WHY JOHNNY CAN'T CALCULATE PH: ISSUES AND ANSWERS

[An Open Discussion Shared with the Members of AIC at the 2005 Annual Meeting]

Margot Hall, Ph.D., FAIC (CPC), FACB, FRACI (CChem), MRSC (CChem)*

Abstract

In this paper, the author addresses some of the educational issues which she has encountered in teaching her clinical chemistry and biochemistry courses and outlines some approaches to these issues that have worked for her. Suggestions by which industrial chemists can help their academic counterparts are also offered. It is hoped that this paper will serve as a stimulus to others to share their information and any solutions that have worked for them. This paper is a brief recapitulation of a presentation given at the 2005 annual meeting of the American Institute of Chemists (AIC).

BACKGROUND

Essential Skills/Knowledge for Chemistry and Clinical Chemistry Students:

A short list of essential skills and knowledge needed by chemistry and clinical chemistry students would have to include the following: 1) reading, 2) writing, 3) speech, 4) math, 5) critical thinking, and 6) other fundamental knowledge required of students and citizens. If you think that this is a given, let me assure you that during the past 20 years of teaching at a southern university I have interacted with several thousand students who had difficulty in some or all of these areas. Additionally my colleagues have reported similar observations from their institutions in different parts of the country. I have even been advised by some that these skills have been rendered obsolete and unnecessary by the introduction of "intelligent computers". Such statements force me to defend the importance of these essential skills.

In Defense of Essential Skills:

The proposition that computers and other instruments will substitute for individual knowledge and skills presupposes that the computers will always be on line and properly programmed. One need only consider the possibility of a massive power outage to realize that this is an unreasonable assumption. One might also wonder if we really want our young people to be subjected to the subtle form of mind control that occurs when an individual is dependent on an instrument to do the analysis, complete the interpretation, and determine the course of action.

Reading, writing, and speech are required for good communication. Students who have difficulty reading invariably have difficulty completing their assignments. Students who write poorly receive lower grades and students whose speech is inadequate tend to be passed over for the better jobs. Not only is good communication required for upwards mobility but it is essential in the clinical laboratory as mistakes can lead to incorrect diagnoses, improper treatment, and even death. For example, insulin is not the same as inulin and should not be substituted for it, nor is castration the same as cannulation, which is not the same as canonization. In the clinical laboratory, the most common error is a transcription error but there is no shortage of miscommunication arising from language barriers. Some errors are easily recognizable and hence correctable but others are not.

Math is required for all of the sciences and mathematical errors may alter the strength of support structures for a building or bridge, the lift factor for an airplane or the perceived kinetics of an enzyme. In clinical chemistry mathematical mistakes cost lives, dollars and jobs. The most common mathematical error in the clinical lab is indubitably a dilution error. It is also the most costly. Examples include: 1) a reported white blood cell count of 3,300 per cubic millimeter when the correct value was 33,000, 2) a reported serum glucose of 650 mg/dL versus 65 mg/dL, and 3) a serum potassium of 15 mmol/L. In the first case, the patient was subjected to ill advised elective surgery from which he died. In the second case, the patient was treated with unnecessary insulin but survived. Similarly, in the third case, the technologist was royally chewed out by her supervisor who reminded the technologist that this result was incompatible with human life. As a teacher, my favorite math error came from a student who had calculated a blood pH of 15.46 and truly believed that this was the correct answer. It was at that time that I realized that for many students a logarithm is a blue button on a hand calculator....

Critical thinking skills are needed in all professions and life choices. Good thinking skills lead to proper decisions and poor skills lead to unsuccessful choices. One need only think of the “infallible computer” which when asked whether a patient’s blood pressure value was significant or not responded that the value was not significant. The computer reasoned that statistically speaking 5% of the values will be outside the normal reference interval, thus a single value of zero for the patient’s blood pressure should not be considered to be significant. Please note that this is not to be construed as a diatribe against computers which are a very useful adjunct both in the lab and in the classroom, but rather it is a form of advocacy for the importance of stressing critical thinking skills for our young students.

