STUDYING STUDENTS' UNDERSTANDING OF THE INTERPLAY BETWEEN THE MICROSCOPIC AND THE MACROSCOPIC DESCRIPTIONS IN CHEMISTRY

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Abstract. *The perception of the distinction and interplay between concepts and models pertaining to the description of the microscopic level and those pertaining to the description of the macroscopic level is a key feature largely determining conceptual understanding in chemistry. Information about the extent and clarity of such perception can therefore be valuable for the design and optimisation of approaches to the presentation of basic and general chemistry material. The paper presents the outcomes of an investigation in this regard, performed by subsequently administering three specifically designed questionnaires to a group of first year students taking a general chemistry course. The discussion considers both the conceptual and the practical relevance of the issue and extends to inferences for classroom work and for the general approaches to chemistry teaching.*
Key words: *microscopic description, macroscopic description, general chemistry courses*.

Introduction

The entire conceptual framework of chemistry is based on the interplay between the *microscopic* and the *macroscopic* levels of description. Chemistry models are rooted in the microscopic world of atoms and molecules and concerned with the way in which microscopic behaviours and events generate the macroscopic ones. The clarity, with which concepts and models belonging to the two levels of description, and their mutual relationships, are identified and understood is, therefore, a key-feature largely determining conceptual understanding and learning results in chemistry (Lijnse, Licht, Vos & Waarlo 1990). The relevance of the issue has prompted numerous studies, so that an adequate review would by itself require the size of a review article. Alternative perceptions and difficulties are highlighted by studies on students' mental images of microscopic particles (Harrison & Treagust, 1996; Maskill, Cachapuz & Koulaidis, 1997), of the microscopic features of matter (Nussbaum & Novick, 1982; Anderson, 1990; Lee, Eichinger, Anderson, Berkleimer & Blakeslee, 1993) and of the microscopic-level interpretation of phenomena, like electric conduction in solids (De Posada, 1997), solubility (Ebenezer & Erickson, 1996), heat and temperature (Dominguez, De Pro Bueno & Garcia-Rodeja, 1998). Diagnostic studies identify learning difficulties (Mitchell & Kellington, 1982), insufficient familiarity with the microscopic description (Sawrey, 1990) and the presence of misconceptions concerning it (Ben-Zvi, Eylon & Silberstein, 1986; Nakhleh, 1992). The findings have prompted general-character reflections on some features of the approaches to chemistry teaching, like the inadequacies of pedagogical approaches largely favouring the symbolic level over the microscopic and the macroscopic ones (Johnstone, 1993). Enhanced comprehension of the molecular level, often favoured by visualisation, proves important for the general understanding of chemical phenomena and their interpretation, and for the generation of chemically-sound mental images (Gabel, Samuel & Hunn, 1987; Gabel, 1993; Smith & Metz, 1996; Cardellini, 1996; Selvaratnam, 1998; Mammino, 1998a).

This paper presents the outcomes of a study exploring students' perceptions and awareness of the distinction and interplay of the two levels of description, across a considerable portion of the material commonly constituting the content of a first year general chemistry course.

Research methodology

The study was initially prompted by the outcomes of a systematic analysis of students' answers in general and physical chemistry courses, complemented by a number of personal interviews, in two different institutions, the University of Zambia (UNZA) and the National University of Lesotho (NUL). The analysis had showed that a broad variety of mistakes (e.g. in problems involving the *molecule* and the *mole* concepts) and misconceptions (e.g. students speaking of the *temperature* of individual molecules) could be traced to a common root – inadequate clarity in the identification of what pertains to each of the two levels of description and of the interplay between the two levels. It was considered that a panoramic overview, comprising the concepts that appeared more critical, could be functional for the design of addressing options to be utilised both at lecturing and tutorial levels. A first study to this purpose was carried out in 1996 at NUL, by means of a questionnaire distributed to the students taking a second year physical chemistry course. The entries were the same as the ones utilised in the first questionnaire of the current study and reported in table 1. They comprised a number of individual terms, selected among those for which incorrect use had been observed more frequently, and few expressions involving some of those terms, in order to broaden the diagnostic range. The request for explanations aimed at stimulating reflection on the individual concepts, thus attempting to ensure that the selection would not be done randomly or superficially. The outcomes confirmed the presence of inadequacies in the distinction of the two levels of description and the perception of their interplay (Mammino, 1997).

