examples of substances that were identified in latter exercises were CBr₄, HOB₃ and CH₄. They were now able to identify S₈ and Br₂ as molecules instead of atoms, when they were presented to them. A lesson which followed closely after that was the identification of mixtures. They were now able to go further to explain that ‘mixtures result when molecules of substances mix up but each retains its units wholly in the new outcome’. Others added that ‘they can be atoms but will not react or change; they will be there individually in the set’. Some examples of mixtures containing elemental gases such as Ne and Ar mixtures and molecules like CO and O₂ as well as SO₂ and CO mixtures were presented. After this, they learned to distinguish single substances into elements and compounds by looking closely at the ‘nucleus’ or ‘core’ of the atoms or molecules. The new scientific term that they learned to use in their descriptive distinction which was found to be helpful was the term, ‘core’. They learned that elements had one type of core which was represented by the symbol of the element concerned in this study, while a compound had two or more different types of cores. The word ‘nucleus’ was discouraged with explanation. Thus, for them Br as an element had one core only while NH₃ had two distinct cores. These new beliefs or reasoning patterns were again confirmed through a post-focus group interview session (with participants). Findings from these sessions showed that if students were presented with a diagram that showed single uncombined atoms that were the same, they deduced with reasons that they were single substances. However, if the atoms (cores) were different, then they deduced that they had a mixture. Again, if they saw the same types of molecules, then they had a single substance, while different molecules (cores) were seen as a mixture. Nevertheless, if they observed the cores in a ‘single molecule’ to be the same, then they deduced that they had an element. If the presentations were different, then they correctly deduced that a molecule was a compound. These trends of logical reasons showed that the students could now distinguish between substances appropriately as mixtures, elements or compounds.

In the post-test, there were marked improvements in students’ answers to similar items presented in the pre-
test. Some examples of substances that had to be identified in the delayed test were as presented in Appendix B.

These purported improvements were evident in their coherent explanations. They sorted out differences in more logical and scientific ways by pointing out obvious similar or distinguishing features of particles of matter in their answers. Their changed scores ranged from 9 to 25 units as attestation of the said fact. Improvement would still be required in identification of mixtures in which the constituents are not well identifies as pure substances through extended assignments and practical activities. However, in the delayed test which came a couple of weeks after the remediation and follow-up post-test, a few students were found to have faltered in their abilities to presents structured logical answers for distinguishing between given substances, as delayed correct responses were lower than what was obtained in the post-test. Nevertheless, about 50% to 60% gained conceptual understanding was retained by majority of the students. The correct responses in the delayed test showed more logical structured reasons than were observed in the post-test, indicating that scientific and conceptual gains had been made with respect to reasoning structures. A few students however obtained lower marks but demonstrated good reasoning and critical thinking skills in the correct answers that they provided; an indication that learning had taken place.

Conclusion
From obtained data from the study, it is apparent that students have many alternative conceptions about the nature and diverse transformations of matter. Nevertheless, their naïve reasoning patterns were re-structured by systematically engaging them in activities that enabled them to build the required framework. In this study, worksheets were successfully employed to enable students to build authentic cognitive structures about elements, mixtures and compounds, which they were able to apply to distinguish between given substances with logical, sequenced reasons appropriately. This demonstration of comprehension, application of knowledge, critical analysis and ability to discern between forms of matter sequentially and logically showed that most of the students developed good reasoning skills and patterns. They were able to evaluate situations that they were presented with through a display of good communicative skills and appropriate use of scientific language, as expected. This observation agrees with Yakmaci-Guzel and Adadan’s (2013) findings that discussions and creation of learning platforms for multiple representations could be used to enhance the understanding of the concept of matter. This could be a gateway to understanding further complex and abstract concepts in chemistry. Furthermore, the findings of this study add on to existing literature on how pre-service teachers perceive matter.

References


Appendix A: Semi-structured focus group interview schedule
Observe the diagram before you carefully. (Desired diagram of interest presented for observation)

- What kind of substance could this be?
- Would you classify picture (named) as an element, mixture or compound? Why?
- Why can’t we classify it as a mixture/element/compound?

