How to Introduce ChE Concepts to non-STEM University Students

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draft 24

In a recent www.teacherspayteachers.com (TpT) eBook, I described how to introduce chemical-engineering concepts to K-12 students. The section headings were as follows [1]:

- **Introduction**
- **Who? Can Grade-Level 6-to-8 students succeed at learning how to use ChemSketch?**
- **How? Three Spiral Curricula**
- ***Stories of the Invisible,* by Philip Ball**
- ***Molecules*, by Peter Atkins**
- **Who? Answer: Educators**
- **Why? Answer: STEM**
- **How? Answer: Spiral Curriculum**
- **Where? Publish in CAChE News and also at www.teacherspayteachers.com (TpT)**
- **References**

I encourage you to visit TpT and download the PDF document that encourages science teachers to download the free, chemsk2015.exe molecular-modeling software and install it on their classroom computers [2-3]. Two other, free, TpT downloads are given in references [4 – 5].

Stories of the Invisible, by Philip Ball [6]

A favorite chemistry book is ***Stories of the Invisible***, by Philip Ball. [6] The book description is:

> *"**Molecules, Philip Ball writes, are the smallest units of meaning in chemistry.** And through these words, scientists have uncovered many fascinating stories of the physical world. In Stories of the Invisible, Ball has compiled a cornucopia of tales spun by these intriguing, invisible words. The book takes us on a tour of a world few of us knew existed. The author describes the remarkable molecular structure of spider's silk – a material that is, pound for pound, much stronger than steel – and shows how the Kevlar fibers in bulletproof vests were invented by imitating the alignment of molecules found in the spider's amazing thread. We also learn about the protein molecules that create movement, without which bacteria would be immobile, cells could not divide, there would be no reproduction and therefore no life. Today we can **invent molecules** that can cure viral infections, store information, or help hold bridges together. But more importantly, Ball provides a fresh perspective on the future of molecular science, revealing how researchers are promising **to reinvent chemistry** as the central creative science of the 21st century".*

A Different Paradigm?

"***the basic unit of chemistry is the molecule and if atoms are letters, then molecules are words.***" [6]

During 2013, I asked myself: could a 2nd-year chemical-engineering (ChE) course be taught that is based upon this principle? I concluded that there was something wrong with how introductory chemistry was taught, and that this "something" had persisted for more than five decades. Could a new course (which would be based upon a different paradigm, namely, molecules) in a department of chemical engineering (ChE) provide an opportunity for non-STEM university students? Such an elective course would be called "enrichment chemistry".

"Enrichment chemistry" would NOT be an alternative to the required, introductory -chemistry course at a university. Instead, it would become a second-year supplement to the introductory course, and it would be available to sophomore, junior, and senior students in any discipline, and in any college. Also, it would become available as an elective course for AP students who opted out of the freshman-chemistry course.

Chemical-engineering educators have a significant advantage; unlike chemistry educators, ChE faculty need not defend the curriculum, content, textbooks, and dogma of existing introductory-chemistry courses.

ChE educators could teach "enrichment chemistry", which could introduce some principles of chemical engineering. My preferred approach would be a collaboration between chemistry and chemical engineering faculty.

It is well known that chemical engineering undergraduates take several chemistry courses – e.g., organic chemistry, physical chemistry, physical chemistry lab, and perhaps polymer chemistry. No reciprocity exists. Based upon my 31 years of teaching ChE at Virginia Tech, I observed that chemistry majors did not take any chemical engineering course.

How do we proceed?

Let us go back to

“***the basic unit of chemistry is the molecule and if atoms are letters, then molecules are words.***” [6]

I characterize this statement by the phrase, “Molecular Identity”. Millions of molecules exist, but the most interesting ones are those that appear within, or interact with, biological systems. Example groups of molecules are vitamins, antioxidants, aromas, phytochemicals, poisons, pesticides, environmental pollutants, medications, and so forth.

Ok, so what is next? Speaking from my viewpoint as a chemical engineer, I offer “Molecular Location” as the next logical question. For a selected molecule in nature, where is it located? Is it dissolved in water, adsorbed within a soil particle, or present in a biological cell?

Within a biological cell, where is a drug molecule located? Is it bound to a cell receptor, dissolved in the cellular liquid, bound at the active site of an enzyme, or permeating through a channel in a cellular membrane?

Having identified a specific molecule and the locations at which it is present, the third question is “Molecular Amount”. An example: For DDT in the environment, the amount of DDT in water, zooplankton, small fish, large fish, and fish-eating birds needs to be measured, or else, estimated (Figure 1).

