SCIENCE, ART, AND AESTHETICS: AN INTERDISCIPLINARY APPROACH TO ABSTRACT REASONING

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Abstract

Scientists and artists share methodologies that are common to both practices. From a behavioral perspective, both scientists and artists utilize observation, contemplation, reflection, and serious play to interpret abstract environmental signals. Abstractions are interpreted through an aesthetic, an algorithm for problem solving, which is the basis for scientific and artistic modeling. Models vary in their presentation, comprising works of art, formulas, theories, or diagrams but all of them have one thing in common: they communicate abstract ideas. In an interdisciplinary approach to teaching undergraduate science, students mimic the behaviors of scientists and artists to engage in complex biological problems. As students observe, contemplate, reflect, and play they visualize and make sense of abstractions that represent cellular, molecular, and evolutionary biology. By reflecting on their own practice of model-building, students achieve an enhanced understanding of their personal aesthetic, the tool they use for problem solving, which is key to abstract reasoning and critical thinking.

Keywords: Abstraction, Aesthetics, Metacognition, Modeling, Visualization

Introduction

In this paper I discuss the role of aesthetics as a tool for scientific inquiry and abstract reasoning in the context of undergraduate education. Interpreting or “making sense” of external (environmental) abstract signals is a primary goal of learning at all stages of cognitive development. It is a challenge undergraduates face when trying to interpret seemingly abstract science concepts. Learning about *how* we make sense of things is metacognition, an advanced cognitive behavior that is key to critical thinking (Kuhn, 1999), which is the goal of higher education. In the arts as well as the sciences, the “finished product,” whether a painting, a piece of music, a formula, or a diagram represents a unique quantum of interpretation that makes sense of external abstract signals. The complex of decisions, activities, and processes that comprise an aesthetic can be considered as the bridge that links the abstract world we sense with the ordered world that we articulate. Instead of being discipline-specific we can consider this complex of behaviors as a critical methodology (see Yanchar et al., 2005), a problem solving framework that transcends disciplines. In this way, an aesthetic framework can be seen as truly interdiciplinary or transdiciplinary. Where a setting (social or physical) or a set (objects or concepts) is unfamiliar we use an aesthetic to come to grips with it. If we accept “problem-solving algorithm“ as one definition of “aesthetic” we can say that scientists use an aesthetic to bring order to a disordered array (for example a group of specimens, an unidentified genetic sequence, or an undefined protein). Similarly artists use an aesthetic to transform paint in tubes into an image on canvas, a lump of clay into sculpture, or a set of notes into a sonata. The product of scientific or artistic work represents, at some level, a problem solved. It can be described as “elegant“ or “aesthetically pleasing” because it communicates effectively (see Dirac, 1963). The product is further interpreted through the aesthetic of "end-users." As museum-goers, music listeners, or textbook readers, we utilize our own aesthetic to come to understand the problem that was solved by the artist, musician, or scientist. Problem solving for them and for us is achieved through observation, contemplation, reflection, and play, innate human behaviors that can be encouraged through training and experience (see Hart, 2004). If these behaviors can be strengthened then it follows that we can encourage them through activities in an academic environment. I have designed and implemented my S.T.E.A.M. laboratories (science classes that incorporate art and aesthetics) at Boston University to include these activities in order to enhance science education in an aesthetic framework.

Grappling with Abstraction

Students enter science classes bombarded by an array of terms, concepts, and models that seem to have little connection with real life. The seeming lack of connection to life is ironic because problems such as the composition of Earth's atmosphere, the activities of a mitochondrion, and the structure of the phospholipid bilayer membrane are vitally important to life processes. Yet these problems seem irrelevant to undergraduates seeking a degree in non-science disciplines such as communications or finance. How can we address this disconnect? Part of the problem is that the abstract "forest" of terminologies, diagrams, and concepts seems remote from the articulated "tree" of biological function. Students appear to lack the tools by which to connect abstract facts to concrete functions, but that is only part of the story. Students are in fact well equipped to make sense of abstract scientific concepts because they make sense of abstract signals in every encounter with the world around them. They already possess an aesthetic, an algorithm for problem solving, that they use in all of their interactions with the external environment. But students behave differently, with a different set of motivations in the "real world" than they do in the science classroom. The abstract signals that they gather from lecture, textbooks, and laboratory are meaningless because they are perceived as something to be memorized, not interpreted. The result is that many students, usually well before they enter university, are disenchanted with, and disinterested in science.