It was thereafter considered that comparison with a different context could bring information suitable for broader reflections on some aspects of the approaches to chemistry teaching – such type of comparison being likely to add new contributions or new perspectives (Maskill, Cachapuz & Koulaidis, 1997). Moreover, it was considered that the probability of obtaining both new qualitative information and interesting opportunities for comparative considerations would be higher if the characteristics of the second context differ widely from the first one. The second group selected was a group of 20 first-year students registered for an Electronic Engineering B.Sc. degree at the University of Ancona (Italy). All the students had taken chemistry courses at secondary school, though at different levels, depending on the type of secondary school attended. Therefore, prior exposure to the basic concepts could be assumed as granted, though the background preparation was not completely homogeneous. The present paper discusses the results of the study with this group.

The complete study with this group involved three questionnaires. The reasons and approaches for the design of the second and third questionnaires are conveniently illustrated through a short history of the administration. The first questionnaire (questions in table 1, a total of 34 entries) was distributed in 1997, when students were halfway of a one-semester general chemistry course, and was returned by 18 students. Many of these did not express reasons for several or most of the assignations that they had chosen: in total, 97 explanations were provided, versus a potential number of 18x34=612. Since such reasons were expected to supply valuable information about the students' actual perceptions on the concepts concerned, it was considered appropriate to explore an alternative way to obtain it.

It was tentatively assumed that the provision of concrete examples might prove easier than the provision of general or theoretical explanations. A second questionnaire was distributed, containing the same entries as the first one and asking for examples. The format chosen was that of a worksheet in which the terms were listed one below the other. Each term was followed by two empty boxes, the first one for examples pertaining to the description of the microscopic world, the second one for examples pertaining to the description of the macroscopic world. It was also suggested that, when a term or expression is not appropriate for one description, the corresponding box be barred. At the end of the questionnaire, a half-page empty box was made available for students to express their doubts, difficulties or comments. 18 students returned the questionnaire. The initial assumption proved basically correct. The proportion of answers

Table 1. Summary of the answers to the first two questionnaires, provided by two groups of Italian students taking a general chemistry course, in samplings conducted in 1997 and 1998, respectively.

1. What do we mean by "microscopic world"?
2. What do we mean by "macroscopic world"?
3. Consider the terms listed below. For each of them:
i) State whether you would use it:
- *only in the description of the microscopic world*
- *only in the description of the macroscopic world*
- *in both descriptions*

ii) Provide a brief explanation to justify your answer.

	micro	*macro*	*both*	*do not know*	examples provided only for micro	only for macro	both cases
atom	14–35	1–0	3–1	0–0	12	1	5
electric charge	13–24	0–0	5–12	0–0	3	0	15
compound	0–2	9–10	8–24	1–0	5	4	8
concentration	2–7	4–4	8–21	4–4	3	4	5
element	6–14	6–4	6–18	0–0	2	1	9
energy	4–5	5–3	9–25	0–2	2	4	9
free energy	2–9	4–4	7–13	5–10	1	0	2
enthalpy	4–17	1–5	1–11	12–3	3	0	1
entropy	6–14	1–6	2–12	9–4	2	0	0
force	2–0	4–9	12–26	0–1	0	1	13
electromotive force	3–8	8–10	5–14	2–4	2	4	3
work	1–1	5–8	12–26	0–1	1	5	7
mole	11–17	1–9	6–10	0–0	4	4	2
molecule	13–30	2–2	2–4	1–0	10	0	0
wave	6–7	1–4	8–21	3–4	0	0	7
particle	15–28	0–0	2–6	1–2	6	0	0
electrical potential	6–9	0–5	10–18	2–4	2	1	0
pressure	1–0	9–15	5–19	3–2	1	7	3
boiling point	1–5	10–11	5–15	2–5	1	4	2
system	0–0	4–14	10–16	4–6	1	1	1
substance	1–3	9–12	6–20	2–1	1	0	2
state	0–5	10–16	6–13	2–2	1	0	2
temperature	1–1	7–18	9–14	1–3	1	3	3
volume	2–1	8–16	5–17	3–2	0	4	2