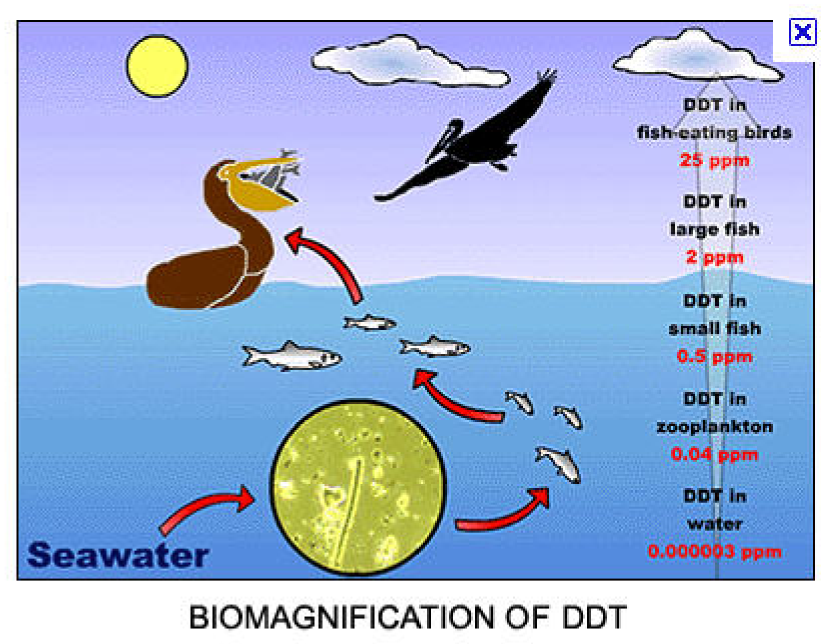


Figure 1. The biomagnification of DDT.

We now know the identity of a specific molecule, its various locations, and its amounts in these locations. What is next? The next question is, what is the molecule doing in each of its locations? The answer is "Molecular Rate Processes".

It is surprising that rate processes such as diffusion and convection are never mentioned in introductory chemistry, biochemistry, and biology textbooks. Apparently, molecules move from one location to another . . . by Harry-Potter-type magic.

Please bear with me here, because chemists and biochemists will read this manuscript.

On a university campus, most disciplines completely ignore the question of how a selected molecule is transported from here to there.

“Here” could be the headwaters of the Mississippi river, and “there” could be the Louisiana delta. As a second example, “here” could be the Sahara Desert in Africa, and “there” could be the Venezuela and Brazil coasts in South America.   Atlantic trade winds carry the airborne grains of Sahara sand westward, and they deposit on these two countries. This process has occurred for millions of years.

Within a biological cell, “here” could be outside of the cellular membrane, and “there” could be within the cell.

Outside of biological cells, the dominant form of molecular transport is called “convection”, which applies to moving water, moving air, and moving solids. Large-scale, industrial-chemical systems employ pumps to move fluids through pipes from one piece of equipment to another. Within the body, molecules are transported by convection via blood, lymph, and breathing.

Pumps and flows do not exist within biological cells, where molecular transport occurs via “diffusion”.

There you have it. For large distances, molecules are transported via convection, and for very small distances, molecules are transported via diffusion.

The sequence of four questions is summarized in Figure 2.

