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# TEXTBOOK ANALYSIS IN THE SERVICE OF CHEMISTRY TEACHING

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RESUMEN

Los autores de libros de texto tienen visiones propias sobre los contenidos y sobre los métodos de enseñanza, los cuales deben conducir hacia un alto nivel de pensamiento científico. Sin embargo, los textos por sí solos no garantizan buenos resultados, ya que las relaciones sociales entre el maestro y los estudiantes tienen una gran influencia sobre la enseñanza y el aprendizaje. Debido a esto es que el estudio hecho por el maestro sobre el libro de texto antes de ejecutar los procesos de enseñanza, facilita estos procesos. Este artículo sugiere un método para el análisis del libro de texto. En el análisis de un curso de química en secundaria se involucra el aprendizaje de una estrategia de clasificación de los conceptos centrales y de una clasificación de las actividades, todo esto basado en el grado de dificultad de las tareas. El estudio también intenta encontrar las bondades de homologar el curriculum nacional con el libro de texto de un curso de química. Los objetivos nacionales se preocupan de los contenidos, el significado social, enfatizan sobre la química experimental y motivan a los estudiantes hacia estudios futuros. El trabajo de la mayoría de los libros de texto cae en categorizaciones de orden superior caracterizadas por el conocimiento de estructuras que asumen la aplicación del conocimiento o la formulación de inferencias. Las actividades de los buenos libros de texto también tienen significado social e incluyen una buena cantidad de trabajo experimental. La calidad de los libros de texto está encaminada hacia la actualización de los contenidos. Todas las cualidades anteriores están encaminadas hacia una alta motivación por el estudio.

**Palabras clave:** estrategia de aprendizaje, clasificación de conceptos, clasificación de actividades, análisis de libros de texto.

ABSTRACT

The authors of textbooks have their own visions of contents and teaching methods, which should lead to a high level of scientific thinking. However, the textbook alone does not guarantee good results because the personal and social relationships between the teacher and students have a major influence on teaching and learning. Therefore, the teacher's study of the textbook before teaching facilitates the teaching process. This paper suggests one method of textbook analysis. In the analysis, one upper secondary level course of chemistry instruction involved the use of a learning strategy: classification of the central concepts and a classification of activities based on task difficulty. The study also attempted to find out the goodness of fit between the national curriculum and the textbook chemistry course. The national objectives concerned the content of knowledge, social significance, emphasis on experimental chemistry, and inspiring students for further study. The majority of the textbook tasks fall into higher order categories characterized by knowledge structures assuming application of knowledge or making inferences. Good textbook activities also have social significance, and a number of experimental tasks are included. The textbook quality is further enhanced by up-to-date content. All of the above qualities are related to high study motivation.

**Key words:** learning strategy classification of concepts, classification of activities, textbook analysis.

## INTRODUCTION

As a central disseminator of knowledge, the textbook has maintained its position in spite of the emergence of electrical data transmission and access to digital educational resources. The majority of teachers rely on the teaching of the subject matter knowledge that is available in the textbook (see e.g. Sánchez & Valcárcel 1999). However, it is very rare that the teachers of the subject evaluate the textbooks themselves, although they would benefit most from the concrete results of textbook evaluations. As groups of students are different as far as their knowledge, skills and experiences are concerned, the study of textbooks will facilitate lesson planning and aid in finding and applying versatile work methods and facilitate individualisation of instruction.

Both in teaching and in textbooks, it is important that scientific concepts are made accessible to the students in a number of different ways so that each student discovers his or her own optimal approach to studying and learning. This is important on the one hand because students need to find an approach that is compatible with their individual worlds of experience and on the other hand to avoid leaving the student with the unfortunate impression that concepts can be defined on the basis of a single occurrence of the concept. The teaching should widen – sometimes even change - the student's world of mental states in such a way that the student, as a result of instruction, will be able to understand the bi-directional dynamics (induction Û deduction) between real world phenomena and theory (figure 1).