4.Consider the following expressions and proceed as for question 3.

	micro	*macro*	*both*	*do not know*	examples provided only for micro	only for macro	both cases
to absorb energy	7–4	3–3	7–26	1–3	0	2	2
to have energy	4–3	2–2	11–28	1–3	1	2	1
to have entropy	4–12	2–4	1–15	11–5	0	0	0
to combine	4–11	2–8	8–16	4–1	4	0	0
to be bonded to...	5–13	2–1	10–17	1–5	1	0	0
to form a bond	7–25	1–2	9–7	1–2	1	1	3
to release energy	5–6	1–5	9–21	3–4	0	0	2
to pass from one state to another	3–11	7–11	6–13	2–1	0	1	2
to react	5–11	3–7	9–15	1–3	0	2	0
to be heated	1–2	5–15	11–15	1–4	0	1	0

The parts in italics constitute the text of the first questionnaire. The first four columns show the numbers of students who chose the corresponding assignations in the first questionnaire in the 1997 sampling (before the hyphen) and in the 1998 sampling (after the hyphen). The last three columns show the numbers of students who provided examples for each category, as requested in the second questionnaire (only for the 1997 sampling).
The entries, as listed here, correspond to the alphabetical order in Italian, such option being meant to prevent any type of suggestions that might stem from conscious or unconscious association of neighbouring words.

increased: 236 examples provided versus a potential number of 612. There was also a noticeable improvement in relation to some assignations (e.g. only five students had assigned *electric charge* to both descriptions in the first questionnaire, while 15 students provided examples for both descriptions in the second questionnaire). However, the cases in which no examples were provided, even in relation to simple concepts, were still numerous. It was considered appropriate to explore still another option to try and obtain more complete and finer information. A perspectively easier third questionnaire, demanding the discussion of supplied examples, instead of the "creation" of examples by students, was distributed. It contained only three questions (Table 2), the third one requiring the discussion of a statement made by one of the students on a previous occasion. Some space for comments was also provided. 19 students returned it. The second questionnaire was administered one month after the first one, the third questionnaire about six weeks later, i.e., towards the end of the course. These intervals were determined by the time taken for the analysis of the answers to the previous questionnaire and for the design of the next one.

Research results: an overview of the students' answers

All students answered the two introductory questions of the first questionnaire. Summaries of the assignations for the various entries are reported in tables 1 and 2 (absence of assignation was considered equivalent to "I do not know"). The explanations and examples provided by the students will be presented here rather extensively, because of their significance as sources of qualitative information. On the basis of their conceptual and mode-of-perception features, they are grouped into the following three major pre-selected categories (or knowledge-domains):

- The distinction between the two worlds. It focuses on the criteria explicitly suggested, or practically assumed, for the distinction between the two levels of description.
- The description of the two worlds. It focuses on the selection of what can be utilised in either description and, therefore, on the assignations of the individual entries to either level. Separating this category from the former, besides having an obvious conceptual significance, is useful for practical purposes. By involving a separate analysis of the assignations – whose number is much higher than the number of explanations – it contributes a self-standing information-area.
- Atoms and matter. It focuses on the relationships between the two worlds.

The distinction between the two worlds. The criteria for the distinction are expressed in the answers to the two introductory questions of the first questionnaire. Only three students relate the distinction to the consideration of "the atomic and molecular level" for the microscopic world, while the macroscopic world is "the world around us", or "the one that we can see". Eight students choose the criterion of "not being visible" or "being visible" to the naked eye and two students relate the distinction to the "reference system" or the "view point", being microscopic "those things that have small dimensions with respect to the reference system from which they are observed". Other criteria – each proposed by one student – consider respectively: ***a)*** not being or being "directly perceivable" by us; ***b)*** the observation range, being microscopic "those events or elements observable in a narrow or infinitesimally small range" and macroscopic those that can be observed "in a broad range"; ***c)*** our description, microscopic being "seeing a system as an ensemble of parts that cannot be further decomposed" and macroscopic being "the description of a system as a homogeneous element having a relevant characteristic that enables a description without resorting to an analysis of sub-components of the system"; ***d)*** the extent to which they can be defined, the microscopic world being "a well defined world", while the macroscopic world is "an individual, imprecise world, remaining vague"; ***e)*** our approach, the microscopic world being "the origin of reality", while "macroscopic world means analysing an issue from the knowledge of general notions".