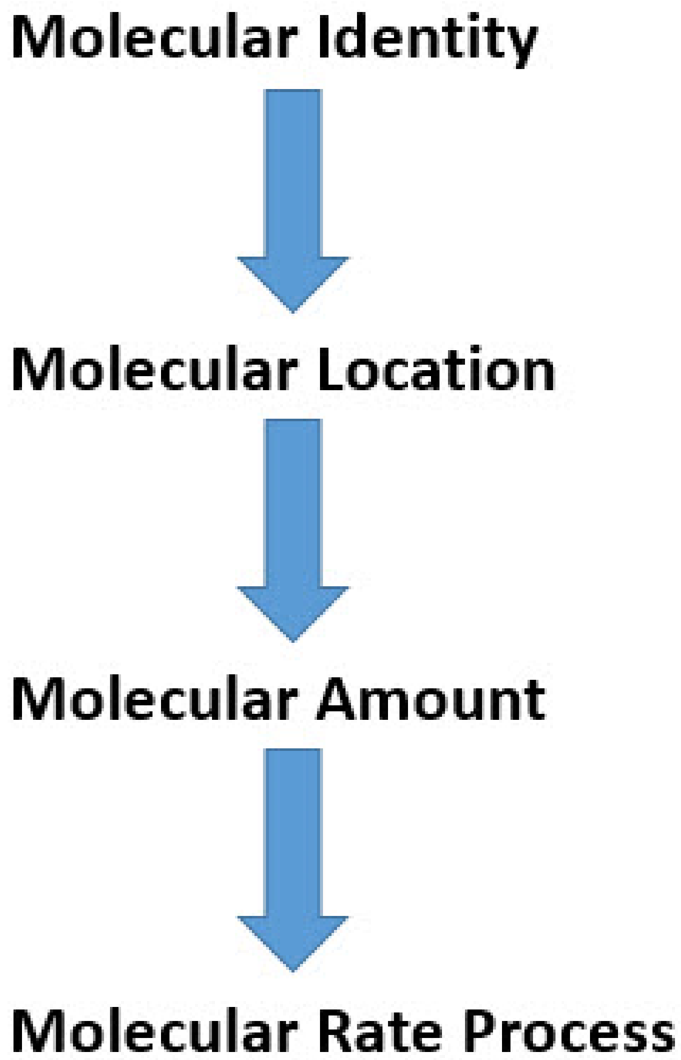


Figure 2. The molecular sequence: identity, location, amount, and rate process.

The paradigm depicted in Figure 2 could make the partnership between chemistry and chemical engineering more valuable for non-STEM students at a university (as well as for non-STEM students at public/private schools, home schools, community colleges, and massive open online courses -- MOOCs). [7-8]

For example, chemistry takes the first step with molecular identity of a selected molecule; chemical engineering takes the second step with molecular location; chemistry takes the third step with molecular amount; and chemical engineering completes the four-step sequence with molecular rate processes.

Are we finished?

Nope. After rate processes, chemical engineering goes solo with its unique, conservation-of-species equation (see Figure 3). Additional ChE concepts include time constants, dimensionless groups, segregation fractions, states, and the basic principles of laboratory techniques such as chromatography, fixed-bed reactor, membrane permeation, and countercurrent separation.