Appendix B: Samples of other substances presented in the post- and delayed-test

<table>
<thead>
<tr>
<th>Item</th>
<th>Substance</th>
<th>Type of substance</th>
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<tbody>
<tr>
<td>1</td>
<td>CS₂</td>
<td>Compound</td>
</tr>
<tr>
<td>2</td>
<td>C₃H₆ &amp; F₂ molecules</td>
<td>Mixture</td>
</tr>
<tr>
<td>3</td>
<td>I₂</td>
<td>Element</td>
</tr>
<tr>
<td>4</td>
<td>C₂H₆O</td>
<td>Compound</td>
</tr>
<tr>
<td>5</td>
<td>Xe and He</td>
<td>Mixture</td>
</tr>
<tr>
<td>6</td>
<td>F₂</td>
<td>Element</td>
</tr>
<tr>
<td>7</td>
<td>C₂H₂ and O₂</td>
<td>Mixture</td>
</tr>
<tr>
<td>8</td>
<td>H₂O</td>
<td>Compound</td>
</tr>
<tr>
<td>9</td>
<td>Na</td>
<td>Element</td>
</tr>
<tr>
<td>10</td>
<td>C₅H₁₀O₄</td>
<td>Compound</td>
</tr>
</tbody>
</table>
Organic Chemistry-Onnline: Pushing the Limits with ChemDraw Direct

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Abstract

Many undergraduate students, especially freshmen, find organic chemistry to be a tough subject. Conceptual comprehension and mastery over this highly visual and often abstract subject demands regular problem solving and supply of active feedback. While online technologies have greatly advanced the critical components of active learning, many conventional online spaces are not equipped for hosting topics in organic chemistry, as they do not possess the capacity to generate or share chemical structures. This report describes the development of a web-based discussion portal integrated with the recently launched online form of ChemDraw called ChemDraw Direct. The system was used for hosting online assignments in an year-1 organic chemistry cohort consisting of 221 students at NTU. The integration of the structure-drawing interface enabled easy generation of structure-based questions and responses online, thereby facilitating smooth flow of structural and symbolic information. The online exercise could be used for formative assessment and/or review purposes. User feedback was largely positive, with the students finding this technology to be helpful towards advancing their subject understanding.

Keywords: First-year undergraduate, Organic Chemistry, Computer-Based Learning, Internet/Web-based learning, Problem solving/Decision making, Testing / Assessment, Mechanisms of Reactions, Stereochemistry

Organic chemistry has the reputation of being a tough subject, especially for beginners, owing to a multitude of factors. The governing principles are blended on an array of electronic and molecular aspects, with even small structural changes resulting in significant deviations in the observed phenomena. The subject also demands mastery over its highly structural and symbolic language that involves understanding the relation between structure and function, making sense of arrow-pushing diagrams, the ability to think three-dimensionally, and the flexibility to work with different representations with an informed ease. Gaining confidence and comprehension over such a subject that belongs to the higher levels of Bloom’s taxonomy is naturally difficult, and this is where the two critical components of active learning, practice & regular feedback, becomes extremely important towards effective conceptual understanding. The advent of technological interventions has been of great help in this regard, and activities such as flipped classes, clickers, and online homework systems have significantly sharpened the process of learning. A vast majority of undergraduate science and engineering courses in NTU have been technologically transformed over the past few years, cultivating a student-centric and continuous learning experience that fosters critical thinking, confidence and collaborative skills. The freshman organic chemistry course that this author has been teaching was a large enrollment course, typically hosting 200-300 students. Though the course was well-equipped with a number of traditional (lectures, small group tutorials, homework questions) and technological (lecture videos, pre-lecture summary videos, E-book, Blackboard) resources, it was generally felt that the large size of the cohort was still hindering conceptual penetration, active two-way communication/feedback, and student collaboration. Increasing the number of small group tutorials and office hours though ideal was not realistic, due to logistical and time constraints. Supplementary homework questions that were delivered as electronic files were largely a product-oriented exercise with minimal feedback. Though web-technology was provided with scalable platforms to supplement in-class learning, none of the conventional web-based systems, to the best of our knowledge, were viable for demonstrating organic chemistry because they did not possess structure-drawing capacity, which was critical for effective communication of the subject. The author had personally encountered this issue, where the students either uploaded static images or resorted to using text to tediously explain their structural questions in terms of text through the discussion forum maintained in our course website (Blackboard). Any response would have to be made in similar fashion, making the entire sequence un-appealing and arduous. Online assignments using NTU-learning activity management system (LAMS) were limited to multiple-choice questions. The absence of a structure-drawing function seriously hindered proper discussion of most of the concepts in organic chemistry, and students often had to take their exams without adequate practice and confidence. Only commercial homework engines from publishers are currently equipped with structural intelligence, but they come pre-loaded with their own questions, so instructors cannot always find problems that match their target-difficulty level or style of teaching. Also these systems operate on an individual level, offering no social environment for interpersonal interaction or peer help. The development of an online portal embedded with a structure-drawing interface was therefore sought, as this missing piece of technology is a critical component for delivering assignments, facilitating discussions and assessments in online organic chemistry education. The perceived online space would enable the instructor to assign questions matching the lecture content and would also enable the
students to present their answers for feedback, thereby mimicking and augmenting in-class tutorials.