Students have been taught to memorize and regurgitate science facts instead of interpreting them. Part of the problem lies in the so-called "scientific method," the set hypothetico-deductive behaviors that they think is the only accepted mode of scientific problem solving. Girod et al. (2010) refer to this as the "cognitive, rational" framework. As scientists we understand that the beauty of the natural world lies in interpretation. We have been trained or are psychologically disposed to constructing a framework for interpretation, something that we can term an "aesthetic." Whether or not we employ hypothetico-deductive reasoning, we engage in the natural world through a suite of behaviors that comprise an aesthetic, including contemplative observation, reflection, and play.

Can we provide students with a similar framework? How can we invest them with tools for interpreting the abstractions of science? How can we help them build an aesthetic to complement the cognitive-rational demands of rigorous scientific inquiry? The philosopher and educator John Dewey (1934) discussed the role of aesthetics as a tool for understanding and provided a framework for an interdisciplinary approach. He described the aesthetic as "the clarified and intensified development of traits that belong to every normally complete experience." He went further to describe the aesthetic sense as inherently connected with the experience of making. If aesthetic is connected to experience and to making things then we might be able to mimic the behaviors that comprise such experience. In student laboratories we are accustomed to reproducing, cookbook-style, the experimental steps that led to scientific discoveries. What if we reproduce the *behaviors* conducive to discovery instead?

Constructing a System of Observation

I teach a required four-credit course in the Origin and Evolution of life to non-major students during the fall semester each year. There are two lectures and one lab session each week. I teach four lab sections that cover the class of 80-100 students. I divide the weeks of course content roughly into three parts; Origins, Interpretations, and Functions. The labs I designed for the course follow a similar pattern based on integrated conceptual and cognitive growth during the semester; Observation, Reflection, and Play.

For the first series of laboratory experiences I designed exercises that allow students to make a gentle landing into the semester. My laboratory exercises are similar to the work students do in their rhetoric classes. In a sense, we are establishing a "rhetoric" of science in the first several weeks. Students choose and describe images, explaining which images appeal to them and why, repeating the exercise several times. They "take apart" complex phenomena, looking below the surface, considering and writing about issues such as "complexity" vs. "simplicity," "surface" vs. "depth, " and "subjective" vs. "objective. " In these exercises students are challenged to think about how they reach their conclusions. They are asked to analyze what lies beneath their opinions. One week they are asked to design their own "twitter" logos and explain their relevance. Another week students find google images of floral parts and conduct a dissection with real flowers based on those idealized images. Another week they sketch and discuss primate skulls. In the first weeks of laboratory we grapple with ideas as far-flung as paleolithic tools, modern art, Renaissance literature, *horror vacuii*, typology, beauty, and botany. Students work individually for most of these labs. All of the lab work is aimed to develop an aesthetic, a set of problem-solving behaviors that link art and science. All of the work in lab is performed to complement a set of lectures on the origin of life, in which we establish the factual basis for biogeochemistry, cell biology, and molecular evolution, topics that we will address during the rest of the semester. Significantly, the laboratories of the first several weeks are intended to increase students' awareness of their modes of observation and to incorporate contemplative behaviors as they move toward more reflective practices.

Practicing Reflection

After establishing a framework for observation in lab I refine the focus to include reflection. My goal is to introduce tools for "close reading" of abstract signals in the external environment. At this point in the semester the lectures have begun to focus on molecular function and evolution. For example, we have studied the structure and properties of water and proteins from an analytical standpoint: polarity, hydrogen bonds, cohesion/adhesion, etc. Laboratory provides the opportunity to change the scale of inquiry. At this point in the semester, conventional cookbook laboratories might provide an appropriate fit. In past years for example, we focused labs on enzyme kinetics in an oxidation experiement. But I want my students to function outside of cognitive-rational constraints. At this point in the semester I want them to begin playing. I begin this laboratory unit with students observing their play at the same time as they observe the behaviors of water. For this lab they are provided with basic materials; water, salt, clay, string, and sponges. Students work individually or in pairs. They are asked to choose any of the materials in front of them and to manipulate water in any way they see fit. As they observe carefully the behavior of water they note these things down: How does the water change in relation to the material they are using? How does water respond to the material? What does the water do to the material? Students are asked to take detailed notes, photos, and videos on the behavior of water that they observe.

