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# On the Importance of Chemical Education

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*Abstract:* Chemical education, together with other scientific and non-scientific fields, plays a role in the construction of a rational mind, and it is therefore of the highest importance to include it as early as possible in the school curriculum. In this short article, the author, not being an expert in educational sciences, expresses his personal opinion based on almost 30 years of teaching chemistry at various levels.

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## 1. Scientific Thinking as a Citizen

It is undeniable that the current world faces very serious challenges. Due to overexploitation, the days of easy access to raw materials (minerals or fossil fuels) are counted. Supplying food to a growing population will not be as obvious as it may have been so far. Increased energy consumption, in conjunction with political decisions about banning the use of certain energy sources seems like a solutionless problem. Extreme weather episodes, the result of human influence on the climate, may become a new normality.

Addressing all these issues requires first to understand their origin, and then devise specific solutions, either technological or political. While finding solutions would be typically handled by scientists and engineers, understanding the situation should, to a variable extent, concern *everyone* on our planet. The goal of natural sciences is to understand the functioning of the world, and therefore a solid education in this field is a prerequisite to understand the consequences of our actions. Flipping a switch to light a lamp, starting a combustion engine, or seeding a plant are localized parts of a much larger chain of events that need to be understood. This is unfortunately less and less the case, and seeing the world becomes a matter of opinion, fueled by reliable, biased or fake information as well as undisputable dogmas. It is quite interesting to see how the pure awe of discovery has turned into a mere utilitarian endeavor. Scientific education, and chemistry in particular, since it is the purpose of the present topical issue of *CHIMIA*, should primarily aim at opening eyes of every child already at primary school about the world as it is, and not to train a future specialist. Fundamental concepts, such as the atomic nature of matter or entropy should be taught as early as possible. Likewise for the carbon and nitrogen cycle. We read almost daily that we may soon run out of lithium, lanthanides or phosphates, and this affects the common perception of the future. Understanding that a lithium atom will remain as such forever (well, within reasonable conditions and timescales that are relevant for today's discussion), but that it will become more difficult to find it in a spatially localized spot will help to shape the public discourse on more realistic bases. More generally, the goal of chemical education should be to question the *why* and the *what's going to happen* for every action. In a broader perspective, education in natural sciences should firmly set the bases for a scientific thinking, with a systematic and logical construction of hypotheses, experiment and conclusions, devoid of cognitive biases and circular arguments. The recent COVID-19 pandemic has shown how ill-prepared our society was facing the unknown, leading sometimes to rejection of the path towards knowledge.

## 2. Scientific Thinking as a Future Professional

For those who are heading to a scientific, technological or medical profession, a solid training in chemistry is essential for a successful curriculum (again, we focus here on chemistry, but mathematics, physics and biology are equally important for future chemists). As we alluded earlier, force feeding useful information is pointless, as it will soon be forgotten by students shortly after a formal evaluation. This is particularly apparent with first-year mathematics: already in the second year, chemistry students are notoriously unable to express the first derivate of a function or to determine the distance between two points in a coordinate system. A stepwise coherent buildup of scientific knowledge requires close concertation between the teachers in the various fields, not just to adjust course schedule and apparent syllabus, but also to understand the mindset, the traditions and the formalisms typical to the fields. To cite just one example observed at the University of Fribourg, where the attempts to have a common course on quantum mechanics for both physics and chemistry students failed. Despite having the identical label 'Introduction to quantum mechanics', and *in fine* covering a similar field, the symbols, nomenclature and applications are so different that communication between the two communities is extremely difficult. One way of addressing this issue is to generate and foster curiosity among students, so that they will build those bridges by themselves. Great discoveries are frequently made by those who applied tools that were not intended for that purpose. A spectacular example of this is the expression of selection rules in pericyclic reactions by Fukui, Woodward and Hoffmann. To be able to link a very abstract

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aspect of chemistry (symmetry of molecular orbitals, at a time where computing time was a barely affordable luxury) to a very practical aspect (organic synthesis, in particular on the way to the landmark vitamin B12 synthesis) required an exceptional capacity. This is nicely described in the series of articles by Jeffrey Seeman:[1,2]