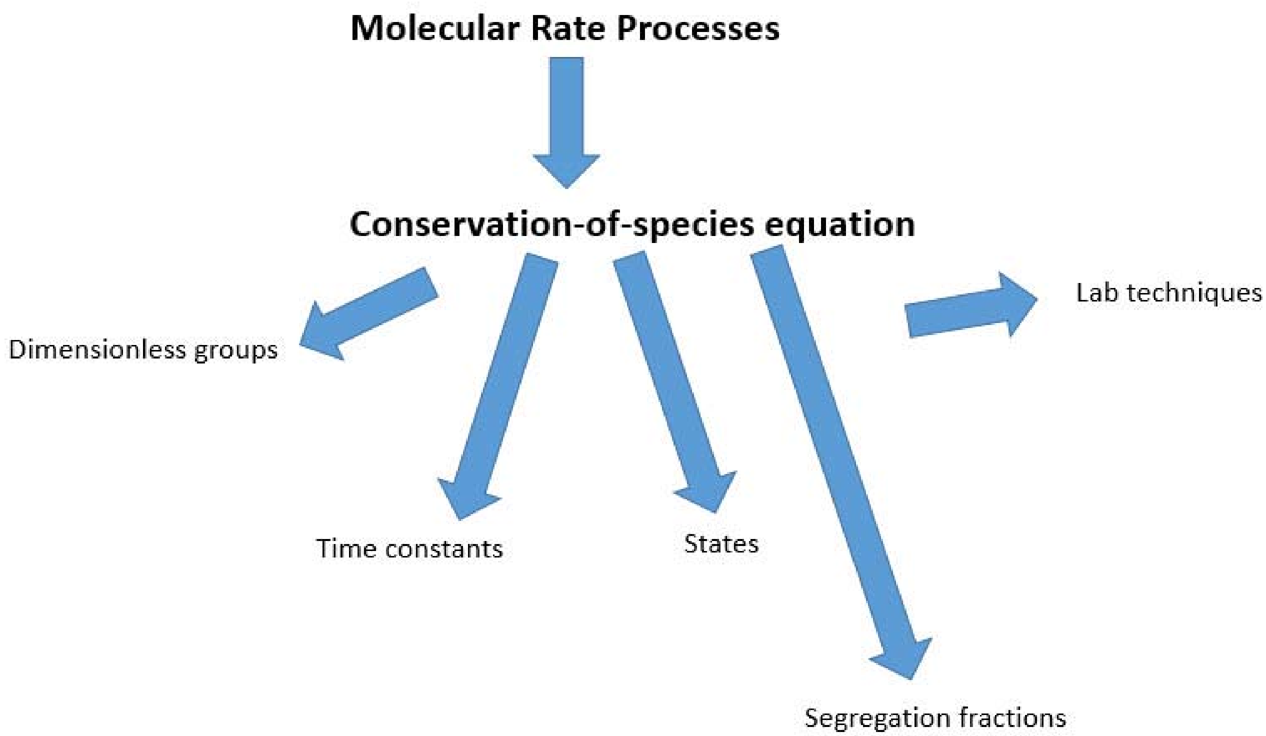


Figure 3. Chemical engineering goes solo, by showing students how to use algebra to calculate dimensionless groups, time constants, segregation fractions, and states, as well as explain the basic principles of laboratory techniques.

What is STEM?

Search Google for the keyword, STEM.

> *"**STEM** is an acronym for Science, Technology, Engineering and Math education. [Educators] focus on these areas together not only because the skills and knowledge in each discipline are essential for student success, but also because these fields are deeply intertwined in the real world, and in how students learn most effectively."*

What is the chemical-engineering discipline doing about **STEM**? This is a question that chemical-engineering educators could ponder. CAChE, AIChE, and chemical-engineering educators could contribute to nationwide efforts to add chemical-engineering **STEM** topics in most K-12 grades. This objective could become our responsibility to the next generation of chemical engineers, as well as to the public.

Complex DESIGN – Building with Engineered Proteins

As stated at the beginning of this essay, a favorite chemistry book is ***Stories of the Invisible***, by Philip Ball. [6] The book description is:

> *"**Molecules, Philip Ball writes, are the smallest units of meaning in chemistry.** And through these words, scientists have uncovered many fascinating stories of the physical world. In Stories of the Invisible, Ball has compiled a cornucopia of tales spun by these intriguing, invisible words. The book takes us on a tour of a world few of us knew existed. The author describes the remarkable molecular structure of spider's silk – a material that is, pound for pound, much stronger than steel – and shows how the Kevlar fibers in bulletproof vests were invented by imitating the alignment of molecules found in the spider's amazing thread. We also learn about the protein molecules that create movement, without which bacteria would be immobile, cells could not divide, there would be no reproduction and therefore no life. Today we can **invent molecules** that can cure viral infections, store information, or help hold bridges together. But more importantly, Ball provides a fresh perspective on the future of molecular science, revealing how researchers are promising **to***

***reinvent chemistry** as the central creative science of the 21st century".* [6]

Let me focus on "invent molecules". In the 22 July 2016 issue of Science magazine, a seminal article --- "Rules of The Game" – was published. The subtitle was "*By deciphering the rules of protein structure, David Baker has learned how to one-up nature and design new medicines and materials*." (Figures 4, 5, 8).

Figure 4. Cover image of the 22 July 2016 issue of Science magazine. [10]


FEATURES

RULES OF THE GAME

By deciphering the rules of protein structure, David Baker has learned how to one-up nature and design new medicines and materials

David Baker shows off models of some of the unnatural proteins his team has designed and made.

enzymes that help microbes suck carbon dioxide out of the atmosphere and convert it into useful chemicals. On p. 389, Baker's team and collaborators report making cages that assemble themselves from as many as 120 designer proteins, which could open the door to a new generation of molecular machines.

If the ability to read and write DNA spawned the revolution of molecular biology, the ability to design novel proteins could transform just about everything else. "Nobody knows the implications," because it has the potential to impact dozens o

Figure 5. Image of David Baker on page 338 of the 22 July 2016 issue of Science magazine. [10]

Molecular Topology, Machines and Electronics [9]

The skills of chemists in creating interesting molecules is accelerating. Such molecules can be organized according to the categories of molecular topology, molecular machines, and molecular electronics. I have been thinking about such molecules as far back as 2001 [9]. NOTE: This section was written on September 1, 2016, a month before the announcement of the Nobel Prize in Chemistry 2016.

