WHAT AND WHO INSPIRED ME TO BECOME A SCIENTIST AND FURTHER A SCIENCE EDUCATOR?

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We Were Playing with the Natural Phenomena

... I was a child who loved to play. These games were improvised. In the sea, in the mountains, in the hills, among the fields that surrounded the town. ... Games with a lot of imagination. Some of which I have put in my writings. And that have shaped my entire frame of mind.
We were playing with the natural phenomena. When it was very windy, the wind was turning into a game for us. When there was a storm again, we took advantage of it to play. When it was completely calm, it was a game again because that allowed us to go into the sea, whether it was summer or winter, and search the seabed.
Iakovos Kampanellis,
TA NEA, Athens Daily National Greek Newspaper, column: Persons, p. 11, 31 Dec 1999.

Introduction

According to Alex H. Johnstone, "most of the concepts we develop in everyday living (such as cars, trees, houses, dogs, and flowers) are based on tangible things; things we can touch, see, smell and taste. … However, concepts such as element, enzyme, atom, gas, resistance, molarity, entropy, and many others cannot be constructed directly by our senses. Some are one or even two steps removed from direct sensory perception" (Johnstone, 2007, p. 8).

The famous Johnstone triangle for the physical sciences (Johnstone, 1982 – see Figure 1) has at one of its corners tangible things, constituting the "Macroscopic" or "Macro Level". The two other levels that facilitate further understanding are the "Symbolic and Mathematical Level", which involves symbols, mathematical and chemical equations, as well as graphs and calculations, and the "Submicroscopic" or "Submicro Level", which refers to entities such as atoms and molecules, that are so tiny that we cannot observe them either directly or even with the help of a strong microscope; these entitles are objects of thought and we draw conclusions about them through logical thinking and inferences. The emphasis among the three levels varies between the physical sciences (physics and chemistry).

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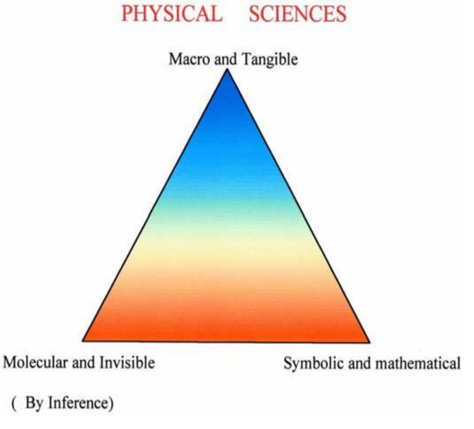
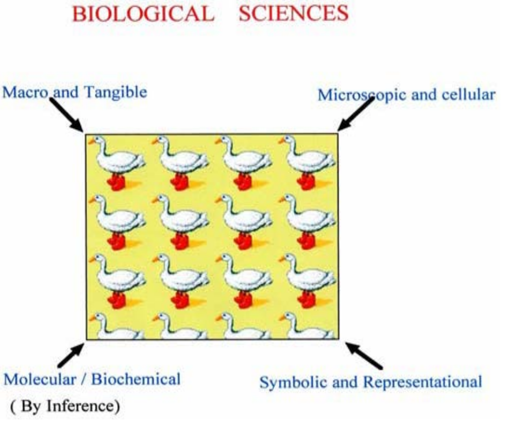
Figure 1
The Johnstone Triangle Depicting the Three Levels of Teaching and Learning Physical Sciences (Physics and Chemistry) (Johnstone, 2007)



For the biological sciences, a fourth level, the "Microscopic Level", is added. We are still able to directly observe this level with our own senses, but only with the aid of a microscope (see Figure 2). Note that the submicro level includes *bio-molecules*, which cannot be directly observed and for which our understanding continues to depend on deductions from indirect measurements.

Because of training, experience, and deep knowledge, scientists and teachers can jump from level to level as they deal with the ideas they are trying to communicate or teach. However, learners initially cannot do this. Therefore, if a teacher employs all levels simultaneously too early, this is likely to overload the pupils' working-memory space and result in poor learning. To avoid this overload, Johnstone recommended that we should stay with the macro level until pupils have formed new concepts before attempting to introduce "explanations" based on submicro aspects. Experiences that treat tangible entities, for instance by doing laboratory experiments, are useful and possibly essential throughout science education. In conclusion, the following are the main outcomes from education research (Johnstone, 2007, p. 10):

Figure 2
The Johnstone Rectangle Depicting the Four Levels of Teaching and Learning Biological Sciences (Johnstone, 2007)



- What we learn is controlled by what we already know.
- Learners can process only a limited amount of information at one time.
- Science concepts exist on more than one intellectual level.
- Many scientific concepts are of a different kind from everyday concepts.
- Learners need to start with concepts built from tangible experience and developed later to include inferred concepts.