Development of the E-Learning Platform

The most important component of a chemically intelligent web application ought to be an integrated structure-drawing software. One of the essential features of the software targeted was the operational ease, enabling users to generate structures and symbols easily on the web interface with just a browser and an internet connection. Thus, plug-in forms (applets) of commercially available drawing software were not considered, as they remain stand-alone components that often suffer from poor browser compatibility and speed. PerkinElmer (PE) had released ChemDraw Direct, an online version of the popular desktop ChemDraw package, in early 2017 just in time when possible alternatives were explored. ChemDraw Direct was built on Javascript and HTML5, with backend ChemDraw web service, and it came with no download components or installations. It carried the core functionality of desktop ChemDraw and generated and read the same file formats (CDXML); hence drawings couldn’t easily be shared between the two platforms.

Thanks to the site-subscription that we had at NTU for ChemDraw Professional, we were able to purchase a site-license for ChemDraw Direct at a nominal charge. The JavaScript library was hosted in the school server and embedded into a web application that was professionally designed and developed. The user interface (UI) of the portal was designed in such a way that the students could be grouped into different clusters and the instructor could deliver assignments individually to each group, with each set forming a discussion thread. The highlight of the system was the ChemDraw Direct functionality that was embedded into the rich-text editor (Figure 1). In addition to all the basic ChemDraw tools, the Java script library offered features such as structure clean up and naming, however advanced features like spectroscopic information were missing. The extended copy/paste allowed easy export of existing ChemDraw files onto the ChemDraw Direct canvas. The structures drawn were inserted to the right window to add any text or further formatting before posting.

Implementation

The e-learning platform was formally introduced for the first time in the year-1 organic chemistry course in AY2018/19. The portal was used mainly in the second half of the semester, by which time, the topics turned intensively toward mechanisms and stereochemistry, which constitute the bulk of the more visual aspect of organic chemistry. The 221 students in the cohort were split into eight groups of about 25-30 students each. The composition of these online groups were kept the same as the in-class tutorial groups, as the interpersonal interactions and collaborative learning in the online space could boost the dynamics of the in-class tutorial activities (where the students were expected to solve problem sets, in small groups, interacting to one another). Four sets of assignments were deployed within the seven teaching weeks, with the second half mainly focusing on questions about resonance, alkene additions, and electrophilic aromatic substitutions. Each assignment had 3-4 questions and was given a week’s time for answers and discussion. The students were required to access the portal from their course website and upon login, were taken to the thread that was created for their group. The questions were displayed on the left panel (Figure 2), and upon clicking a “post button,” the text/structure-editor window appeared, along with the questions reappearing in a pop-up box (SI contains more screenshots of the interface). The students were to submit their answers before a certain deadline set by the instructor (usually 3-4 days) during which period the students were not able to see each others’ responses. This ensured confidentiality and prevented students from directly copying answers from previous posts, although the possibility of students sharing screen shots of the answers through other forms of online media could not be excluded. The responses were then graded (a small point incentive of 2% was accounted for the first three assignments, mainly to encourage participation and to discourage students from sharing their answers with others) using a star-grading feature (out of five) and short, individual feedback, either in the form of text or structure, was given below.
Figure 2. Screenshot of a graded student response (the name of the individual is shaded to respect privacy) with comments from the instructor. Contains PerkinElmer, Inc. copyrighted material. Printed with permission. All Rights Reserved.

each answer using a “comment” function (Figure 2). This short feedback highlighted major conceptual/drawing errors in the answer to provide a timely rectification for the student. The instructor then posted the answers before making the thread public to enable the students to see their feedback and grades, as well as the responses from others. Student participation was not limited to just answering the questions; further discussion and/or clarifying questions were also encouraged. Students were also able to view other groups’ posts, but they were not allowed to post outside their own groups.

Observations and Student Feedback

The major motivation behind the online exercise was to provide a chemicalized, digital platform enabling structural problem solving and feedback. Undergraduate organic chemistry students are expected to concisely present answers using necessary symbolisms avoiding unnecessary text, for which they received training as one of the learning outcomes of our online exercise. (Over years of experience, the author has observed that freshmen organic chemistry students tend to either supplement or substitute a required structural answer with a text-based narrative. This could be a habit they picked up from pre-university practices or a sign of low confidence with structural representations).  