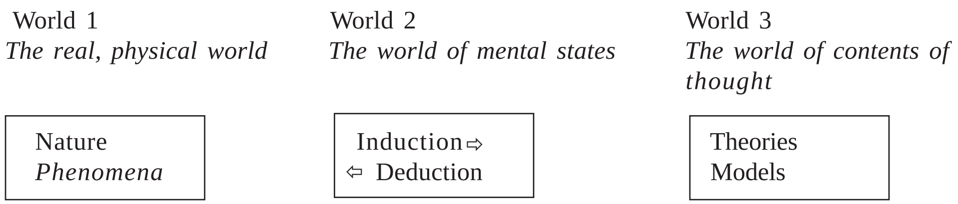


**Figure 1.** The real world, the world of mental states and the world of the products of the human mind (cf. Popper & Eccles 1977, 36-50)

## INVESTIGATION METHODOLOGY

### 1. A strategy classification for concept learning

Textbooks describe links between real world phenomena and scientific theories. In order to make it possible for students with such varying previous experiences to understand these associations, it is important to offer a variety of strategies and clarify the ways in which the information is manifested in the textbook. The manifestation of textbook information is best approached through an analysis of concepts and their organization in each individual textbook. As a basis for the construction of such a conceptual analysis, Klafki's (1963, 135-143) and Perkins's (1987, 62-85) questions about the meaning and structure, with examples and explanations of knowledge are applied. The *meaning of knowledge* is related to the use and application of knowledge. In a textbook, knowledge is typically presented and integrated in the text and then applied in examples and exercises. The *structure of knowledge* may be evaluated on the basis of how coherently the knowledge and related key concepts are presented in the textbook, and whether *model examples* are provided with accompanying pictures and examples. The text, pictures, examples and exercises explain knowledge. These are the criteria that may be used to study the key concepts of a textbook from the viewpoints of

1) integration within the subject,
2) integration between two or more subjects,
3) pictures accompanying concepts, and
4) examples or exercises clarifying concepts.

As the teaching of science emphasizes the empirical nature and social significance of knowledge, it is relevant to add the dimensions of how to *approach the concept empirically* as well as how the *concept is related to the world of mental states* in the classification of concepts.

**2. Classification of exercises**

A textbook has to provide possibilities for both inductive and deductive (see figure 1) reasoning. The goal of inductive reasoning is to discover relationships among the elements of knowledge that connect the items of knowledge. The goal of deductive reasoning is verify an individual item of knowledge on the basis of a definition or rule. Science instruction seems to prioritize the inductive mode in the presentation of the concept and the deductive verification after the concept has first been defined.

In textbooks, examples and activities are used to teach reasoning skills. The demands of reasoning skills may be evaluated on the basis of the width and depth of the knowledge needed in managing tasks. Using a four-level classification (see Mikkilä 1992; Nurrenbern & Robinson 1998; Ahtineva 2000) have carried out task analyses of examples. The lowest level of the processing hierarchy, the recall task level, is represented by tasks which either require rote learning of the material or mechanic transfer of knowledge from a table format to a note format, for example. The learner is much less active in carrying out repetitive tasks than in performing tasks at the next level of the hierarchy. The next level tasks are more demanding, as they require the application of knowledge or the transformation of knowledge, i.e. the original knowledge must change in some way as a result of performing the task. The tasks on the third level are increasingly demanding. The prerequisite for successful solution of such tasks is the control and evaluation of a number of items of knowledge within one task. Finally, the highest level, i.e. the fourth level, contains tasks that can be described as extensively activating, because they frequently involve the use of material and the application of information that have to be derived from sources other than the textbook. In addition to the above four-level classification, it is useful to analyse tasks from the viewpoints of the empirical approach (cf. the bidirectional induction Û deduction dynamics, figure 1) and social significance (cf. the real world, figure 1).

**RESULTS AND DISCUSSION**

**1. Conceptual analysis**

**The most common way** to present knowledge is to provide it in the text. The concept of *element*, for example, is defined in a textbook (Kemian maailma 1, [The World of Chemistry 1] Ahtineva, Karjalainen A., Karjalainen M. & Muilu H. 1995, 6) as follows (freely translated from the original Finnish version): *In Chemistry, elements traditionally refer to substances that cannot be decomposed chemically. This definition does not, however, help us* *understand why elements are different and why they react with each other. In order to explain these phenomena, one has to study atoms, the particles that elements are made of.* In textbooks, this approach is commonly applied to definitions of all key concepts. In the above example, for instance, the text links the concept of the element to its constituent particles, the atoms, within the subject of Chemistry.