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Color in Chemistry

Personally, I was very much attracted by the color of tangible things. As a little boy, I used to collect bus tickets that came in various colors: red, yellow, green, blue, and pink. I was also impressed and liked to look through the little bottles of "Pelican" transparent drawing ink, which again came in the various colors that I used for coloring my drawings. I had no idea about the connection of color with chemistry at that time, but that attraction and interest in color was later to determine my future career.

The Mathematics Side of Chemistry

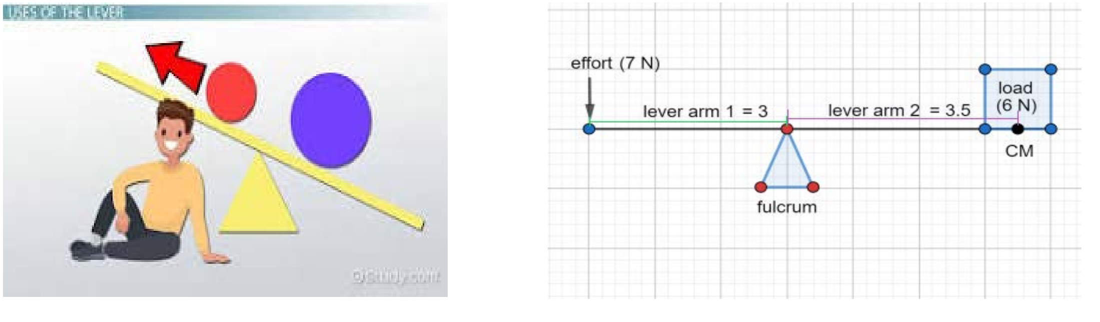
My initial contact with real science came in the 5th and 6th grades when a course on "Experimental Physics and Chemistry" was part of the curriculum. I was first enthralled by the topic of levers, especially their mathematics side. Using analogies, one could explain and predict phenomena, and this became an enthusiastic pastime (see Figure 3). Then came surface tension. Using a metallic ring, a detergent solution, and a piece of thread, one can place a loop of thread on top of a detergent solution to form an irregular shape. On puncturing the detergent film inside the loop with a pin, the thread was seen to push outwards to form a *circle*. What is important here about surface tension is that for any given perimeter, the circle is the figure with the maximum area (see Figure 4).

Moving on to the 7th grade, the school lessons on "Experimental Physics and Chemistry" led me, with the aid of a schoolmate, to attempt a dangerous experiment (because of ignorance). We unsuccessfully tried to inflate a balloon with hydrogen gas produced by reacting sulfuric acid solution with iron nails or slices of zinc metal. The mathematical side of chemistry continued to attract me in the 10th grade, when I focused on the study of chemical reactions, especially on predicting the products (given the reactants) and writing the corresponding balanced chemical equations. The colors of chemistry re-emerged in the 11th grade when I reacted an aqueous solution of copper sulfate with an aqueous ammonia solution, forming at first a white precipitate of $Cu(OH)_2$, which subsequently dissolved on adding more ammonia solution to form a soluble deep blue copper/ammonia complex ion.[1]

Higher Mathematics in Chemistry

During my first year at university, I was particularly interested in the mathematics course, so I rushed to the university library searching for books dealing with mathematics in chemistry. I found satisfaction in a physical chemistry text (written by a Greek physical chemistry professor) focusing on the traditional parts of physical chemistry (thermodynamics, kinetics, and electrochemistry). What resolved my personal "existential" problem and made me much happier about continuing to study chemistry, was the occurrence in the book of numerous mathematical equations involving derivatives, partial derivatives, and integrals. I really became enticed and enthusiastic.

Figure 3
*Applying the Law of Levers**



* https://study.com/academy/lesson/law-of-the-lever-definition-formula-examples.html

1 The coordination chemistry of divalent copper in aqueous ammonia is quite complex. In aqueous solution, divalent copper exists as the hexacoordinated species $[Cu(H_2O)_6]^{2+}$. This is not octahedral but is tetragonally distorted due to the Jahn-Teller effect. When ammonia is added to the mix, it rapidly starts to replace water molecules in the coordination sphere of the copper. However, after the first four water molecules have been replaced, the free energy change for the introduction of a fifth ammonia turns out to be slightly positive. So it is believed that the species giving the deep blue color is $[Cu(NH_3)_4(H_2O)_2]^{2+}$.

