# Developing Student Heuristic Characterizations to Help them “Bond” with Organic Chemistry

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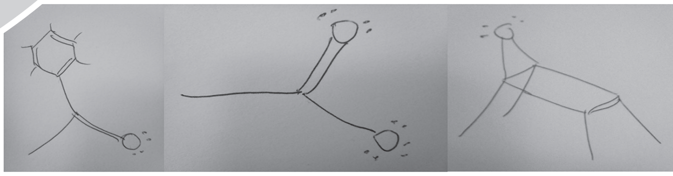
TIPS, TRICKS & TECHNIQUES

# Developing Student Heuristic Characterizations to Help Them "Bond" with Organic Chemistry

RECOMMENDED FOR *AP Biology*

PHILIP MIRKIN



**Abstract**

*The volume of content and abstract nature of organic chemistry is challenging and potentially intimidating for students. I describe a strategy for facilitating student development of heuristic tools for engaging with the subject. By using experimental and researched data on carbon, oxygen, nitrogen, and hydrogen, the bulk chemical elements of organic chemistry, my students were encouraged to develop a "character reference" for each. The heuristics of characterization enabled them to relate more easily and engage more creatively with the work, including when working with complex organic molecules later on. I used this approach when teaching carbohydrates, alcohols, fats and proteins to 12- to 14-year-old students.*

**Key Words:** *heuristics, characterization, organic chemistry, education, Ancient Greek elements*

## ○ Introduction

Heuristics in relation to the learning of chemistry helps students to make decisions "using implicit and preconscious reasoning mechanisms" (McClary & Talanquer, 2011). McClary & Talanquer found that over 90% of their research participants used heuristics in order to make rapid decisions when confronted with new chemistry questions, using their existing concepts to intuit new outcomes. When Moran (2013) began studying toward her medical doctor degree, she perceived organic chemistry as difficult and with a high failure rate. She says, "You have to rely on intuition, generalizing from specific examples" (Moran, 2013, p. 2).

Moran developed her heuristic intuition through repeatedly drawing the diagrams for the reactions under different conditions. The building, and necessary repeated testing, of student heuristics takes an enormous amount of time (Alter et al., 2007; McClary & Talanquer, 2011; Moran, 2013). In my experience, this process can be accelerated by guiding students to develop their heuristic characterizations from the start. Some approaches to help students develop learning strategies in organic chemistry, like OCLUE's three-dimensional framework system (Cooper et al., 2019) are certainly helpful. Without the right guidance, however, such strategies can become mechanical and rote learning processes rather than one where students use and develop their independent intuitions.

Avenas (2021), who used linguistics and metaphor to characterize the chemical elements of carbon (C), oxygen (O), nitrogen (N) and hydrogen (H), compared them to the ancient Greek earth, water, air, and fire. My characterization is the same as Avenas's, while also drawing on the element's relationship to human temperaments, increasing the scope for student heuristic characterizations (Evans, 2019). Further, I encouraged my students to develop their own heuristic notions, to give them agency, ownership and autonomy in the learning process.

## ○ Building a Characterization for Each Chemical Element

The following example was used with 12- to 14-year-old students in a high school natural-science classroom when introducing them to organic chemistry. Although the details vary, I have usually used one 50-minute session for experiments, further information, and student characterization per element. Heuristics were elicited through structured classroom conversation. After the discussion, students were asked to express their characterizations through diagrams, creative/narrative writing and/or poetry. Marks were awarded for evidence that substantiated their characterization.

### *Session 1: Hydrogen*

Demonstration; electrolysis of water: I set up an electrolysis of water demonstration for students to see how the $H_{2(g)}$ volume formed is twice that of the $O_{2(g)}$. I let it build up enough gas to be tested during the next session. This visually demonstrated the formula $H_2O$.

Practical; zinc and hydrochloric acid: This experiment was conducted in small groups using strict safety protocols. Zinc granules were put into a wide test tube. As soon as the acid was poured into this test tube, another student placed an empty test tube upside down over it to catch the released $H_2$. A third student stood ready with a candle flame to ignite the $H_2$, producing the characteristic "pop."

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In a guided conversation, students then shared their experiences about hydrogen. I challenged them to think carefully about their observations, adding further facts about hydrogen to complement their developing characterization. They wrote these down, leaving space to add new insights.

***Further information about hydrogen.*** Hydrogen is the smallest and lightest element, being first on the periodic table. It can escape Earth's gravity and drift out into space, where it is the most abundant element in the universe as the fuel of stars in the plasma state; as flame. We find it on earth mostly in water and organic compounds. It is the cleanest burning fuel, producing only water. The transfer of hydrogen ions creates acid–base reactions.

***Characterization of hydrogen.*** Highly flammable/reactive, tiny and light, intense, committed, etc. hydrogen resembles something like a gravity-free fireball, which I associate with the ancient Greek element of "fire."