**The second approach** used in dealing with concepts is one that takes into account the integration between different subjects; information such as the etymology of the name of the concept or its developmental history is included in this analysis. This approach also involves a text account. In the following example, the concept is linked with some historical information: *John Dalton (1766-1844), an English scientist, published his work, "New System of Chemical Philosophy", in 1808, in which he suggested that elements consist of atoms and justified this conception by the standard composition of chemical compounds. [...] (*Ahtineva et al. 1995, 6*)*

**The third approach** to a concept is to link it with a picture. The concept of the element is illustrated by means of a number of pictures in the Chemistry textbook The World of Chemistry 1. Some illustrative examples are the Scanning Tunnelling Microscope picture of coal (p.6), the diagrams of the isotopes of hydrogen (p. 8) and the symbolic re-presentations of the isotopes of elements (p. 9).

**The fourth approach** to the study of the concept is to give examples or exercises related to the concept. A number of examples (pp. 9 and 25) and exercises (example 6 below) are related to the concept of the element.

6. The names of elements often have interesting histories. Where do you think the names, a) helium, b) cobalt, c) chloride, d) iodine, and e) phosphorus come from?

**The fifth approach** is the empirical one; i.e., does the concept's definition, whether given in text, illustrated by a picture, by an example, or by an activity, provide a prompt for the student to carry out a demonstration, an assignment, or make inferences on the basis of a demonstration or an assignment. For example, activity 29 (p. 18) in the textbook studied provides an option for an empirical approach to the concept of energy of the electron shell. *29. Study the flame reactions of calcium, strontium, barium, copper, lithium, and sodium chlorides by means of a gas burner and a chrome-nickel or platinum wire. Cleanse the wire carefully before each test and between the trials with strong hydrochloric acid (a water solution of hydrogen chloride) and by annealing. What is the smallest amount of substance that yields the substance's typical flame colour?*

**The sixth approach** links the concept to the real world, as for example the text section, "Radiochemistry solves problems" in the chapter, 'Elements', in this Chemistry textbook indicates. **One concept may be approached in many ways**, as the above example on elements shows.

In addition to the concept of the element, all the key concepts (N = 14) in the textbook were analyzed similarly. The superordinate concepts were: elements (1), compounds (2), states of aggregation (3), mixtures (4) and chemical reactions (5). The superordinate concept, element, relates to the structure of the atom (6), the periodic table (7) and amounts (8), and the concept of mixtures relates to concentration (9). Chemical reactions were dealt with by means of stoichiometric calculations (10), reaction rates (11), energy changes (12), oxidation - reduction reactions (13) and protolysis reactions (14).

The study (Ahtineva 2000, 73-78) showed that all of the above key concepts were integrated with other school subjects, most commonly with mathematics (7/14). For example, the student would have to be able to deal with the formula *a = b/c* in order to calculate amounts and concentrations. In addition, to comprehend the textbook subject matter the student is expected to know the following concepts: mean, per cent, coefficient and ratio. Key concepts were also integrated with other subjects, such as: home economics (5/14), biology (4/14), physics (3/14) and health science (2/14). Half of the concepts also contained historical background information on the development of Chemistry as a discipline or personal information about a scholar in relation to a concept.

Each key concept was illustrated with at least one picture and two or more examples. A total of 62 examples were used to illustrate key concepts and the information provided was applicable in 201 exercises. Everyday and real world concepts were illustrated in text or picture in 43 instances. When an empirical approach to each key concept was possible; this was either referred to in the text, the teacher's book, or in the exercises (a total of 100 references). According to the analysis, the teacher could always opt for an inductive approach to a concept with the help of a model example.

## 2. Classification of activities

The following tasks in Kemian maailma 1 (The World of Chemistry 1) may be classified as fairly undemanding first level **recall** questions (cf. Nurrenbern & Robinson 1998).

34. What are the symbols, periods and groups of the following elements:
a) iron b) silicon c) sulphur d) wolfram e) silver f) coal

55. Look up in the handbook and study the names of the following polyatomic ions:
a) OH- b) $NO_3$- c) $SO_4^{2-}$ d) $CO_3^{2-}$e) $PO_4^{3-}$

Answers to these questions can be directly located and picked from the tables. This group does not contain any experimental tasks in this chemistry textbook. Also tasks related to the real world are infrequent among recall tasks (Ahtineva 2000).