Table 2. Summary of the answers to the third questionnaire, provided by two groups of Italian students taking a general chemistry course, in samplings conducted in 1997 and 1998.

1. Consider a gas container. The container is at rest. Which of the following quantities/aspects can be defined for the gas as a whole, and which can be defined for each molecule?

quantity/aspect	*it has a meaning with reference to each single gas molecule*			*it has a meaning with reference to the gas as a whole*		
	yes	*no*	*do not know*	*yes*	*no*	*do not know*
heat	4–14	9–22	6–5	17–37	1–0	1–4
kinetic energy	17–37	1–1	1–3	8–17	7–18	4–6
internal energy	6–22	8–9	5–10	15–17	2–12	2–12
enthalpy	3–18	8–14	8–9	15–24	1–9	3–8
entropy	5–18	7–16	7–7	12–28	2–5	5-8
mass	9–35	5–5	5–1	13–34	2–6	4–1
translational motion	12–20	2–10	5–11	1–7	10–25	8–9
rotational motion	11–23	2–11	6–7	1–7	9–29	9–5
vibrational motion	12–26	2–9	5–6	2–9	7–26	10–6
weight	11–25	4–9	4–2	13–32	2–5	4–4
pressure	6–10	8–26	5–5	16–39	3–1	0–1
linear momentum	15–28	2–4	2–9	6–16	8–17	5–8
temperature	6–14	8–23	5–4	17–38	1–2	1–1
velocity	16–31	3–6	1–4	4–15	10–18	5–8
average velocity	9–20	6–14	4–7	7–19	10–15	2–7
volume	6–12	9–23	4–6	16–37	1–3	2–1

2. Consider an electron in an atom. With reference to it, you may speak of:

	yes	*no*	*do not know*
heat	3–7	2–31	14–3
electric charge	1–41	16–0	2–0
enthalpy	2–1	12–31	5–9
entropy	19–4	0–30	0–7
kinetic energy	14–31	3–4	2–6
electrostatic potential energy: attraction	18–34	0–3	1–4
repulsion	14–31	2–7	3–3
mass	19–38	0– 3	0–0
angular momentum	10–21	8–13	1–7
motion	19–38	0–1	0–2
position	15–31	4–6	0–4
linear momentum	11–27	7–8	1–7
temperature	1–4	16–30	2–7
trajectory	16–35	2–5	1–1
velocity	18–39	1–1	0–1

3. Discuss the sentence "Atoms constitute the matter of the microscopic world". Explain whether you consider it correct or not and why. (Try to provide a "thought out" answer, taking into account the meaning of "microscopic world", "macroscopic world" and "matter").

The parts in italics constitute the text of the questionnaire. The columns show the number of students choosing each of the options in the 1997 sampling (before the hyphen) and in the 1998 sampling (after the hyphen).

The explanations accompanying the assignation of individual entries to either description highlight the way in which students interpret what they have stated in the answers to the first two questions. The explanations are largely consistent with the previous answers. In most cases, they refer to the size of the object (the atom is "one of the smallest things", "a small particle", "something very small") or to our possibility of perceiving it ("the atom cannot be seen or perceived by our senses"). In some cases, the size-criterion becomes misleading, like in an answer stating that "concentration" applies to both descriptions because "it can be in small or large amounts". Some incorrect assignations and explanations result from a consistent application of the criteria selected initially: e.g., the student choosing the criterion of being "well defined" for the microscopic world and "imprecise and vague" for the macroscopic one, assigns the atom to the macroscopic description because "it is, in turn, made up of electrons, protons and neutrons", force and work to the macroscopic world for being "generic", energy to the macroscopic world because "there are various types of energy", the e.m.f. to the microscopic world because "we speak specifically of it", etc. Aspects encountered in the description of atoms are frequently assigned to the microscopic world. For instance, 13 students assign *electric charge* to the microscopic world because "it is referred to protons and electrons", "it is part of the interactions between atoms", "it is obviously something small", etc.