Students were challenged to develop their own characterizations of hydrogen, with many imagining it as a person with a no-nonsense, idealistic, hardworking ethic, like a superhero or Judge Judy. Others thought of hydrogen as an animal, like bees busily making perfect hives filled with energy-rich honey, and giving a fiery sting in defense. In each case, and with each element, I encouraged them to keep testing and refining their character by adding new information, making sure it is a true representation.

### Session 2: Oxygen

Demonstration; electrolysis of water: Ignite the $H_2$ to remind students of the nature of hydrogen. Put a glowing splinter into the pure $O_2$ and see it burst into flames.

In a guided conversation, students are challenged to think "what gives life to flame?" while adding further information to build a broad-based characterization.

***Further information about oxygen***. Pure $O_2$ is used in hospitals to strengthen healing vitality in patients. Ozone ($O_3$) is highly toxic to life as it is too reactive, but it absorbs harmful solar UV radiation, protecting life. $O_2$ forms 21% of air, and was put there through plant photosynthesis that absorbs energy from the sun. Only when bound to the tiny fiery fellow hydrogen, does oxygen create a fluid medium that supports life. Oxygen makes up 89% of the mass of water. It also makes up about 46% of Earth's crust.

***Characterization of oxygen***. Highly active, supporting all combustion and life. Abundant in solid, liquid, and gas, with its highest percentage in "life-giving" water. Associated with ancient Greek "water." Many students thought of hardworking characters who often do their work behind the scenes and unnoticed. Crop-plants, such as corn, and people who are dependable and life-supporting, such as Mother Theresa, were mentioned.

### Session 3: Nitrogen

Demonstration; making black powder: Mix one-third each of carbon, sulfur, and potassium nitrate. Burn in a fume cupboard or a safe area outdoors. It burns hot and fast, so be careful.

Practical, dissolving potassium nitrate: Place an inch depth of water in a test tube and get students to feel its temperature; they should not hold the test tube where the water is, in order to avoid warming it up with their hands. Place a heaped teaspoon of potassium nitrate in the test tube and swirl. (It should cool down.)

Students discuss these observations while further information enriches their characterizations.

***Further information about nitrogen***. Many explosives, such as black powder and TNT, are nitrogen based. Nitrate and ammonium salts are almost all soluble, and readily absorb energy from the environment to dissolve, hence why the test tube got cold. An initially proposed name for nitrogen was azote, from French, meaning "not for life" (Avenas, 2021, p. 9). Nitrogen makes up 78% of the air and is mostly nonreactive in this state.

***Nature of nitrogen.*** Nitrogen will do whatever it takes to move, including risking life with explosions or sucking up energy. It is a slightly dangerous element unless it is already in "its element." Associated with the ancient Greek "air." Birds such as swallows who fly so playfully, or comedians such as Dave Chapelle who lift "heavy topics" into laughter, are common student ideas.

### Session 4: Carbon

Demonstration; sugar and acid: Half-fill a wide test tube with sugar. Pour sufficient concentrated sulfuric acid to soak the sugar. Use appropriate laboratory safety precautions. The sugar turns black and rises up and out of the test tube.

Demonstration; burning charcoal: Try igniting a single piece of charcoal with a Bunsen burner. You may get it glowing and then keep blowing to prevent it from going out. Burn a few pieces together, and they keep each other burning by sharing their heat with each other.

Practical; testing a candle flame: Students briefly put a horizontal flat piece of paper in the middle of the flame and see the carbon deposit from where the candle glows brightest.

In the discussion, draw out the sacrificial nature of carbon; to be hidden in organic matter (such as sugar and wax) and show itself only when the life ($H_2O$) has been "sucked out of it" by the acid or by flame.

***Further information about carbon.*** Carbon bonds firmly with 4 covalent "sharing of electrons" bonds. Carbon makes 10 times more compounds than all other elements combined.

Plants keep carbon out of the atmosphere, where $CO_2$ (or $CH_4$) is the way in which carbon moves before becoming absorbed into life again. $CO_2$ and $CH_4$ are both powerful greenhouse gasses. What carbon does, through the help of plants, is to capture light energy, then bind and hold it in the bonds with carbon. It is this potential (fossilized) energy that is accessible to life.

Carbon is the only solid of these bulk elements, the others are gasses. The hardest natural substance is diamond, a form of pure carbon. Another form of pure carbon is graphite, which forms slippery layers.

***Nature of carbon.*** Carbon is highly committed to bonding with itself and other elements. It is thus the anchor upon which energy-rich, plastic, living bodies build themselves. Associated with ancient Greek "earth." Here students thought of fertile soils or characters who are steady, earnest, and melancholic, such as Nelson Mandela.