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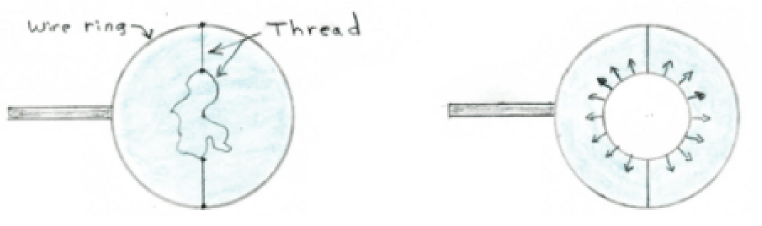
Figure 4
*Experiment for Surface Tension with a Detergent Solution***



(a) Wire ring dipped in detergent solution. (b) Wire ring after puncturing detergent film inside the loop.

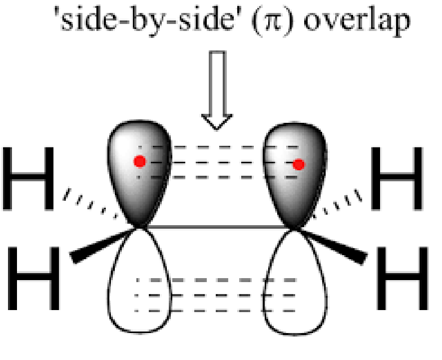
** Surface tension. SolitaryRoad.com Website owner: James Miller https://solitaryroad.com/c1022.html

The Submicroscopic Level

When I first encountered atomic and molecular structure in my 10th grade, I was not particularly interested in it. This is in contrast, for instance, with Professor Dimitri V. Nanopoulos, a Greek theoretical physicist, who, according to Wikipedia is one of the most regularly cited researchers in the world. In an interview with a Greek national newspaper, asked about which was his favorite course, Nanopoulos answered "chemistry", and then asked about which chemical element he liked most, he answered "I did not like chemical elements" (meaning apparently descriptive inorganic chemistry), "but I liked the introduction to chemistry, which included the study of atoms and molecules". However, in his opinion, this was actually physics.

My interest in atoms and molecules really started in my first year at university, when I was taught about atomic and molecular orbitals in the inorganic chemistry course. At this point, however, I would like to mention an issue that puzzled me in the inorganic course: it was "side-by-side" π overlap, which in the course book was modeled by *dashed lines* (see Figure 5). These dashed lines continued to be a mystery for me until the quantum chemistry course in my third university year.

Figure 5
*"Side-By-Side" π Overlap, Indicated by the Dashed Lines****



*** https://www.toppr.com/ask/content/concept/sigma-and-pi-bonds-203460/

By the time I was in the final (fourth) year of my undergraduate course, quantum chemistry had become my favorite topic, so it is no surprise that in my graduate studies, I followed spectroscopy and theoretical chemistry, and my research projects were on quantum mechanics. Note the connection of spectroscopy with color. Note also that the mathematics of quantum mechanics is *esoteric* to it: "Mathematics is now so central, so much 'inside' that without it cannot hope to understand our chemistry. … These [quantum-chemical] concepts have their origin in the bringing together of mathematics and chemistry" (Coulson, 1974, p. 17).

The previous information answers the first question of this editorial (*What inspired me to become a scientist?).*

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Turning and Moving on to Science Education

Throughout my academic career, a dominant influence on my commitment to chemistry education has come through my reading of the *Journal of Chemical Education*. This journal, since its launch in 1924, has established itself as a useful tool for chemistry teachers both in the U.S. and worldwide. The journal offers a very commendable range of articles presenting views, ideas, positions and suggestions about courses, content, and teaching practices at all levels of education. Such articles can support a rich *pedagogical content knowledge* (PCK).

The origins of chemistry education research go back to the 1970s. I consider the Americans J. Dudley Herron and Dorothy L. Gabel and the Briton Alex H. Johnstone as the originators of the field. Herron was the first who attracted my interest through the application of cognitive science, especially Piaget's theory of intellectual development, to teaching chemistry (Herron, 1975, 1978). Johnstone was the second great influence on me, leading to my spending a sabbatical semester with him in his Centre for Science Education at the University of Glasgow, Scotland, in 1990. I referred to Johnstone's triangle at the beginning of this editorial. For Johnstone, if young students are to catch our enthusiasm about our subject, a harmonization of a logical approach to chemistry with a psychological one will be necessary and this can be provided through education research (Johnstone, 2000). Johnstone's great work on problem solving was another main attraction in my education research (see, for instance: Johnstone, 1984, 1993; Johnstone and H. El-Banna, 1986, 1989; Tsaparlis, 2021a, 2021b).