Chemistry students also need a broad based background of general knowledge and discipline related knowledge. Clearly, the more knowledge students have in the sciences the better prepared they are to learn, apply, and make the appropriate scientific connections. But our young students are also the future of the nation. Like all other young people, they may vote, hold office, serve on a jury, and help lead the nation. During the past 20 years I have put a free question to hundreds of students. To date, not one student has correctly answered the question: “Please list the three branches of the US government and state their functions". If our government is important to us, then it is perhaps important that our students know how it functions and have the essential skills and knowledge to address the issues and make the necessary choices that they and the nation will be faced with.

The Need:

There is a real need for educated citizens who can help make important decisions. Major issues affecting life on this planet will be presented to our younger generation and the young people need to be able to make good choices. Examples of issues that they will be faced with include stem cell research, genetically engineered plant and animal life, industrial and chemical toxic wastes, radiation research/use, global warming and numerous others. The decisions that they make will dictate the future of this country and others. Thus the more people who are engaged in the debates and the better educated they are the better the choices that are likely to be made. There is also a need for more professionals in the sciences and in particular in chemistry. At a recent American Association for Clinical Chemistry (AACC) meeting, it was stated that best estimates suggest that the United States will require at least 20,000 additional clinical chemists within the very near future (1). In the industrial nations, national economies and workers' salaries are somewhat dependent on the level of science and technology. Thus there is a need to prepare our young people adequately in these disciplines. Finally, today's students need a greater knowledge in the sciences upon graduation than students of prior generations did. Simply put, there is a lot more chemistry/science for them to know today.

THE PROBLEM

Unfortunately, while more scientific knowledge is required of today's students, they often enter college less well prepared than those of prior generations. As the gap between matriculation and graduation widens, so does the difficulty facing the student and the professor. From 1970 to the present (2005), two changes/trends have been observed with respect to the typical undergraduate student placement scores. First there has been a shift from a Gaussian curve to a bimodal curve with one mode reflecting college/university students with the expected level of preparation and the other mode including college/university students who are seriously under-prepared. The second change involves a reduced emphasis on national college-board exam scores (ACT or SAT) and other placement scores as a part of the college/university admission requirements. Combined with grade inflation, this results in the admission of students who are increasingly deficient in fundamental knowledge and skills. Consequently, students struggle academically and become frustrated and demoralized. Some even become hostile as the gap between their expectations and performance becomes evident. Similarly, members of the faculty become increasingly drained from the effort of trying to teach to a bimodal class.

Some causes of student under-preparedness include student health, teacher ability, class size, the extent of television viewing, the use of hand calculators and computers, and decreased volume and frequency of student homework assignments. Clearly, exposure to any chemical toxicants or other toxins that affect the central nervous system (CNS) will have a profound effect on neuronal development and function, and hence on student learning. In the South, one is particularly concerned with exposure to heavy metals and pesticides through contaminated ground and well water. Additionally, the timing of vaccinations and the nutritional status of children can affect their neurological development and academic performance. There is even an apparent “neurological switch effect” seen in children with autistic spectrum disorders. This problem is of major concern to parents, teachers, and physicians. It has been postulated by Dr. Stephanie Cave (2) that the use of mercury containing preservatives (e.g. thimerosal) in multi-dose vials of vaccine and the vaccination of children at very young ages (e.g. hepatitis B vaccination of neonates) may account for the increased incidence of autistic spectrum disorders observed in American children. It should also be acknowledged that some young people experiment with drugs of abuse and other toxic chemicals which can diminish neuronal function.

A teacher’s mastery of his subject area will affect his ability to transmit discipline related knowledge/information to the students. Since many K-12 and community college (CC) teachers have received considerable instruction in pedagogy (teaching methods courses) but perhaps less instruction in their specific subject area (content based courses), and many other teachers are forced to teach outside of their major discipline (e.g. one teacher for physics, chemistry, and biology), it is not surprising that these teachers and their students sometimes feel stressed. Additionally, many teachers cite experiencing difficulty with keeping abreast of new developments in chemistry and the other scientific disciplines. Class size and the student/teacher ratio have also been cited as causes of poor teacher-student communication and hence a possible source of student failure to learn. One very specific effect of large class size and increased student/teacher ratio is the inevitable decrease in volume, frequency, and quality of student homework assignments. Homework serves to reinforce concepts and this leads to concept retention. To put it mildly: “use it or lose it”. High school and community college students who never work chemistry problems are more likely to “memorize and regurgitate” on an exam important chemical concepts which they then quickly forget.