Student participation was quite high, with each group consistently registering more than 80% of its members completing the assignments. Both conceptual and common mistakes, such as missing atoms/formal charges, sloppy arrows, overly distorted tetrahedra etc. were identified and these errors were highlighted in the feedback comments. Providing individual feedback to all the 221 students on every assignment was certainly a demanding task, but most mistakes were representative in nature, allowing the instructor to replicate a certain comment on multiple responses. The grading was quite lenient, as it was employed mainly to incentivize participation. It helped that the responses remained interactive ChemDraw files, which allowed for editing. The students also had the option of transferring individual responses they chose to a repository for future reference. The assignments helped the year-1 students an early mastery over the usage of ChemDraw, a skill that is quite essential in later years. The ChemDraw Direct functionality amply supported the smooth generation of all required symbolisms, not only in mouse-controlled PC/laptops but also on touchscreen devices such as iPads. The portal was multi-browser compatible, although the performance and clarity of structures appeared better on later versions of Firefox and google chrome. The system did have some developmental pitfalls in the form of occasional lag and certain formatting issues on the submitted responses.

An online Likert-type survey was conducted on the last teaching week to collect student feedback on the usefulness, efficiency, and other aspects of the ChemDraw-equipped portal. The survey was optional and anonymous, and 101 students (of the total 221) volunteered to register their feedback (Table 1 for selected responses, SI for the complete survey). The feedback generally indicated the project to be a useful step towards online learning of organic chemistry, though technological refinements were suggested. Seventy-seven percent of participants either agreed or strongly agreed that a structure-drawing interface was indispensable to discussing organic chemistry online, while 19% were neutral to this statement (statement 2, Table 1). Seventy-four percent of participants agreed/strongly agreed that participation in the weekly discussions helped to enhance their subject understanding, while 18% were neutral on this point (statement 5, Table 1). Open-ended responses (collected for Q7 in the SI) in this regard included:

“I think it is a very useful platform that enables students to effectively ask questions and receive feedback based on their written descriptions as well as diagrams drawn”, “It helped me to see how different molecules with different functional groups reacts with reactants provided. The different stereochemistry is easier to see with the use of ChemDraw”, and “with the different opinions made by different people on what the answers should be, it allowed me to think of reasons why their answers are not correct. This helps me to understand the topics better”.
Table 1. Selected statements and their responses from the student survey conducted in Blackboard

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree/Strongly disagree</th>
<th>Unanswered/Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
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<td>12</td>
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<td>13</td>
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<tr>
<td>19</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Seventy-two percent of students stated that it was the first time they dealt with ChemDraw or any drawing software, while 26% of students had prior basic experience using chemical drawing software. This lack of ChemDraw experience was understandable, as the participants were all year-1 students. Naturally, many of them found it challenging and time-consuming to maneuver the ChemDraw interface initially, as only 54% positively agreed/strongly agreed that it was easy to use. Twenty-five percent remained neutral on this statement, while 19% disagreed/strongly disagreed (statement 12, Table 1). Part of this difficulty could have stemmed from the technical glitches mentioned above. Statements that indicated these issues (collected in response to Q20 in the SI) included:

“It took quite a lot of my time to use the ChemDraw software”, “Resolution after posting the answers can be improved”, and “The spacing of ChemDraw is not very organized and the answers are jumped everywhere. It is difficult to manage this software for homework discussion”.

Seventy-four percent of the users still generated most of their drawings using the canvas (statement 13, Table 1), though they had the option of copying drawings made on the desktop ChemDraw (Only 12% of the users chose to do it always/very often). 71% of users agreed/strongly agreed that the online assignments have greatly helped to improve their ChemDraw skills, while 23% chose to be neutral (statement 10, Table 1). The majority (82%) of participants used a Windows computer, while 9% students reported the usage of a touchscreen device frequently/very frequently to generate their responses. While 70% of the students recommended the usage of the online platform for future courses in organic chemistry, 9% opposed this proposal (statement 19, Table 1). The overall user experience, including that of the author, is well-represented by a single statement a student registered: “It is a good, feasible only platform for interactive organic chemistry learning. Not only does it provide us with more questions to practice on, we can also receive live feedback from the teachers of the course and also discuss the answers with our peers. It is definitely a novel approach and a very good start to online chemistry learning, but definitely there are areas for improvement”.

Conclusions
The study presented here investigated the implementation of an online system equipped with a structure-drawing interface to materialize smooth online communication of organic chemistry, effectively bridging the teacher-student gap, typical for large classroom settings. The portal was successfully used for conducting online tutorials, enabling regular practice and feedback to a large cohort of year-1 organic chemistry students. The overall system is a work in progress, but the potential of a chemically intelligent web space to bolster the structural needs of organic chemistry is quite evident. Future work is directed towards increasing the robustness of the system by rectifying the technological issues observed in the first
round. A deeper integration with Blackboard is targeted so as to enable direct transfer of grades. Evaluation and quantification of the impact of the online exercise on exam performance by forming control groups would also be worth investigating.