In a vignette published in the ACS magazine "*Chemical & Engineering News*", on the occasion of the 2024 ACS National Award winners (in which I was the winner of the "*Award for Achievement in Research for the Teaching and Learning of Chemistry*"), I was asked about my favorite educational project and I answered:[2] "My background in theoretical chemistry stimulated a line of research on how learning theories could inform the teaching and learning of atomic and molecular structure (Tsaparlis, 1997a). This work led to investigations on the basic concepts of quantum mechanics and was followed by work on facilitating conceptual change and a phenomenographic study of students' explanations, models, and misconceptions.[3] The project was extended, more recently, to new pedagogies for teaching and learning chemical bonding, including the use of electrostatic potential maps."[4] [5] My education work in quantum chemistry culminated in the co-editing with Hannah Sevian of a Springer volume (Tsaparlis and Sevian, 2013), which followed an international seminar I organized in Athens in 2010. The book title is "Concepts of Matter in Science Education", while "Learning and Teaching the basic quantum chemical concepts" is the title of my chapter in that book.

Epilogue: Chemistry is a keystone science

Chemistry is central among the science disciplines that have provided us with a theoretical explanation of how nature works. Together with other disciplines, it has increased the quality and availability of new materials, safe and healthy food, drugs and vaccines, efficient and environmentally safe energy transformations, thus contributing to the sustainability of our planet (Tsaparlis, 2021c). The themes of recent Nobel Prizes in Chemistry show its rich theoretical basis and applications:

2023 "for the discovery and synthesis of quantum dots"
2022 "for the development of click chemistry and biorthogonal chemistry"
2021 "for the development of asymmetric organocatalysis"
2020: "for the development of a method for genome editing"
2019: "for the development of lithium-ion batteries"
2018: "for the directed evolution of enzymes" and "for the phage display of peptides and antibodies"
2017: "for developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution".
2016: "for the design and synthesis of molecular machines"
2015: "for mechanistic studies of DNA repair".

2 Chem. & Eng. News, Volume 102, Issue 1, 5 Janauary 2024
https://cen.acs.org/people/awards/2024-ACS-National-Award-winners-Part-I/102/i1
3 Relevant references: Stefani & Tsaparlis, 2009 ; Tsaparlis, 1997b; Tsaparlis & Papaphotis, 2009.
4 Relevant references: Tsaparlis et al., 2018, 2020.
5 Relevant reference: Tsaparlis et al., 2021.

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Concerning the 2017 prize, I should add that cryo-electron microscopy was used for determining the structure of SARS-CoV-2, the virus that causes COVID-19. Scientists at the University of Texas at Austin had previously studied several coronaviruses and appreciated that determining the structure of the COVID-19 virus was the first very important step towards designing an effective vaccine. The whole work of determining the structure took just twenty days! (Pool, 2020). I would also like to make reference to the 1993 Nobel Prize in Chemistry: "for contributions to the developments of methods within DNA-based chemistry". One half of the prize went "for the invention of the polymerase chain reaction (PCR) method", with one of its applications being the preparation of the most important test (the "molecular test") for detecting the COVID-19 virus.

Synthetic chemistry is science and art of creation

Kyriacos C. Nicolaou, a Cypriot-American organic chemist is considered as the composer of molecules – the creator of taxol and one of the leaders of chemistry. The following is an excerpt from a newspaper interview with Nicolaou:[6]

> "*At the age of 13, I left my village to go to a "good school" in Nicosia, Cyprus, the Pancyprian High School (Pancyprian Gymnasium). There, I was fascinated by my teacher's chemistry, and I started studies for a chemistry degree in England."*
> *"From a drawing on paper or on the computer the chemist can arrive at the synthesis in his lab of a molecule that may be of great value to the pharmaceutical, cosmetics or any other area. Anything that comes to mind from the goods around us, from medicines, fertilizers, plastics, and airplanes, like cell phones and clothes, has to do with synthetic chemistry's achievement to convert matter."*
> *"Chemists have another view of the world, a view that bridges the macrocosm with the microcosm. And if they use their "laboratory microscope", they can play with one structure and synthesize something else from it."*
> *"Playing with the microscope and computers is something I see as common ground for scientists. ... We have now computational physics, computational chemistry, computational biology"."*

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6 Interview by Tasos Kafantaris in VIMA Sunday National Greek Newspaper/section: Science, Sunday 5-2-2012.

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