**Tasks requiring application of information** are exemplified below.

12. Natural copper contains 69,1% of the isotope $^{63}Cu$ ($A_r$ = 62,93) and 30,9% of the isotope $^{65}Cu$ ($A_r$ = 64,93). Calculate the relative atomic mass of copper.

98. Health checks often involve assessing the value of haemoglobin (Hb) in blood. Normal values in women are 120 – 160 mg/ml and in men 140 – 180 mg/ml. $M_r$(Hb) is approximately 64 - 500.

a) Calculate the above values as mol/l.

b) Each haemoglobin molecule contains four $Fe^{2+}$ions. How many grams of iron are there in 5,5 litres of blood (average total volume of blood in the human organism) with a Hb value of 150 mg/ml?

192. What is the pH value of the resulting solution when equal volumes of 0,001M NaOH solution and 0,003 M HCl solution are combined?

Application of information requires understanding. In *12* above, for example, the relative atomic mass can be calculated if both the symbols are understood and the concept of percentage is understood. In this case, a similar example has preceded the present one earlier in the textbook (calculation of the relative atomic mass of magnesium). Tasks which require application of knowledge demand modification of a previously given formula; inserting the values in the formula in an intact form is not enough. The formulas that are needed in the first course of upper secondary Chemistry frequently have the form of $a = b/c$, as for example in calculations of concentration. The majority of application tasks involve mathematical operations (cf. Nurrenbern & Robinson 1998 *"algorithmic questions"*) and are thus integrated with mathematics. Some tasks, such as *98*, are linked to the real world. Task *98* has integrative links to health science. Task *192* can be classified as empirical, because both solutions can be prepared in class; equal quantities of each solution can be measured out, and finally, the pH value of the resulting solution can be measured in class.

Some examples of **tasks requiring comparison and justification** are given below.

38. The following compounds exist: $H_2O$, $MgCl_2$, $CCl_4$ and $NH_3$. On the basis of the periodic table, judge what compounds the following elements can form: a) H and P b) F and Si c) Sr and I d) H and S.

74. The car's safety cushion ("air bag") is protective equipment, in which an explosive decomposition reaction of sodium azide ($NaN_3$) takes place in crashes. Nitrogen gas ($N_2$) is released in the reaction. Which properties of gases is the protective effect of the safety cushion based on?

175. Wrap a tarnished silver object loosely in a piece of aluminium foil and put it in a kettle. Pour in water to cover the object properly. Add a few tablespoons of sodium bicarbonate ($NaHCO_3$). Let boil for 5-10 minutes. Remove the object, rinse well and wipe dry. What has happened to the silver object? What about the aluminium foil? Why was sodium bicarbonate needed? Write the equation to describe the reaction that took place on the surface of the silver object.

A prerequisite for tasks belonging to this category is comparing and combining a number of concepts that have been introduced earlier in order for inferences to be successful (cf. Nurrenbern & Robinson 1998 *"conceptual questions"*). The first step in exercise *38* is to identify the matching elements in the periodic table. In the next phase, the learner is to determine the number of atoms in each element on the basis of the position in the periodic table.

Characteristic of exercises in this category is that direct answers to questions are not found in the immediately preceding text (for example task *175*). In exercise *74*, the relevant gas properties have to be picked from several passages, pictures and captions in the preceding text. Exercise *74* is related to the real world, as a safety cushion is a common safety precaution in many cars today. Some exercises, like *175* for example, may be classified as both em-pirical and as being linked to the real world. The significance of the oxidation and reduction reactions and the relevance of the galvanic cell are justified in physical reality, when it becomes apparent that silver can really be polished using this method.

The following tasks represent the highest processing level, i.e. they are examples of **extensively activating tasks** (cf. Mikkilä 1992, 113; Ahtineva 2000, 80):

10. A dosimeter is used to measure radioactivity. Think of some jobs in which the use of a dosimeter is necessary. Why does the dosimeter have to be used?