Molecular topology provides a selection of interesting molecules, which include:

Molecular cage (clathrate)
Molecular claw (chelate)
Molecular tube (nanotube)
Molecular geodesic dome (Buckminsterfullurene)
Molecular channel (e.g., in biological cells)
Molecular separator (semipermeable membrane)
Molecular spiral (DNA)
Molecular monolayer (graphene, a fullerene consisting of bonded carbon atoms in sheet form that is one atom thick)

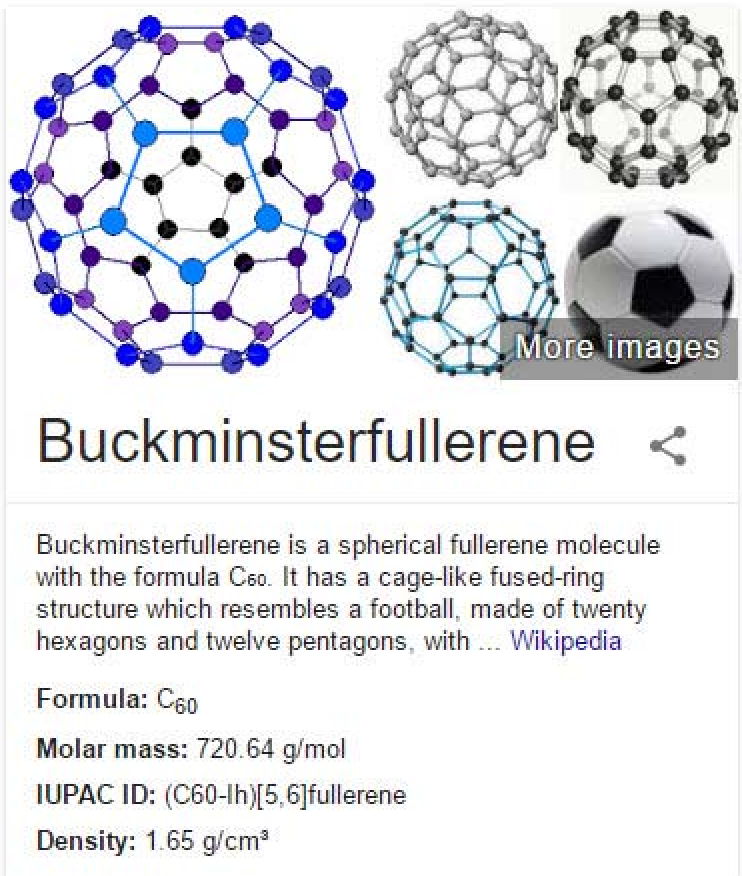
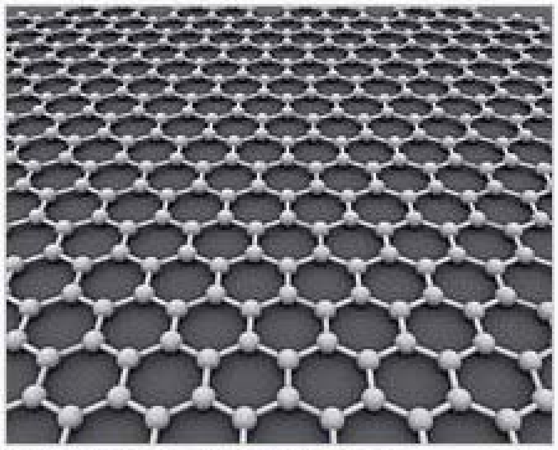


Figure 6. Buckminsterfullerene.
https://en.wikipedia.org/wiki/Buckminsterfullerene



Graphene is an atomic-scale honeycomb lattice made of carbon atoms.

Figure 7. Graphene. https://en.wikipedia.org/wiki/Graphene

Possible examples of molecular machines include:

Molecular brush
Molecular zipper
Molecular bearing
Molecular drill
Molecular handle
Molecular chain

Possible examples of molecular electronics include:

Molecular diode
Molecular switch
Molecular logic gate
Molecular AND gate
Molecular OR gate
Molecular NAND gate
Molecular NOR gate
Molecular Exclusive-OR gate
Molecular counter
Molecular shift register
Molecular memory

Molecular decoder
Molecular encoder
Molecular multiplexer
Molecular flip-flop
Molecular latch
Molecular buffer
Molecular RAM
Molecular ROM
Molecular resistor
Molecular capacitor
Molecular inductor

To these lists add (Figure 8): [10]

Molecular lantern
Molecular cage (protein-based)
Molecular 2D array
Molecular information
Molecular antagonist
Molecular sensor