## ○ Application

Heuristic characterizations are never right or wrong, they are only helpful or unhelpful for our understanding and intuitions of reality. I encouraged the students to use and develop their characterizations further as we studied organic compounds, using some of the thoughts that follow. Carbohydrates are solid (carbon) and are rich in energy (hydrogen) and health giving (oxygen). Alcohols are formed by the fermenting of carbohydrates where carbon dioxide is given off, so the loss of carbon (solid) and oxygen (life) make alcohols more energy rich, less solid, and less healthy. This is similarly true for the larger fat molecules who have now lost their (dissolving) relationship to water. Proteins are large molecules that also contain nitrogen (air or movement). Heuristically, this can be associated with animal bodies, which are protein based and move freely. Plant seeds, which are free to move to new locations, are rich in protein. Many hallucinogens and plant poisons are denatured proteins.

When students successfully apply their heuristic characterizations in new situations, they strengthen their self-belief to develop rich and valid heuristics in their biology studies (McClary & Talanquer, 2011).

## ○ Parting Thought

Almost all Nobel Laureates in the sciences prior to 2010 were engaged in the arts in some form, and many claim that this stimulation supported them in their scientific work (Root-Bernstein, 2011). This reflects how science at the highest level is enriched through training our intuitive and creative faculties. Let this help to persuade us of the enormous potential for students to heuristically “bond” with the content that we teach.

Wishing you fun and many scientifically meaningful heuristic intuitions.

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ABT AUTHORS & PHOTOGRAPHERS

# Guidelines

We encourage our readers, biologists with teaching interests, and biology educators in general, to write for *The American Biology Teacher.* This peer-reviewed journal includes articles for practitioners at every level, with a special focus on high school and post-secondary biology instruction.

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## Article Categories

A note about article word count: Please recognize that tables, figures, and photographs add to the overall length of the article. One page of text has approximately 1,000 words, therefore a 1/4-page graphic will count for 250 words. More extensive graphics should be budgeted accordingly. References are also included in the final article word count.

**Feature Article** (up to 4,500 words) includes topics of general interest to readers of *ABT*. Consider the following examples of content that would be suitable for the feature article category:

- Research on teaching alternatives, including evaluation of a new method, cooperative learning, concept maps, learning contracts, investigative experiences, educational technology, simulations and games, and biology and life science education standards
- Social and ethical implications of biology and how to teach such issues as genetic modification, energy production, agriculture, climate change, health care, nutrition, and cultural responsiveness
- Reviews and updates of recent advances in the life sciences in the form of an "Instant Update" that brings readers up-to-date in a specific area
- Imaginative views of the future of biology education and suggestions for adjusting to changes in schools, classrooms, and student populations
- Other timely, relevant, and interesting content such as discussions of the role of the Next Generation Science Standards in biology teaching, considerations of the nature of science with implications for the classroom, considerations of the continuum of biology instruction from K–12 to post-secondary teaching environments, or contributions that consider the likely/ideal future of science and biology instruction

**Research on Learning** (up to 5,000 words) includes reports of original research on innovative teaching strategies, learning methods, or curriculum comparisons. Studies should be based on sound research questions, hypotheses, discussion of appropriate design and procedures, data and analysis, discussion on study limitations, and recommendations for improved learning outcomes.

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**Tips, Tricks and Techniques** (up to 1,700 words but may be much shorter) features a range of suggestions useful for teachers including laboratory, field, and classroom activities; motivational strategies to assist students in learning specific concepts; modifications of traditional activities; new ways to prepare some aspect of laboratory instruction; etc.

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The *APA Style (current edition)* is the guide for questions of punctuation, abbreviation, and style. List all references in alphabetical order on a separate page at the end of the manuscript. Use first person and a friendly tone whenever appropriate. Use concise words to emphasize your point rather than capitalization, underlining, italics, or boldface. Use the SI (metric) system for all weights and measures.

Themed issues of the ABT traditionally occur in February (Evolution) and April (Ecology).

## Preparing Tables, Figures, and Photographs

### General Requirements

- When your article is accepted, we will require that figures be submitted as individual figure files in higher resolution format. See below for file format and resolution requirements.
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- Minimum resolution of 300 DPI, 600 DPI is preferred
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### Tables and Figures

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**If you have any questions, contact Valerie Haff at managingeditor@nabt.org.**

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ABT AUTHORS & PHOTOGRAPHERS **Guidelines**

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- Authors will be asked to register the first time they enter the site. Upon receiving a password, authors can proceed to upload their manuscripts through a step-by-step process. Assistance is available using the "Help" button found on the bottom right corner of most pages. Additional assistance is available from the Managing Editor (managingeditor@nabt.org).
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- Format manuscripts for 8.5 × 11-inch paper, 12-point font, double-spaced throughout, including tables, figure legends, and references.
- Please place figures (including photos) and tables where they are first cited in the text along with appropriate labels. Make sure to include figure and table citations in the text, as it is not always obvious where they should be placed. At the time of initial submission, figures, tables and images should be low resolution so that the final file size remains manageable.
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In order to maintain the word count for individual articles, we are pleased to facilitate publication of supplemental materials accompanying the online issue. If authors have materials (figures, examples, worksheets, appendices, multimedia files, etc.) that support but are not essential to the printed text of the article, authors can include those as separate files with their article submission.

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