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Applying Hand-Held 3D Printing Technology to the Teaching of VSEPR Theory

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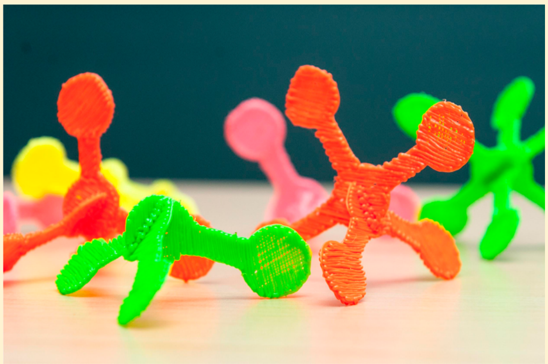
Supporting Information

ABSTRACT: The use of hand-held 3D printing technology provides a unique and engaging approach to learning VSEPR theory by enabling students to draw three-dimensional depictions of different molecular geometries, giving them an appreciation of the shapes of the building blocks of complex molecular structures. Students are provided with 3D printing pens and two-dimensional templates which allows them to construct three-dimensional ABS models of the basic VSEPR shapes. We found that the learning curve associated with manipulating the pen accurately and the time required to draw a structure is sufficiently high that this exercise would need to be limited in a laboratory setting to students each being tasked with drawing a different molecule; however, in the correct setting, hand-held 3D printing pens are a potentially powerful tool for the teaching of VSEPR theory.



KEYWORDS: *First-Year Undergraduate/General, High School/Introductory Chemistry, Collaborative/Cooperative Learning, Hands-On Learning/Manipulatives, VSEPR Theory*

INTRODUCTION

Undergraduate chemistry students are taught many concepts that require the engagement of spatial abilities. Grasping the relationship between a two-dimensional representation and the corresponding three-dimensional object is a critical concept in chemistry, underpinning much of what students learn throughout their degree. For example, valence shell electron pair repulsion (VSEPR) theory,[1] often taught in introductory chemistry courses as a model for predicting molecular geometries based on the arrangement of electron pairs around a central atom, requires students to have the ability to take a two-dimensional representation on the page and transform it into a three-dimensional object in their minds. It has been our experience that students find this to be a challenging task, and when considering that these skills are heavily relied upon in second and third year courses both in organic and inorganic chemistry, it may well be one of the most significant conceptual hurdles for budding chemists to overcome. As such, mastering these skills early on will allow students' a firm foundation upon which to build higher level skills.

Many types of models have been used to help visualize the shapes predicted by VSEPR theory, including (but not limited to): computer animations,[2] touch screen devices,[3] computational laboratories,[4] various materials to build models including whiteboard markers,[5] beads and rods,[6] snap hooks and latex tubing,[7] circular magnets,[8] bar magnets and Styrofoam balls,[9] festive trees,[10] Styrofoam balls with Velcro strips,[11] and plastic globes,[12] clay models and kite kits.[13] However, many of these examples are designed for in-lecture demonstrations and do not focus on building students' skill sets in a hands-on fashion. Our department currently uses a combination of Styrofoam balls with pipe cleaners and plastic model kits to teach first year chemistry students about molecular shape and geometry.

3D printing technology has taken off in recent years, with 3D printed models being applied to the teaching of a wide range of topics in chemical education including: symmetry and point group theory,[14] protein domains,[15] unit cell theory,[16] orbital theory,[17] and structure-energy relationships.[18] A recent development in 3D printing technology is the hand-held 3D printing pen, a device that extrudes hot plastic at a constant rate at a point in three-dimensional space defined by the operator. Applying this technology in the teaching of molecular geometry is potentially a valuable way to enhance student understanding of molecular structure by adding a third dimension to a student's ability to draw molecules.

METHOD

Novices to the 3D printing pen find it difficult to manipulate the pen accurately in three dimensions, and even experts usually generate 3D models by drawing 2D sections and assembling them together to make the final model. In order to streamline the drawing process for students, a 2D template was designed (Figure 1). Students are able to trace over the images with the 3D printing pen, eliminating the need for strong artistic skills to produce quality models.