Three byproducts of the modern technological age (TV, hand calculators, and computers) are both a blessing and a curse when it comes to student learning and preparedness. The visual and auditory impact of a good TV program is tremendous. Unfortunately, all too often the script writer has tried to appeal to the lowest common denominator and therefore uses very poor English and incorporates little useful content. The more often students listen to poor English the more they are inclined to use poor English and frankly their time could be better spent elsewhere. The use of hand calculators has the advantage that one obtains answers relatively quickly but it also has the disadvantage that the students don't get the reinforcement necessary to really understand and learn math. The most obvious example of this is the difficulty that many college students have making serial and other dilutions of solutions in the laboratory. The students are having obvious difficulty with common fractions and they cannot use a hand calculator to obtain the correct answer. Another place where their mathematical difficulties are evident is in the calculation of pH which requires the use of logarithms. The calculator will give them a correct answer but many students have no clue whether the answer calculated is reasonable or not because they have no understanding of what a logarithm is. Finally, computers can be a wonderful teaching tool and source of information, and I have observed that today's high school graduate is increasingly computer literate. However, often the speed with which the students obtain information and the availability of "prepackaged and predigested" information has led to compromised critical thinking skills. Today's high school graduate wants instant answers but tomorrow's chemist must be able to analyze a problem and synthesize a (the) correct response.

SOME APPROACHES TO THE PROBLEM

There are many different possible solutions to the problem of poor student performance. Some of the approaches can be applied directly by faculty and teachers. Other approaches require the concerted effort of scientists, business leaders, physicians, parents, educators, and voters....to name but a few. It is my opinion that it is worth the investment of time, energy, and money required by these approaches because improved student learning will change the future for our young people and hence for the nation. One thing which I stress is to *never give up* on young people because they will surprise and amaze us with their motivation and their ability to overcome obstacles.

General Approaches:

A few general approaches to the problem outlined above would include improved student health, improved teacher preparation, improved class size, and, where appropriate, remediation. Clearly, there is a role for industrial chemists in the reduction of toxic wastes (e.g. heavy metals) from the environment. Similarly, there is a role for research chemists in developing better drugs, vaccines, and nutritional substances plus better strategies for their use. All Americans should collaborate in efforts to reduce the incidence of chemical dependency and abuse. This should lead to healthier young people who can better profit from their scholastic work.

Industrial chemists are ideally situated to offer current and relevant science workshops for teachers and to help fund rewards for good science teachers. It is my hope that AIC might offer a high school science teacher award with a small monetary award to be spent by the teacher for instructional needs. There has also been a movement at some colleges and universities to return control of the curriculum for education majors to the home department. Thus the chemistry department faculty would control the curriculum (certificate program) for education majors planning to teach high school chemistry. This should lead to better prepared high school teachers which in turn could lead to better prepared high school graduates. There are opportunities for industrial, research, and academic chemists to serve as guest lecturers at local schools and to serve on local school boards where they can advocate better teacher/student ratios and class sizes.

Since the television and film industry commands an important place in the development of language skills and the transmission of knowledge to our children, one could encourage the industry's leaders and script writers to use better English and introduce more interesting content into their programming. Finally, the introduction of drill and, where needed, remedial work with individual tutoring can be an effective approach.

Specific Approaches:

