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# DO GENERAL CHEMISTRY TEXTBOOKS FACILITATE CONCEPTUAL UNDERSTANDING?[#]

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Research in chemistry education has recognized the need for facilitating students' understanding of different concepts. In contrast, most general chemistry curricula and textbooks not only ignore the context in which science progresses but also emphasize rote learning and algorithmic strategies. A historical reconstruction of scientific progress shows that it inevitably leads to controversy and debate, which can arouse students' interest and thus facilitate understanding. The objective of this article is to review research related to the evaluation of general chemistry textbooks (based on history and philosophy of science, HPS) and suggest alternatives that can facilitate conceptual understanding.

Keywords: general chemistry textbooks; conceptual understanding; history and philosophy of science.

Recent research in science education has recognized not only the importance of history and philosophy of science but also its implications for science textbooks[1]. Most teachers in different parts of the world rely quite heavily on the textbook, as perhaps the only source of information. In the case of chemistry most students at the secondary and freshman level think that they do not have to understand chemistry but rather memorize the different concepts. Thus, it is not difficult to appreciate why students do not like chemistry. Nevertheless, the interesting point is that many freshman general chemistry courses and textbooks present material that does not call for much conceptual understanding. Taking atomic structure as an example, it is plausible to suggest that an evaluation of textbooks (all published in U.S.A.) based on criteria derived from a history and philosophy of science perspective can provide teachers with insight as to how atomic models or theories developed.

## Heuristic principles

According to Schwab[2] scientific inquiry tends to look for patterns of change and relationship, which constitute the heuristic (explanatory) principles of our knowledge. A fresh line of scientific research has its origins not in objective facts alone but in a conception, a deliberate construction of the mind - a heuristic principle. This tells us what facts to look for in the research and what meaning to assign. Chemistry textbooks and curricula have ignored Schwab's advice, which leads to a lack of an epistemological distinction between the methodological (experimental) and interpretative (heuristic) components. After almost four decades we still have to agree with Schwab[2] that in most parts of the world, chemistry is taught as an:

> … unmitigated *rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths … A rhetoric of conclusions, then, is a structure of discourse which persuades men to accept the tentative as certain, the doubtful as the undoubted, by making no mention of reasons or evidence for what it asserts, as if to say, '*This* everyone of importance knows to be true'[2].

## Were cathode rays ions or a universal charged particle?

Thomson[3] measured mass to charge ratio in order to identify cathode rays as ions (if the ratio was not constant) or as a universal charged particle (constant ratio). Of the 23 textbooks (all published in U.S.A.) analyzed only 2 described satisfactorily the reason why Thomson decided to measure the charge to mass ratio[4]. Following is an example of a textbook that had a satisfactory presentation:

> A very striking and important observation made by Thomson is that the *e/m* [charge to mass] ratio does not depend on the gas inside the tube or the metal used for the cathode or anode. The fact that the *e/m* ratio is the same whatever gas is present in the tube proves that the cathode ray does not consist of gaseous ions, for it did, *e/m* would depend on the nature of the gas[5].

Let us now observe how another textbook dealt with this important issue:

> A physicist in England named J. J. Thomson showed in the late 1890s that the atoms of any element can be made to emit tiny negative particles. (He knew they had a negative charge because he could show that they were repelled by the negative part of an electric field). Thus he concluded that all types of atoms must contain these negative particles, which are now called *electrons*[6].

This example constitutes what Schwab[2] has referred to as a 'rhetoric of conclusions', viz., 'they were repelled by the negative part of an electric field' leads to the conclusion that 'all types of atoms must contain these negative particles'. It is interesting to observe that the textbook makes no effort to connect the experimental observation (repelled by the negative part of an electric field) with the conclusion (all types of atoms must contain these negative particles). In the absence of any logical step that could connect the two (i.e., observation and conclusion) , students are forced to simply memorize. It is concluded that the presentation by Segal[5] provides a better opportunity for students to think and thus facilitates conceptual understanding.