*"Yet another reason was that theoretical chemists of that era did not apply their knowledge and solve the pericyclic no-mechanism problem. They simply were unaware of the state-of-the-art organic chemistry. They did not know the problems that were the main struggles for organic chemists. And there was little incentive to look across the barriers of interdisciplinary. There were plenty of important problems for theoretical chemists and chemical physicists to solve within their own discipline."*

An alternative expression of the same (regrettable) phenomenon was recently pointed out by Peter Chen, quoting Louis Hammett:[3]

*"For a time, it was almost a point of honor with both physical and organic chemists to profess ignorance of the other's field, and it remains a useful defense mechanism, if any is needed, to excuse the fact that specialization entails limitation as well as intensification of knowledge."*

It is interesting to note that the gap that was closed by Woodward and others is widening again. In my own experience in teaching physical organic chemistry (6th semester), linking the color of lobes in schematized molecular orbitals to the sign of a wavefunction, and its relationship to electron density is a difficult step for the average student. Teachers should not merely point out what it is, but genuinely convince students that all the scientific fields constitute a coherent construct.

## 3. Opportunities and Traps of New Technologies

Until the mid 1990s, the use of computers to find chemical information was severely limited by the cost of consulting databases and learning large amounts of data (ranging from named organic reactions to bond strengths and pKa values) was worth the effort, to a certain extent, as the alternative would be consulting the thick volumes of *Chemical Abstracts*. The same was true for designing synthetic routes, based on reasonable reaction mechanisms rather than close analogies from the literature. In the meantime, finding such information has become trivially simple, and it became tempting, also from teachers, to "know where to find", rather to "know". This is a dangerous approach that will curb the scientist's ability to create new things (the underlying concept being "we don't know what we don't know"). This trend has accelerated even more in the last few months, with the widely available AI engines such as ChatGPT. On top of what was just said, the absence of verification mechanisms of their answers makes their use highly unreliable. We were amused (but it is in fact much more worrying than amusing) by a query that was run in January 2023, a day before the oral examination of our stereochemistry course: "what is the difference between enantiomers and diastereoisomers?" (The original query and the answer were made in French). The answer: "an enantiomer is a molecule that is the mirror image of the other enantiomer, (…). For example, glucose and fructose are enantiomers because they have the same skeleton, but their substituents are placed so that they are symmetrical with respect to a symmetry plane". *Quod erat demonstrandum*. With the generalization of the use of those tools in the press and probably even textbooks, a sound scientific and critical thinking as well as a solid knowledge of the fundamentals will be required to filter out nonsense. As we said earlier, natural sciences are intimately linked to physical, and not virtual or even alternate reality.

## 4. Challenges for Today's Teachers

The global increase of knowledge, in all directions, is by itself very positive. But it comes with its challenges for teachers, as the teachable matter is not infinitely extensible. There is a strategic decision to be taken, mostly at the discretion of the teacher or their immediate supervision body, in balancing depth *vs* wide coverage. This is particularly apparent in analytical chemistry, where the last decade has shown a multitude of new analytical techniques and instruments. Each of them has its importance, and it would be a shame just to ignore them. But the underlying physics is frequently too complicated to be taught by and to non-specialists, leaving a certain risk of misinterpretation of results by lack of understanding of the meaning and limitations. We regularly see in the literature fluorescence spectra in which the emission wavelength is exactly twice the excitation wavelength! It is the opinion of the author that, as a rule, if a choice needs to be taken between the utilitarian and the fundamental, the latter should always be favored. A solid understanding of the bases will help the scientist in training to acquire later the specific knowledge of a certain tool or technique.

## 5. Positioning of Academics: Teacher vs Researcher

In today's organization of most universities, academics play both researcher's and teacher's roles, with the underlying principle that both activities enrich each other. The best researchers are also frequently the best teachers, with their ability to explain things with a unique angle. At the same time, the *why?* asked by candid students forces teachers to think deeper about something they took for granted. This is widely recognized in the scientific community, and most professors actually enjoy teaching (or so they say!). Pressure from political authorities, always in search for 'efficiency' and 'excellence' (in their nomenclature: 'cost saving'), to dissociate research from teaching remains, but so far Humboldt is still winning over McKinsey.[4,5]

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