**Acknowledgments**

The project was financially supported by NTU-EdeX learning and teaching project grant (2017). Solutionify IT SOLUTIONS (Singapore) is thanked for the development, deployment and maintenance service of the software system. Centre for IT Services (CITS), NTU is acknowledged for the necessary help with technical matters. PerkinElmer, Inc. is acknowledged for providing ChemDraw Direct and necessary technical advice whenever required. Mr. Harry Lee, the General Manager of GNX Technologies Pte Ltd (official reseller of ChemDraw products in Singapore) is especially thanked for kindly facilitating the purchases and communications.

**References**

8. J. S. Moore has reported the usage of wiki-based online system utilizing a MarvinSketch applet for structure drawing. See ref. 6e.
9. LAMS, the assessment tool for online activities. See: https://www.lamsfoundation.org/ (last assessed Dec-2018).
Supporting information

I. Online portal integrated with Chemdraw® Direct

II. Screen Shots

III. Student Feedback Survey

I. Online portal integrated with Chemdraw Direct

The Chemdraw Discussion System is a HTML5/JavaScript (Progressive Web Application) implementation of ChemDraw that enables users to utilize the embedded chemical drawing tool, to draw chemical structures in an online discussion setting.

System Overview

The system consists of:

- .NET Web Services Endpoint (C#)
  The Web services is developed in such that the system will be able to integrate with future systems, catered for multiple platforms, which will allow them to utilize the existing functions.

- HTML5 web application with implemented Chemdraw JavaScript API
  The embedded Chemdraw drawing tool is developed based on HTML Canvas to allow users to draw structures on Web devices before converting to the CDXML/ SVG format. The chemdraw structures drawn by users will be saved on the backend as SVG document (image) and as a CDXML for future editing.

II. Screenshots

1) The main page (instructor view)

```
<table>
<thead>
<tr>
<th>DISCUSSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussion Title</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Feedback on Platforms</td>
</tr>
<tr>
<td>Michelle's Challenge</td>
</tr>
<tr>
<td>Chemistry</td>
</tr>
<tr>
<td>CH 4</td>
</tr>
<tr>
<td>Atoms 1</td>
</tr>
<tr>
<td>Atoms 2</td>
</tr>
<tr>
<td>Atoms 3</td>
</tr>
</tbody>
</table>

| Atoms 3 | Addition | 31 January 2019 | Yes |
```

2) The main page (student view)
III. Student Feedback Survey
The online feedback survey was conducted in the course web site to collect user experience. The survey was optional and anonymous. A total of 20 questions featuring Likert type, open-ended, multiple-choice and either/or type were presented. 101 students participated in the survey. The collated survey results are given below.

Q1. I have participated regularly in the weekly assignments using the E-learning platform based on chemdraw.

Q2. A structure-drawing interface is indispensable to discuss organic chemistry online.

Q3. The structure drawing facility in the platform has enabled me to present my questions/answers better.
Q4. I found participation by drawing responses helpful to my understanding of organic chemistry.

Q5. The online assignments helped to advance my subject understanding.

Q6. The online assignments were worth the effort.

Q7. Any other comments on how the E-learning platform has helped (or hindered) your learning process in CM1031? (All comments given by the students are unedited and collated below)

- The diagram provided with chemdraw help me to understand the reaction's mechanism without having to picture it in my mind
- i only answered the questions that i know so im not sure if i am sure of the concepts entirely.
- I like how we can use chem draw to identify compounds that we do not know using the name function.
- i think it is a very useful platform that enables students to effectively ask questions and receive feedback based on their written descriptions as well as diagrams drawn.
- The electron’s movement arrows’ start and endpoints are automatically adjusted by the program and hence it is unclear to me where I should start and end my arrows on paper
- Useful but for the first time user need more time to build up the skills.
- It was ok. has potential
- It helped me to see how different molecules with different functional groups react with reactants provided. The different stereochemistry is easier to see with the use of chemdraw.
- took time to figure out how to draw the structures.
- MOre time needed when drawing the structures because we are still amateur to the software
- The scaling of the drawings on the platform is often off.
- The drawing can make easier and more efficient. As I Spend quite some time just to draw out the structure in the platform
- It was great fun and exciting to be able to draw compounds online for the first time, though there was not enough questions; i.e I had to reuse questions and could already see what others had replied and that felt like cheating/not learning.
- It was difficult to navigate through and draw using the interface. Perhaps more practice is needed.
- get to see the mistakes of others.
- It is a good, feasible only platform for interactive organic chemistry learning. Not only does it provide us with more questions to practice on, we can also receive live feedback from the teachers of the course and also discuss the answers with our peers. It is definitely a novel approach and a very good start to online chemistry learning, but definitely there are areas for improvement.
- The drawings helped me better understand the problems and solutions.
- While grading forces us to do, it’s extremely difficult to access it without using a computer since I used the ipad mini provided to access online learning resources.
- Good platform for us to have a better understanding of organic chemistry.
- It is much easier to draw it on paper and post it through a picture of the drawings rather than to draw it on a computer
- it takes time to learn how to draw the structures on chemdraw.
- This platform should start earlier in the semester. Is useful and a good way to clarify doubts.
- The curly arrow to show transfer of electrons could be improved to directed to exactly where we want it to be
- it was quite challenging to draw simple molecules
- I think the chemdraw assignment shouldn’t be graded. We have a lot of assignments and revision to do, sometimes this may just slip our mind especially during periods of nearing tests.
- I feel that the elearning platform took up a lot of my time trying to draw structures on laptop. Essentially, i feel that the questions could have been set on tutorial worksheet instead of using the chemdraw platform.
• I still think that the use of the normal discussion forum is sufficient and this chemdraw platform did not significantly improve my understanding of the subject.