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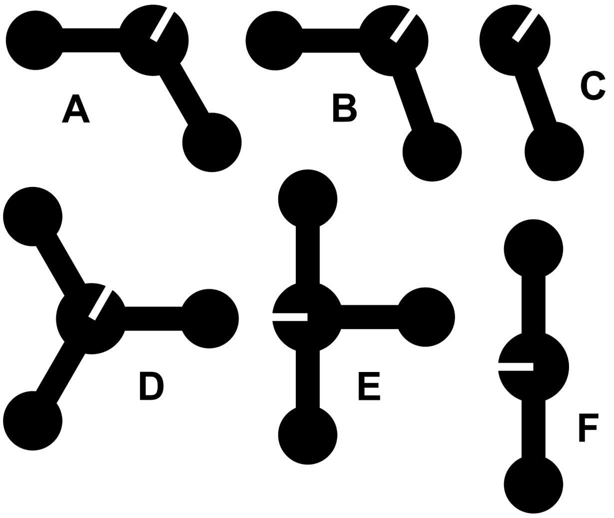

Figure 1. Two-dimensional templates. Linear = F (without notch). Trigonal planar = D (without notch). Bent (120°) = A (without notch). Tetrahedral = B + B. Trigonal pyramidal = B + C. Bent (109.5°) = B (without notch). Trigonal bipyramidal = A + E (or D + F). Seesaw = A + F. T-shaped = E (without notch). Octahedral = E + E. Square pyramidal = E + F. Square planar = F + F. Refer to Supporting Information.

We found that the best results were achieved when the user drew the circles for the atoms first, then joined them together by drawing in the bonds (Figure 2a), and finally colored in both sides (Figure 2b)—a process that not only makes them more visually pleasing, but also adds a factor of strength to the model.

The resulting shapes obtained using the 2D digital template were designed to be like puzzle pieces, where the students would trace two pieces with the 3D printing pen and then combine them into the corresponding molecular shape. The student would then hold the pieces in place and affix them together using the printing pen. For example, to produce an octahedral model, students would draw two copies of the T-shaped template (Figure 2b) and then join them together and fix them into place using a little extra plastic (Figure 2c). The end result is beautiful, brightly colored 3D models of the basic VSEPR shapes (Figure 2d).

The key to avoiding ink transfer into the plastic and the resulting discoloration of the models was to place a piece of paper on top of the template and trace directly on this blank top layer. Attempts were made to use glass and acrylic sheets in place of paper as a top layer, but the plastic did not adhere well enough to either to enable a high success rate. We found the ABS plastic to be superior to PLA for building the models, as the ABS structures were more pliable and were easier to peel off paper. On average, each model required one to two strands of ABS (~1.5−3 g ABS per model), depending on the user.