After students have "played" with the water, they are asked to list at least 10 sentences that "take apart" the observations they have made. They are asked to write a detailed description of how the water behaved in the "experiment" they set up. How did the water move? How have their manipulations changed the behavior of the water? How is the water influencing its environment? How many and what kinds of water behavior are going on in the experiment? How many and what kinds of water behavior are occurring at each lab table?

As the final deliverable students are asked refer to lecture notes where we discussed the characteristics of water. Using the properties we discussed in lecture students write a short paragraph, which discusses how the water they observed behaved according to these known scientific characteristics. For example, did they observe surface tension? How? How did it manifest itself? Cohesion? Adhesion? Solvent properties? In this exercise they are taking their own observations and building a scientific narrative from them. They are operating at a different level than the strictly cognitive-rational but they are incorporating the cognitive-rational into their narrative. There is no predicted or “ideal” outcome to this lab experience. Students are using their aesthetic and deciphering the natural world from a personal perspective. The “model” they build is the narrative they produce, which is based on abstract reasoning. As students develop their skills in focused abstract reasoning they are also developing metacognitive skills that help them observe and analyze their own process of learning.

Playing and Modeling

During the third series of labs students play with zometool building materials to make outsize molecules and molecular structures. The zometools resemble traditional molecular modeling sets, and can be arranged in millions of different combinations. This is the point of the semester where, in lecture, we discuss the evolution of biochemistry and metabolic systems from a functional and evolutionary (rather than definitional) perspective. Serious play for these exercises occurs as group work. Students are free to design their own molecules, modeling approximate molecular structures that are based on function and form rather than chemical formulas. One week students are asked to explore the concept of permeability from a non-cellular perspective, considering permeability as a function of color, sound, and texture. After students have read and responded to an exploratory text they then build models of phospholipid bilayer membranes based on their notes from lecture (the cognitive-rational part of the course), and from images they find on the internet. Not surprisingly, because the images they copied from lecture are one-dimensional, students start by making one-dimensional models, using the lab table as a blank surface. They interpret literally the phospholipids but arranging them into a roughly planar structure, the way scientists visualize them, is a conceptual leap. Another challenge comes with visualizing and embedding the proteins in the phospholipid bilayer. Because we have not yet studied proteins, and because they are generally depicted as linear figures (polypeptide chains), students generally do not depict them as objects with volume. Constructing a model of a working cell membrane takes hours of experimental play. It is a challenge for the students just as it was for decades of scientists who grappled with this problem. By building 3-dimensional structures students begin to visualize cellular components such as membranes, and through this work they are able to comprehend the functionality of biological membranes as semi-permeable structures with a wide variety of functions.

The following week students build gigantic models of enzymes and their target (substrate) molecules. There are three rules: 1) The structures have to be as large as a person, 2) The enzyme must be at least 10 times the size of the substrate, and 3) There must be an active site where “lock and key” functionality can occur. Students are asked in addition to consider questions of linearity, volume, folding, surface conformation, and electrostatic interactions when preparing their models. The proteins that students build, because they are so large, are actually flexible and can be modeled to mimic the behavior of enzymes by attaching to and altering their substrate.

Conclusion

The abstract signals that we apprehend from the natural world are interpreted through an aesthetic, an algorithm for problem solving. Behaviors that engender aesthetics, for example contemplative observation, reflection, and serious play, can be encouraged in the classroom setting. Making the irrational (abstract) world into a coherent narrative is the goal. Conventional rational-cognitive science is a "mode of reason that is still incomplete" (see Caillois, 2003). But by complementing the rationalities of science with the interpretive power of aesthetics we can make natural phenomena accessible and understandable to non-scientists. Introducing an aesthetic approach to science learning met with enthusiasm among my second-year undergraduates, all of whom are non-science majors. Students reported the success of the experience through their reflections, for example,"it takes a lot of creativity to explore the world and discover" and "A lot of creativity and innovation goes into science." For the first time in over 20 years of teaching I experienced 100% attendance throughout the semester, and engagement for the entire lab session, outcomes that were never possible in past years. Changing the nature of lab experiences was a risk (see Hammer, 2012) but one that rewarded both me and my students.

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