• Good discussion platform

• It allows other students who have better knowledge on the topic to help weaker students, however the drawing tool is fairly difficult to use and takes a while to get use to.

• It has made learning slower as it takes very long to complete drawing the organic molecule

• harder thinking questions should be placed on it instead as some questions were very straight forward however it did helped with the usage of chemdraw

• The chemdraw platform would sometimes not register the response - either having a blank response or none at all and the structure drawing platform was sightly confusing. Other than that I believe that chemdraw was a good way for us to practice questions.

• It has helped me in terms of being better able to visualise three dimensional structures. However, unfortunately, since the platform is still in the process of being developed, an outstanding problem would be the lack of an autosave option. After spending a long time and lots of effort to draw the strcutures, I have lost my data by accidentally clicking the back option, or refresh button, or simply when my desktop hangs and I am forced to redo the entire thing. Another problem is that the drawing of structures itself is very time consuming as it is difficult to constantly toggle between the different functions.

• It was not extremely useful because a lot of time had to be spent drawing the structure using a mouse. However, this could be due to my inexperience in using such a software.

• With the different opinions made by different people on what the answers should be, it allowed me to think of reasons why their answers are not correct. This helps me to understand the topics better.

• I like the chemdraw simple interface and its easy to use. But it will be better if I can access it on smartphone or iPad and be able to draw the structure with ease. Because I’m at school most of the time and are unable to draw on my smartphone, it is inconvenient to have wait till when I get home to use the chemdraw.

• Is not very user-friendly because I need to go through one by one to read on specifically what are the suggest answers posted by peers

• It provides me with critical thinking and helped me in understanding the topic better with more practice question.

• It is definitely a very useful tool for learning chemistry as we can use it to clarify our doubts effectively and immediately through this online platform, which enhances our learning experience. The chemdraw software is also very user friendly and easy to use.

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Q8. Have you ever used chemdraw (or other chemical drawing software) before taking CM1031?

Q9. If yes, how good you were at chemdraw (or other chemical drawing software) before taking CM1031?

Q10. The online assignments has greatly helped to improve my chemdraw skills.

Q11. The overall user interface of the E-learning platform was intuitive and easy to use.
Q12. It was quite easy to draw structures and symbols in the integrated chemdraw interface in the E-learning platform.

Q13. I have always generated the structural part of my responses using the chemdraw interface of the E-learning platform.

Q14. How often did you resort to drawing your structures in desktop chemdraw and then pasted to the online chemdraw interface of the E-learning platform?

Q15. Which of the following systems have you used the most to access the E-learning platform?

Q16. Have you ever used a touch screen (e.g., ipad) to draw structures in the E-learning platform?

Q17. Pertaining to Q-16, if yes how was your experience?

Q18. Which web browser have you used the most to access the chemdraw based E-learning platform?