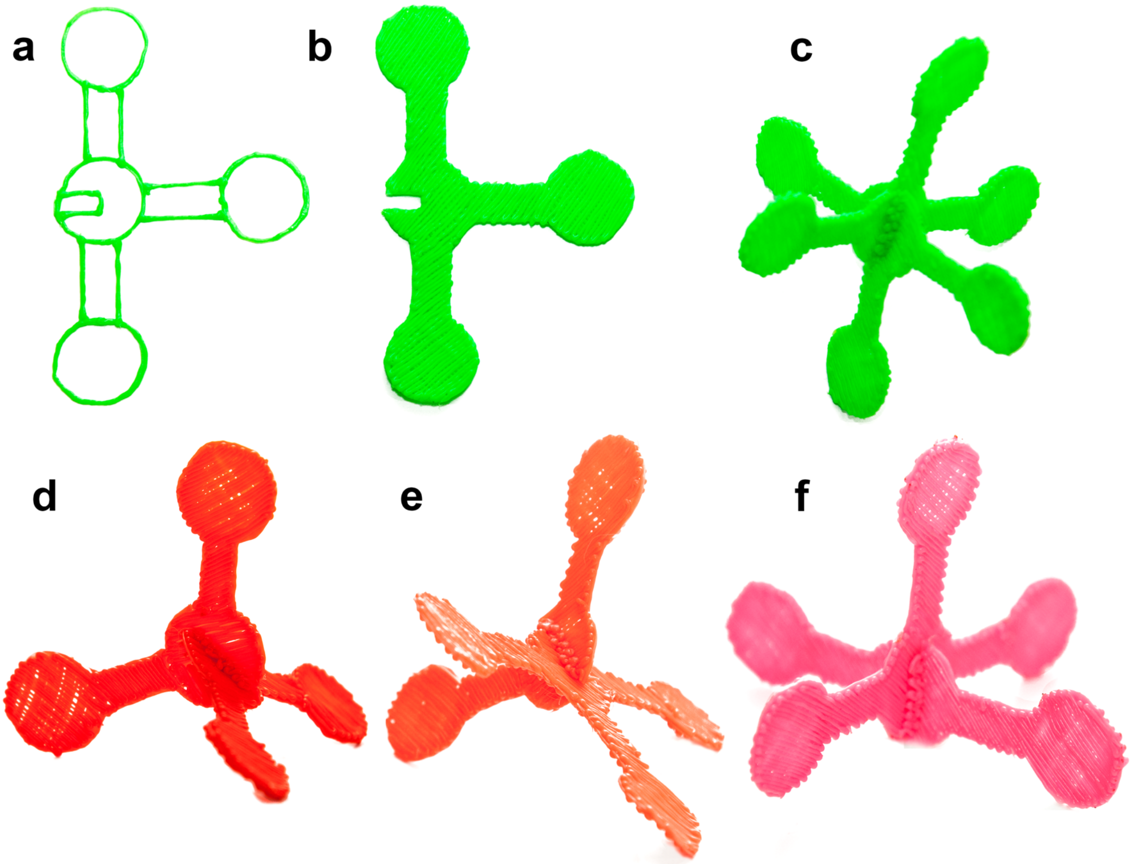

Figure 2. Top: the three stages of the octahedral model construction from the template: (a) outline, (b) infill, (c) assembly. Note that after the infill process, the plastic blocking the notch on the central atom of the outline needs to be cut away with scissors before assembly. Bottom: examples of the final product obtained, based on (d) four (tetrahedral), (e) five (trigonal bipyramidal), and (f) six (square pyramidal) electron domains. Photo credit: Kari Matusiak.

DISCUSSION AND CONCLUSIONS

There are 13 commonly encountered VSEPR geometries, but six: linear (2 electron domains and 5 electron domains); bent (120° and 109.5°); trigonal planar; T-shaped and square planar, have all of their atoms in the same plane and are the least in need of 3D representation. That leaves six that require a genuine three-dimensional understanding: trigonal pyramidal, tetrahedral (4 electron domains), seesaw, trigonal bipyramidal (5 electron domains), square pyramidal, and octahedral (6 electron domains). Interestingly, when we let our test class have free rein to draw whatever they liked the majority chose to draw a trigonal bipyramid, perhaps because this was the only one of the five basic VSEPR shapes that required two different components. The test class, consisting of 20 first year students working in pairs, found the task of producing the models challenging, producing only one or two models in the allotted 60 min. This demonstrated that the learning curve associated with manipulating the pen accurately and the time required to draw a structure is sufficiently high that this exercise would need to be limited in a laboratory setting to students each being tasked with drawing a different molecule. The mechanical integrity of the produced models is also a potential drawback, as the models are relatively fragile and would probably not hold up to a day spent rolling around in a backpack. It is noted that the mechanical integrity of the models is also dependent on the amount of plastic used. Another consideration is the safety of using the 3D printing pen, as the tip of the pen reaches a temperature of 240 °C (on the "high" setting), which does present burn hazard for students using the pen; however, with proper instruction and supervision, this hazard could be limited.