Some approaches that I have used in my classes include: 1) tutorials with a lot of drill, 2) increased emphasis on written English, 3) increased emphasis on math, and 4) exercises in critical thinking. I spend about 4-5 hours per day tutoring students who are struggling academically. Additionally, I offer a recitation period from 3-5 PM on Fridays for students in my courses. And I meet with students who have questions within 24 hours so that the students get rapid feedback and don't waste time on unproductive work. Exams are both cumulative and comprehensive. When the students sit for the second semester of clinical chemistry (Clinical Chemistry II), they are required to take a comprehensive exam covering the material from the first semester clinical chemistry course (Clinical Chemistry I). If a student fails this entrance exam, he is required to sit for a 2 hour/day review of the first semester material in addition to the usual requirements for the second semester course. The final exam for Clinical Chemistry II covers the material from both courses (Clinical Chemistry I & II). Homework assignments, laboratory questions and report forms, and tutorial exercises are designed to reinforce concepts and to drill the students ("practice makes perfect"). Additionally, the students are given review lectures with homework sets and weekly exams during their final clinical work (hospital practicum) in preparation for taking their national certification exams and state licensure exams. It is my policy not to give partial credit and not to curve grades. However, I do give a lot of exams and exam questions as this allows the students to overcome a weak beginning.

To address an apparent weakness in our students' English language skills, our faculty recently implemented a system of writing intensive and senior capstone courses. In each of these courses, the students are required to write major term papers which will be graded on the use of English as well as content. It is too early to say whether this will correct the reading and writing deficiencies of the students.

To help correct their math deficiencies, we have introduced a laboratory mathematics course into the curriculum. In this course, students do some work without the use of a hand calculator. Similarly, they are required to learn to use log tables and I demonstrate the use of a slide rule. It is at this point that my mathematically challenged students finally grasp the concept of what a logarithm's function is. This naturally leads to calculations involving acid base status. In their first clinical chemistry course, I have the students derive the equations involving pH and perform pH titrations in lab. When introducing the concepts of metabolic and respiratory acidosis and alkalosis, I color code the parts of the Henderson-Hasselbalch equation. This allows the students to see the relationship between pH and the base/acid ratio. It helps enormously when I am teaching them about compensatory mechanisms to acid base imbalance. Next, I have the students calculate pH, given values for pCO_2 and bicarbonate or pCO_2 and TCO_2. Likewise, I have them calculate bicarbonate from pH and pCO_2 and also from TCO_2 and pCO_2. Then I have them analyze and interpret the results using the 4- step method. Refinements involving body temperature, DPG concentrations, hemoglobin concentrations can then be mentioned and algorithms can be introduced. Additionally, I have acid-base and other laboratory math problems on every exam in each of the clinical chemistry courses (Clinical Chemistry I, II, III, and Special Chemistry). This helps to reinforce the concepts learned.

To address the need for the students to learn to do critical thinking, I have developed and used a series of case studies. With each case study there is a brief description of the patient's symptoms and physical exam results, a list of presenting laboratory values, and in some cases further symptoms and lab values. The case study will include a series of questions designed to lead the student to a diagnosis for the patient and to reinforce concepts learned in class. In some cases, the student will be required to select further tests to be ordered or recognize a discordant value and determine why the analysis failed. To help the students "connect the dots" I have included some case studies that cross disciplines (e.g. hematology, microbiology, and clinical chemistry). Answers to the case study questions follow each case. Additionally, I have included some critical thinking questions on each exam. For example, I might ask the students to think of multiple factors which could lead to obtaining a physiologically impossible blood gas (acid/base) result and then indicate how they could correct the system.

In conclusion, some issues relating to chemical education have been discussed and possible ways of addressing them offered. It is hoped that others will add to this list and share their findings with us.

REFERENCES

1. American Association for Clinical Chemistry Annual Meeting. Orlando, FL. July 28-August 1, 2002.
2. Cave, Stephanie. “Vaccine Controversies: Past and Present”. Dodgen Lecture. Mississippi Academy of Science Annual Meeting. Biloxi, MS. February 21-22, 2002.

ABOUT THE AUTHOR

Margot Hall, Ph.D., FAIC, CPC, FACB, FRACI (CChem), MRSC (CChem) is a professor of clinical chemistry in the Department of Medical Technology at the University of Southern Mississippi, Hattiesburg, Mississippi 39406- 0001, USA. Telephone (601) 266-4912, Fax (601) 266-4913, E-mail: Margot.Hall@usm.edu

She received her Ph.D. in Biochemistry from the University of North Carolina at Chapel Hill where she worked as a research assistant (UNC Medical Center). Since moving to Mississippi, she has taught in the Medical Technology Department at the University of Southern Mississippi and as an adjunct in the Department of Chemistry and Biochemistry.