## Interpretation of alpha particle experiments

In order to maintain his model of the atom and explain large angle deflections of alpha particles, J. J. Thomson had put forward the hypothesis of compound scattering (multitude of small scattering).

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On the other hand, Rutherford[7] explained the experiment by the hypothesis of single scattering. The two hypotheses based on the same experimental results led to two entirely different atomic models and to a bitter dispute between Thomson and Rutherford. Of the 23 textbooks analyzed[4] none described the controversy between Thomson and Rutherford and the fact that experimental data often lead to more than one model/interpretation. Inclusion of this aspect of nature of science can facilitate students' conceptual understanding.

A recent textbook deals with this issue in the following terms:

> The only way to account for the observations [deflection of alpha particles] was to conclude that all of the positive charge and most of the mass of the atom are concentrated in a very small region[8].

This makes interesting reading in retrospect, as it distorts historical facts. Thomson considered to be the 'world master in the design of atomic models' did not agree with Rutherford's interpretation and the controversy between the two lasted for many years and is well recorded in the history of science[9]. Textbook authors could easily use this example to show that interpretation of empirical data is difficult even for those scientists working in cutting-edge experimental work, and thus students must be aware that doing and understanding an experiment are two different facets of scientific development.

### Bohr's incorporation of Planck's 'quantum of action': a contradictory graft

Bohr's[10] incorporation of Planck's 'quantum of action' to the classical electrodynamics of Maxwell, represented a strange 'mixture' for many of Bohr's contemporaries and philosophers of science. This episode illustrates how scientists, when faced with difficulties, often resort to contradictory 'grafts', for which there is little justification on logical grounds. Of the 23 textbooks analyzed[4] only two described satisfactorily Bohr's dilemma and the following is an example:

> There are two ways of proposing a new theory in science, and Bohr's work illustrates the less obvious one. One way is to amass such an amount of data that the new theory becomes obvious and self-evident to any observer. The theory then is almost a summary of the data. The other way is to make a bold new assertion that initially does not seem to follow from the data, and then to demonstrate that the consequences of this assertion, when worked out, explain many observations. With this method, a theorist says, 'You may not see why, yet, but please suspend judgment on my hypothesis [cf. hard core[11]] until I show you what I can do with it'. Bohr's theory is of this type. Bohr said to classical physicists, 'You have been misled by your physics to expect that the electron would radiate energy and spiral into the nucleus. Let us assume that it does not, and see if we can account for more observations than by assuming that it does'[12].

This detailed presentation of Bohr's dilemma may seem surprising to some chemistry teachers and students, and still it illustrates how scientists at times have to resort to 'heuristic principles' for which they can provide little justification. Let us now compare this presentation with that of a recent textbook:

> Although Rutherford was never able to incorporate electrons into his model of the atom, one of his students, Niels Bohr, proposed a model for the hydrogen atom that accounted for its spectrum. The Bohr model assumed that the negatively charged electron and the positively charged nucleus of a hydrogen atom were held together by the force of attraction between oppositely charged particles[13].

Students who follow this textbook may come to the conclusion that Bohr's model had no inconsistencies and his contemporaries accepted it without any arguments or controversies. This presentation is indeed a very 'sterilized' version of scientific progress and deprives students of historical details that can help to arouse their curiosity, interest and conceptual understanding.

## CONCLUSION

Most of the general chemistry textbooks seem to emphasize experimental details based on observations and generally ignore the 'heuristic principles'[2], that led the scientists in the first place to design their experiments and facilitated greater conceptual understanding[11]. Besides atomic structure, a review of the literature shows that textbooks follow the same approach in many other topics, such as: determination of the elementary electrical charge[14], kinetic theory[15], origin of the covalent bond[16], laws of definite and multiple proportions[17] and the periodic table[18]. It is suggested that chemistry teachers can facilitate greater conceptual understanding by incorporating historical episodes that form part of the curriculum and at the same time illustrate that progress in science inevitably leads to discussions, arguments and controversies. Hopefully, this approach may provide students evidence to the effect that science is tentative and that much remains to be done and hence they can also participate in this human endeavor.

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