While the commonly used ball and stick model kits are an effective tool for teaching VSEPR theory, the application of hand-held 3D printing pens provides a fresh and unique way for students to learn about molecular geometries. Not only could this to be a fun and engaging learning exercise for students, but the students could also keep their models afterward as the raw material, ABS plastic, is inexpensive. We envisage that this would result in students being likely to share their experience with friends and family, potentially promoting a more positive attitude toward learning VSEPR theory.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00186.

Full-size printable version of the 2D template (PDF)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) (a) Gillespie, R. J.; Nyholm, R. S. Inorganic stereochemistry. *Q. Rev., Chem. Soc.* **1957**, *11* (4), 339. (b) Gillespie, R. J. The valence-shell electron-pair repulsion (VSEPR) theory of directed valency. *J. Chem. Educ.* **1963**, *40* (6), 295.

(2) Jennings, A. S. The VSEPR Challenge: A Student's Perspective. *J. Chem. Educ.* **2010**, *87* (5), 462−463.

(3) McCollum, B. M.; Regier, L.; Leong, J.; Simpson, S.; Sterner, S. The Effects of Using Touch-Screen Devices on Students' Molecular Visualization and Representational Competence Skills. *J. Chem. Educ.* **2014**, *91* (11), 1810−1817.

(4) Ruddick, K. R.; Parrill, A. L.; Petersen, R. L. Introductory Molecular Orbital Theory: An Honors General Chemistry Computational Lab As Implemented Using Three-Dimensional Modeling Software. *J. Chem. Educ.* **2012**, *89* (11), 1358−1363.

(5) Dragojlovic, V. Improving a Lecture-Size Molecular Model Set by Repurposing Used Whiteboard Markers. *J. Chem. Educ.* **2015**, *92* (8), 1412−1414.

(6) Sunderland, D. P. Studying Crystal Structures through the Use of Solid-State Model Kits. *J. Chem. Educ.* **2014**, *91* (3), 432−436.

(7) Kundell, F. A. A simple VSEPR demonstration. *J. Chem. Educ.* **1992**, *69* (4), 277.

(8) Shaw, C. F.; Shaw, B. A. A magnetic two-dimensional analogue of VSEPR. *J. Chem. Educ.* **1991**, *68* (10), 861.

(9) Hervas, M.; Silverman, L. P. A magnetic illustration of the VSEPR theory. *J. Chem. Educ.* **1991**, *68* (10), 861.

(10) Lechner, J. H. The VSEPR Tree: A Hands-On Activity for Learning Molecular Geometry. *J. Chem. Educ.* **1994**, *71* (12), 1021.

(11) Kemp, K. C. A novel, simple, and inexpensive model for teaching VSEPR theory. *J. Chem. Educ.* **1988**, *65* (3), 222.

(12) Meloan, C. E. A visual aid to demonstrate the VSEPR theory. *J. Chem. Educ.* **1980**, *57* (9), 668.

(13) Donaghy, K. J.; Saxton, K. J. Connecting Geometry and Chemistry: A Three-Step Approach to Three-Dimensional Thinking. *J. Chem. Educ.* **2012**, *89* (7), 917−920.

(14) Scalfani, V. F.; Vaid, T. P. 3D Printed Molecules and Extended Solid Models for Teaching Symmetry and Point Groups. *J. Chem. Educ.* **2014**, *91* (8), 1174−1180.

(15) Meyer, S. C. 3D Printing of Protein Models in an Undergraduate Laboratory: Leucine Zippers. *J. Chem. Educ.* **2015**, *92* (12), 2120−2125.

(16) Rodenbough, P. P.; Vanti, W. B.; Chan, S.-W. 3D-Printing Crystallographic Unit Cells for Learning Materials Science and Engineering. *J. Chem. Educ.* **2015**, *92* (11), 1960−1962.

(17) Robertson, M. J.; Jorgensen, W. L. Illustrating Concepts in Physical Organic Chemistry with 3D Printed Orbitals. *J. Chem. Educ.* **2015**, *92* (12), 2113−2116.

(18) Blauch, D. N.; Carroll, F. A. 3D Printers Can Provide an Added Dimension for Teaching Structure−Energy Relationships. *J. Chem. Educ.* **2014**, *91* (8), 1254−1256.