58. Food industry uses E codes in additives. Why? Where can you get information on E-coded additives?

81. Ammonia and chlorine, which are important gases for industrial purposes, are transported in liquid form in large containers by rail. Find out what the properties of these gases are and make an action plan for a potential leakage.

The above higher order processing tasks all have links to the real world. Figure 2 below illustrates the type, degree of processing demanded and number of tasks in the textbook investigated.

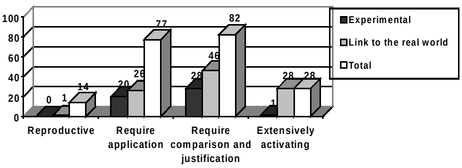


**Figure 2.** The World of Chemistry 1- classification of activities

The majority (79%) of the textbook studied presupposed either application of knowledge, comparison or making inferences. Apart from one exercise, all the empirical exercises fell into these two categories. The number of empirical exercises was 49, i.e. every four exercises could be implemented in practice either as student work or as teacher-led demonstrations. Proportionally the most empirical exercises (13/26) were found in the chapter on the protolysis (photolysis???) reaction. Many of these consisted of preparing solutions, measuring and defining their acidity or concentration. Half of the textbook exercises (101/201) had a connection to the real world (Figure 2). Proportionally the most everyday exercises were linked to the concepts of element (12/14) and energy (11/13). All the concepts do not have an empirical or everyday extension. Take the periodic system, for example, which is defined in isolation from the empirical world or practice. On the other hand, all higher-level exercises had a link to the real world.

## CONCLUSIONS

### Implications for Chemistry teaching and learning

These above methods were used in analyzing the textbook before teaching the first Chemistry course at upper secondary school. The analysis was useful in the choice of teaching methods, and it helped in the individualisation of teaching. The concept learning strategies that were identified in the book made it easier to plan learning situations that allowed a number of knowledge strategies to be used. In some instances the planning process resulted in an entirely novel strategy to be used in dealing with the issue, which was different from the one in the textbook, and more appropriate for the target group. There is research evidence (e.g. Coppola, Ege & Lawton 1997; Kyyrönen 1999) that the integration of experimental and theoretical approaches in demonstrations and the associated instructional discourse aid learners in integrating everyday conceptions into the scientific conceptual system. Whenever possible, the inductive approach and demonstrations were used also in this chemistry course, even though the textbook did not provide an explicit model for this. For example, the atomic structure was illustrated by means of a needle and a balloon, factors affecting the speed of the chemical reaction were illustrated by acid catalysed dissociation of sodium thiosulfate, a computer program was used to model acid – base titration etc.

In addition to the analysis which was used in drawing up the course plan, information drawn from tests (n = 3) affected the teaching. For example, the first test at the beginning of course pointed out some problems in solving a simple mathematical formulae. The task producing the formula for volume caused problems. *If the mass (m) and volume (V) of a substance are known, the density of the substance can be calculated using the formula* r = *m/V. How is the volume of a substance calculated if its density and mass are known?* As the students were familiar with this formula from earlier instruction in the comprehensive school in both physics and mathematics, it was surprising that only five students out of the total 26 were able to rewrite the formula for calculating volume. Because the same kind of mathematics would also be needed in calculating concentrations or amounts in chemical reactions later on in the course, it was necessary to practice this solving process.

Tasks of various levels aided in the individualisation of teaching. The task analysis made it easier to provide different students with different levels and types of tasks. Experimental tasks in which inductive and deductive thinking are practised tended to motivate the students even if the tasks were not carried out in the lab (Ahtineva 2000). The experimental Chemistry course consisted of 30 lessons in all, during which time more than 100 tasks were covered. Of these, half fell into the two lower-level categories and the other half were divided between the two higher-level categories. Approximately 60% of the tasks were so called homework assignments. Questionnaires administered to students were used to evaluate their experiences and opinions of the textbook activities. The results of the study (Ahtineva 2000) showed that tasks that had a link to the practical and the real world motivated the students. 14 students in this course (54%) were inspired to undertake further chemistry study in upper secondary school (cf. 35 - 40% approximately). Although the real world tasks were in general considered difficult, the students - irrespective of study motivation - regarded the more demanding tasks as better than the less demanding and simple ones.

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