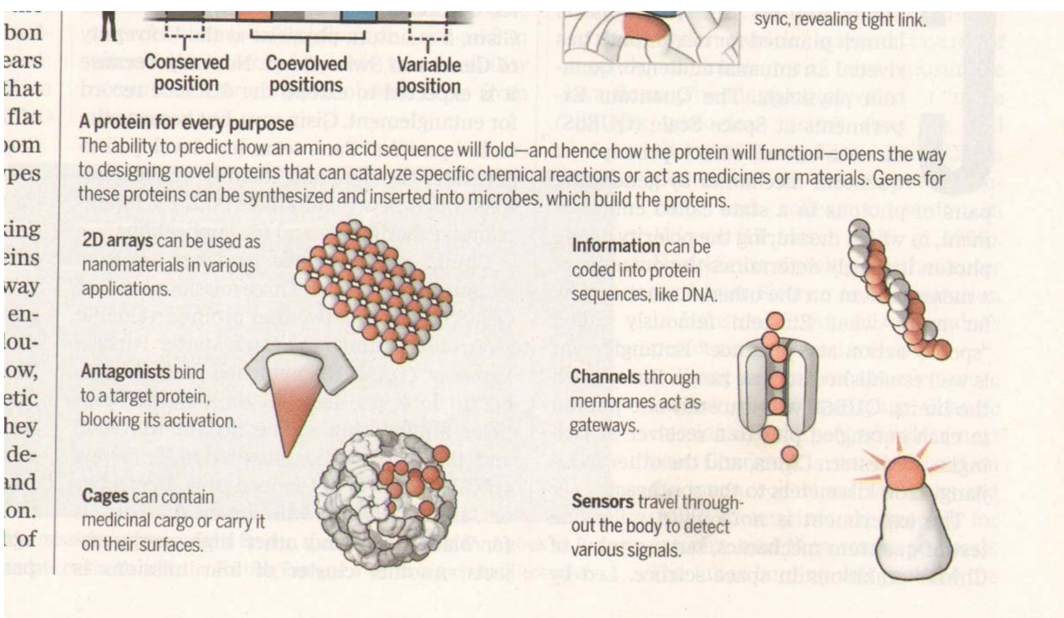


Figure 8. Dr. David Baker's suggestions for the design of proteins such as novel catalysts, medicines, and materials. One can predict that Dr. Baker will become a candidate for a Nobel Prize in Chemistry. [10]

Molecular Machines: 2016 Nobel Prize for Chemistry [11]

5 October 2016

"The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Chemistry 2016 to

"Jean-Pierre Sauvage
University of Strasbourg, France

"Sir J. Fraser Stoddart
Northwestern University, Evanston, IL, USA

and

"Bernard L. Feringa
University of Groningen, the Netherlands

"for the design and synthesis of molecular machines"

"**They developed the world's smallest machines.** A tiny lift, artificial muscles and minuscule motors. The Nobel Prize in Chemistry 2016 is awarded to Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa for their design and production of molecular machines. They have developed molecules with controllable movements, which can perform a task when energy is added. The development of computing demonstrates how the miniaturization of technology can lead to a revolution. The 2016 Nobel Laureates in Chemistry have miniaturized machines and taken chemistry to a new dimension. The first step towards a molecular machine was taken by Jean-Pierre Sauvage in 1983, when he succeeded in linking two ring-shaped molecules together to form a chain, called a *catenane*. Normally, molecules are joined by strong covalent bonds in which the atoms share electrons, but in the chain they were instead linked by a freer *mechanical bond*. For a machine to be able to perform a task it must consist of parts that can move relative to each other. The two interlocked rings fulfilled exactly this requirement. The second step was taken by Fraser Stoddart in 1991, when he developed a*rotaxane*. He threaded a molecular ring onto a thin molecular axle and demonstrated that the ring was able to move along the axle. Among his developments based on rotaxanes are a molecular lift, a molecular muscle and a molecule-based computer chip. Bernard Feringa was the first person to develop a molecular motor; in 1999 he got a molecular rotor blade to spin continually in the same direction. Using molecular motors, he has rotated a glass cylinder that is 10,000 times bigger than the motor and also designed a nanocar. 2016's Nobel Laureates in Chemistry have taken molecular systems out of equilibrium's stalemate and into energy-filled states in which their movements can be controlled. In terms of development, the molecular motor is at the same stage as the electric motor was in the 1830s, when scientists displayed various spinning cranks and wheels, unaware that they would lead to washing machines, fans and food processors. Molecular machines will most likely be used in the development of things such as new materials, sensors and energy storage systems"

Therefore, from the Nobel Prize for Chemistry 2016 press release, to the above lists add: [11]

Molecular elevator
Molecular chain (catenane)
Molecular motor
Molecular lift
Molecular muscle
Molecular-based computer chip
Molecular shuttle
Molecular knots
Molecular nanocar
Molecular elastic structure

A Cultural Change?