Q19. I would recommend this E-learning platform to be used in future courses of organic chemistry.
Q20. Any other comments or suggestions on the user interface of the platform? (All the comments given by the students are collated unedited below)

- mac safari cannot access the platform. cannot even draw.
- If chemdraw were to be made into an app for smartphones, it will definitely be easier to access it.
- It is good to have an autosave function during the process of drawing the structures. There are times when I accidentally pressed the 'back' button of my browser and the whole structure is gone when I come back to the page. At least for the structures we have drawn, it is painful to redraw them again.
- Also, there should be an option to save the draft of the post before submitting it. Right now there is only 'cancel' and 'submit' functions, if I'm not wrong. Sometimes I don't want my random scribbles to be seen by others before I'm done.
- Option to remember and change password will be greatly appreciated.
- Home screen interface could have been made to look more professional.
- Arrows for electron movement is hard to manipulate. It will be good if the arrow can "pivot and rotate" around freely, instead of having them 'clicking' into some fixed angles or position. Moreover, the process of adding bonds to the same carbon, and replacing a certain functional. Again, I'm not really sure how to explain this. These are all the areas for improvement I can think about for now. There should be more, but it doesn't cross my mind. Overall, I do think that there is a lot of potential in this platform and with further polishing and fine-tuning, this could be a good supplement to normal organic chemistry learning.
- There could be an online tutorial that allows one to practice drawing before the first assignment, that provides step by step instructions on what to select to get certain shapes and structures.
- Way easier to use chemdraw than the platform
- Edge didn't work at all. Switching to Chrome made it work totally fine.
- Thank you for the effort in developing this to help us discuss organic chem
- A step by step guide for first time users.
- Make it easier to copy and paste diagrams from one persons answer/question or the sets of questions into the answer!
- Resolution after posting the answers can be improved.
- To be very honest. I feel that chem-draw is a good platform for learning. However, you can clearly see that once there's no grading for chem-draw, everyone is lazy to do it. I'm not too sure the exact reason, whether singaporeans are shy or they are lazy. Nonetheless, I think this is a good start, maybe if its introduced slightly earlier, it will be better. I am not a CBC student so i do not use the platform much.
- The chemdraw platform can be extended to various chem courses beyond CM 1031 as a platform to clarify doubts from students.
- I always find myself difficult to view the Chemdraw page using Safari (iPad). The replying box is too big that it blocks something else there.
- the forum discussion board could really use some work. The structures are also very small, it's very difficult to place minutiae like lone pairs and charges. It would be much better if it could be enlarged in some ways, like making the base length of the C-C bond longer etc.
- Can conduct a more detailed introduction about how to use the chem draw system for the newbie. (Use about 1 hours to done my first mechanism)
- It is quite tedious to get the simple drawing out. What i normally do is to draw the actual answer on paper, then replicate it on Chemdraw platform. However, it is an additional step which in my opinion, is not needed.
- It takes quite a fair amount of time to draw the structures in chemdraw as compared to drawing the structures by hand on paper so some students may find it more time-efficient to complete the questions on paper instead.
- The spacing of chemdraw is not very organised and the answers are jumped everywhere. It is difficult to manage this software for homework discussion.
- Can make it compatible to mobile device or Ipad (mobile friendly) so that we are able to access the chemdraw anywhere without the need of a computer.
- I hope that something can be done to make it user friendly to reply and comment. For eg, when I commented on something and wished to know if Someone has replied to my comment, I would have to scroll down all the way to find the thread, which could be a hassle. It makes matters worse if the thread is full of comments. overall I really like it!
VSEPR shapes: A musical mnemonic

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Abstract
The use of songs to help learning of content is consistent with multi-sensory models of learning. Here, a song to the tune of "Friar Jacques" ("Brother John") can be used in the classroom to assist the learning of VSEPR shapes. One of the reasons that songs are not more commonly used is that there is a limited variety of chemistry topics, vocal ranges, and varieties of musical genres. This song adds to the repertoire of chemistry songs.

Introduction
The valence-shell electron-pair repulsion (VSEPR) model is commonly used in both senior high school and undergraduate chemistry to predict the bond angles in covalently bonded molecules. The fundamental idea is that the bond angles about any atom is given as follows:

- Students first draw a Lewis structure for a molecule, where possible, using pairs of valence-shell electrons;
- Lone pairs, single bonds, double bonds and triple bonds, each count as one “electronic direction” about an atom;
- Since interatomic electronic charge is localised along the electronic directions, there will be lower electronic repulsion energy when the angles between the electronic directions are maximised.

<table>
<thead>
<tr>
<th>Number of electronic directions</th>
<th>Name of electronic shape</th>
<th>Idealised angles between electronic directions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Linear</td>
<td>180°</td>
</tr>
<tr>
<td>3</td>
<td>Trigonal planar</td>
<td>120°</td>
</tr>
<tr>
<td>4</td>
<td>Tetrahedral</td>
<td>109.5°</td>
</tr>
<tr>
<td>5</td>
<td>Trigonal bipyramidal</td>
<td>90°, 120°</td>
</tr>
<tr>
<td>6</td>
<td>Octahedral</td>
<td>90°</td>
</tr>
</tbody>
</table>

This simple model leads to the idealised shapes and angles listed in Table 1, and shown in the Figures. The actual angles are affected by the steric bulk of the bonded ligand and by the effective cone angle of the electron pairs. Since lone pair electrons are closer to the nucleus than bonding electrons, lone pairs “repel” more than bonding pairs (Table 2). Similarly, the electron density of multiple bonds is larger than that of a single bond: multiple bonds “repel” more than single bonds (Table 2).