I started this CAChE News article with the objective of suggesting three or four opportunities for introducing chemical-engineering concepts to public-and private-school students. One reason for doing so is the fact that students who enter universities – as well as most adults – do not have the foggiest idea of what chemical engineers do. My objective was not to increase the number of sophomores who will seek careers in chemical engineering, but rather to encourage a long-term, cultural change concerning how adults perceive the discipline of chemical engineering.

In my opinion, students, teachers, and adults could learn that a knowledge of basic, chemical-engineering concepts is much more important than a superficial understanding of historic, smoke-and-steam-emitting (or dust-emitting), large-scale systems.

Why? Because chemical engineering is the only discipline at a university that teaches all of the consequences of the *conservation-of-species equation*. Such concepts – which can be taught using algebra -- are important to students of chemistry, biochemistry, biology, medicine, dentistry, nursing, environmental chemistry, food science, nutrition, forestry, parasitology, and horticulture.

STEM versus non-STEM Students

Is the public aware that the two jargon terms – diffusion and convection -- exist? Does any **non-STEM** member of the public understand the difference between these two terms? (Figure 9). Perhaps molecules move from here to there by . . . Harry Potter magic.

To repeat, chemical-engineering educators have an opportunity to teach an elective, “enrichment-chemistry” course to **STEM** and **non-STEM** students. Can you imagine a future lawyer who defends his client by describing “permeation through a molecular barrier” in a courtroom?

Figure 9. STEM icon, one among many icons. Search Google Images for the keyword, STEM.

Polymath on Smartphones [12]

In his section, “Mobile Smartphones Are Coming to the World” [12], Cutlip pointed out the following:

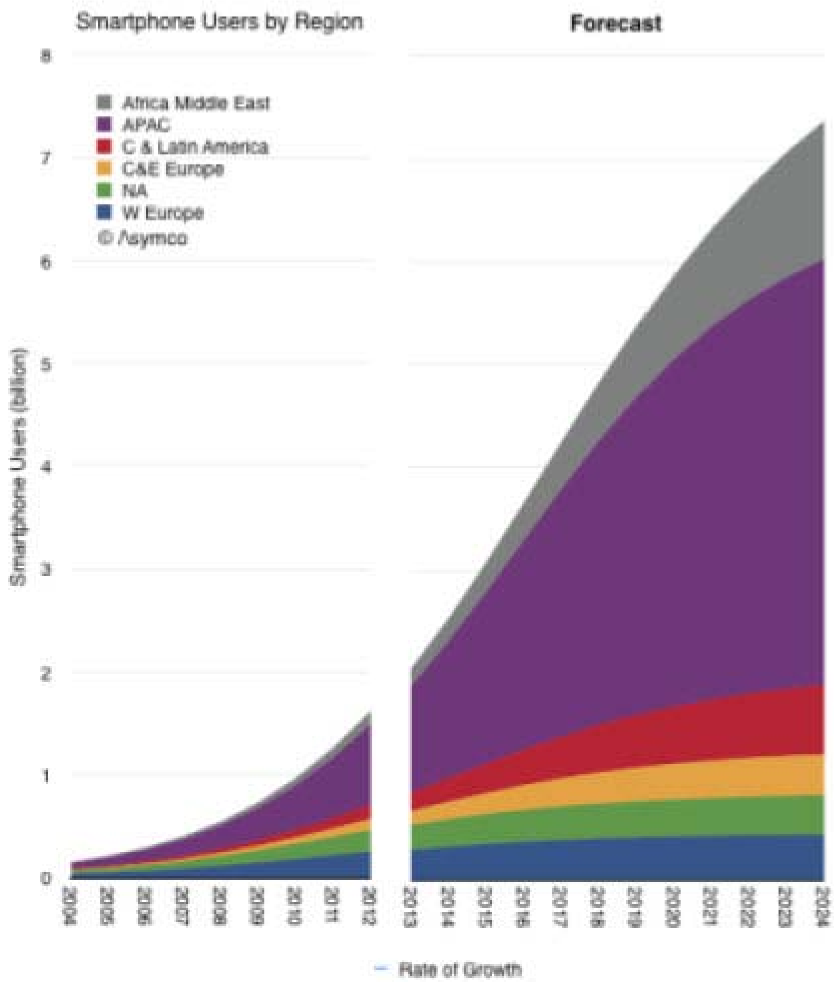


Figure 1 – Projection of Smartphone Users for 10 Years by World Region from H. Dediu [4]