Table 2. The actual angles are affected by the type of electron pairs.

<table>
<thead>
<tr>
<th>Angles involving lone pairs (biggest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angles involving triple bonds</td>
</tr>
<tr>
<td>Angles involving double bonds</td>
</tr>
<tr>
<td>Angles involving single bonds (smallest)</td>
</tr>
</tbody>
</table>

Learners are often overwhelmed by the amount of information in a new topic; mnemonics help learning and recall, through the chunking of information by associations, acronyms, rhymes, repetition, the use of pictures, etc. The success of mnemonics is due to a decrease in the cognitive load.

Songs have long been used as mnemonics to aid the learning of factual information, for example, one commonly-used “Alphabet Song” is set to the tune of of Twinkle Twinkle Little Star. Song has been used by non-literate cultures as one way of memorising their oral traditions. A number of studies have shown that putting information into songs promotes better learning and recall than when the information is presented only as text. The use of familiar rhythms and familiar songs is more effective for learning than unfamiliar rhythms and songs. Also see reference and references therein for more information about how the melodic and rhythmic context of song enhances learners’ abilities to encode and recall information.

Here, a song to the tune of “Friar Jacques” (“Brother John”) can be used in the classroom to assist the learning of VSEPR shapes.

VSEPR shapes
(To the tune of Frère Jacques.)

Lewis structures (Lewis structures)
Help us out (Help us out)
In pre-dict-ing struc-ture (In predicting structure)
Mol-e-cules (Molecules).
Two directions (Two directions)
Op-po-site (Opposite)
Do re-pel each o-ther (Do repel each other)
Lin-e-ar (Linear).
Six dir-ec-tions (Six directions)
Point-ing like (Pointing like)
Ca-ar-tes-ian ax-es (Cartesian axes)
Oct-hed-ral (Oct-hedral).\(^\text{20}\)

\[
\begin{array}{c}
\text{H} - \text{C} = \text{N} : \\
\end{array}
\]

**Figure 1.** Linear geometry associated with two electronic directions about a central atom.

Three dir-ec-tions (Three directions)
Tri-an-gle (Triangle)
Three-ee-point-ed sta-ar (Three-pointed star)
Trig plan-ar (Trig planar).\(^\text{17}\)

\[
\begin{array}{c}
\text{H} - \text{S} - \text{H} \\
\text{H} - \text{N} - \text{H} \\
\end{array}
\]

**Figure 2.** Idealised trigonal planar geometry associated with three electronic directions about a central atom.

Four dir-ec-tions (Four directions)
Is trick-y (Is tricky)
Like a lit-tle tri-pod (Like a little tripod)
Tet-hed-ral (Tet-hedral).\(^\text{18}\)

\[
\begin{array}{c}
\text{H} - \text{S} = \text{H} \\
\text{H} - \text{N} = \text{H} \\
\end{array}
\]

**Figure 3.** Idealised tetrahedral geometry associated with four electronic directions about a central atom.

Five dir-ec-tions (Five directions)
Jew-el-like (Jewel-like)
Tri-gon-al bi-pyra-mid (Trigonal bipyramid)\(^\text{19}\)
Mol-e-cules (Molecules).

\[
\begin{array}{c}
\text{H} - \text{S} : \text{F} \\
\text{F} : \text{S} : \text{F} \\
\end{array}
\]

**Figure 4.** Idealised trigonal bipyramidal geometry associated with five electronic directions about a central atom.

**Discussion**

Note that the correct names of the shapes (linear, trigonal planar, tetrahedral, trigonal bipyramidal, and octahedral) are listed in Table 1. The names of many of the shapes have been slightly changed in the song to maintain the flow of the rhythm.

The use of songs in chemistry is not new; songs can add interest and engagement, and promote learning through rhyme, rhythm and repetition.\(^\text{10-11, 13-16, 21-25}\) One of the reasons that songs are not more commonly used is that there is a limited variety of chemistry topics, vocal ranges and varieties of musical genres. This song, set to a well-known tune, adds to the repertoire of chemistry songs.

**References**


17. The full and correct name for the geometry with three electronic directions is "trigonal planar".

18. The full and correct name for the geometry with four electronic directions is "tetrahedral".

19. The full and correct name for the geometry with five electronic directions is "trigonal bipyramidal".

20. The full and correct name for the geometry with six electronic directions is "octahedral".