"As engineering educators consider the future, particularly in developing countries, there are some emerging tools that can provide assistance with educational calculations and thus with the delivery of e-learning materials. A very exciting tool for engineering calculations is the smartphone that is rapidly taking over the mobile phone marketplace worldwide. Consider that the smartphone will be the preference for engineering students and engineering professionals. The eMarketer (3) , a leading

market research company, suggests that "smartphone users worldwide will total 1.75 billion in 2014." eMarketer "expects 4.55 billion people worldwide to use a mobile phone in 2014." Horace Dediu, founder of Asymco, who covers the mobile industry has made some predictions(4) regarding the future of smartphones. A particularly interesting graphic is reproduced as Figure 1. Note that the smartphone numbers seem to be approaching the world's population in the next 10 years. This is a challenge to consider, but it does indicate that smartphones will probably be available as a possible educational tool with increasing popularity with younger persons as educators look toward the future. Special Considerations for Africa Matthew Labrooy, who works with eLearning Africa(5) , has written about Africa's smartphone revolution(6) . He has estimated that "Smartphone growth in Africa has increased by 43% every year since 2000, and experts predict that 69% of mobiles in Africa will have Internet access by 2014. As a result, smartphone manufacturers are showing increased interest in the region in a bid to gain their share of half a billion potential customers. Currently a simple budget smartphone produced for the African market is available on the streets of Kenya for as little as €37 (US$50) and has sold more than 300,000 units across the country. Smartphone penetration in Africa is estimated between 17-19%, though rates vary wildly from country to country. Nigeria, Africa's most populous nation, has a smartphone penetration as high as 41%." Spurred by the success of the African budget smartphone, Microsoft has produced a *smartphone (Windows Phone 8) specifically for the African Market, the Huawei 4 Afrika(7) , which was released in South Africa, Egypt, Nigeria, Kenya, Ivory Coast, Angola, and Morocco in February 2013."*

Publishing at TpT

To Cutlip's observations, I add the fact that Acrobat for Android is now available as a freeware download [13]. I conclude that PDF files will be viewed worldwide on smartphones. I am in the process of publishing PDF files about enrichment chemistry.

The publication of eBooks at www.teacherspayteachers.com (TpT) is a significant improvement over my soft-cover, publishing activities during the 1970s. The most interesting download is the freeware chemsk2015.exe installation file (Figure 10).

Download Freeware ChemSketch 2015 installation program (Enrichment Chemistry Ser

5 Downloads

Subjects	Chemistry
Grade Levels	5th, 6th, 7th, Homeschool
Resource Types	Homeschool Curricula, Computation, For Parents
Product Rating	Not yet rated
File Type	Executable Program File Be sure that you have an application to open this file type before downloading and/or purchasing. 53.35 MB | N/A pages

PRODUCT DESCRIPTION

The purpose of this FREE TpT product is to assist you to download the freeware chemsk2015.exe installation file from the ACD Labs website. First, use Google to search for ACD/Chemsketch. You should go to the Google page where the first URL is entitled, "ACD/ChemSketch for Academic and Personal Use". If you click on the link, you are transferred to a web page that includes in the title "A Free Comprehensive Chemical Drawing Package". At the bottom of this web page, there is a yellow "Download Freeware" button. Click on this button and you are transferred to a form that states "Register here to create a new account". Please complete this form and click on the orange "Register" button. If you do not have a company, make one up using your last name followed by the letters LLC. I tried to register, but I failed because my email address was already registered. Therefore, I cannot show you what happens next. Just use your instincts to download the freeware chemsk2015.exe installation file.

However, if you fail with the above, you can download the installation file that is associated with this FREE product. I want to make certain that you are successful.

Figure 10. Available at TpT, **chemsk2015.exe** is freeware molecular-modeling software. I believe that it could be useful for students from grade school to 2nd-year chemistry and chemical engineering students who take an organic chemistry course. At TpT, I have already provided four groups of self-extracting, skeletal-model (*.sk2) files. More groups are forthcoming.

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