The examples provided in the second questionnaire highlight an additional feature, i.e., a marked tendency to assign chemical aspects to the microscopic world, and to avoid selecting examples of macroscopic descriptions from the *science* domain. Under *compound*, examples like "water", "two or more elements bonded together", "chemical compounds", are listed in the *micro* section, while the *macro* section contains examples like "a pizza", "concrete", "pig iron", "wine", "a steel bar", "a wall (as composed of bricks)". Under *concentration*, examples like "concentration of a solution", "salt concentration", "percent amount of compounds in a solution" are listed in the *micro* section, while eight examples of the *macro* section are of the type "concentration of people in a country", "concentration of inhabitants in a zone", "concentration of houses", and only three of them are chemical. Several other concepts and aspects from chemistry and physics are listed in the *micro* section: the pressure of a mole of gas (under *pressure*), the temperature of a mole of gas (under *temperature)*, electric and magnetic force (under *force*), electrical work (under *work*), etc. When the word pertains also to common language (like *work* and *force*), the *macro* examples are nearly all from everyday life. Nine *macro* examples of *work* are of the type "manual work", "the work of a worker", "physical activity", "the work done in one day", etc. and only three are worded in a physics-like manner ("the work done to displace a weight"). Under the expression *to form a bond*, two students write "to form a chemical bond" in the *micro* section and "to form a family bond" in the *macro* section, and one writes "between molecules" and "between persons" respectively. The tendency to assign scientific concepts to the microscopic description increases for terms that are far from common language, like *enthalpy* and *entropy*. The examples given under *enthalpy* ("enthalpy is the amount of heat exchanged at constant pressure", "enthalpy is a concept of thermodynamics", "enthalpy is a state function", "enthalpy of reaction") are all listed as *micro* cases.

The description of the two worlds. The main source of information is the assignation of the individual entries. On matching the assignations with the answers to the first two questions, no straightforward relationship can be identified between the provision of the best answers about the distinction criteria and the number of correct assignations. Of the three students providing more than 20 correct assignations in the first questionnaire, two had chosen the criterion of not being or being "visible to the naked eye", and one had chosen the criterion of "being perceivable" by us. Of the six students providing 15 to 20 correct assignations, four had chosen the criterion of being or not being "visible to the naked eye" and two had identified the microscopic world as the world of atoms and molecules. Incorrect assignations are more frequent in relation to thermodynamic properties and to the atomic theory. For example, six students consider the *temperature* concept applicable to individual gas molecules and 15 students consider the *position* concept applicable to an electron, although they were given basic information on the uncertainty principle at secondary school.

Atoms and matter. Information about the students' perception is mainly offered by the discussion of the third question of the third questionnaire. Four students explicitly state that the statement is not correct or not complete: "matter is fundamentally constituted by atoms; but affirming that atoms constitute the microscopic world is restrictive, because it does not take into account the macroscopic world which, in turn, contains the microscopic world"; "If we consider matter as a sum of atoms and molecules, the sentence is wrong, because one should refer to the macroscopic world and not to the microscopic one"; "Atoms constitute also the matter of the macroscopic world; therefore, the sentence is incomplete"; "I do not think that the sentence is totally correct, since the macroscopic world is built on the basis of the microscopic one". Two students comment that "atoms are the smallest part of matter, which, in turn, constitutes the macroscopic world". All the other students consider the statement correct. Their reasons vary widely. The following perceptions are considered the most significant: ***a)*** a framework in terms of "macroscopic matter" and "microscopic matter", where atoms are "the bricks of macroscopic matter", and can be defined as "microscopic matter" because they are in turn made by "protons, neutrons, electrons, quarks, etc., that are the bricks of microscopic matter"; ***b)*** the reference to the "point of view of the observer", either because "one has to refer to atoms when studying the microscopic world", or because "if we put ourselves in the point of view of the electron, the atom will be part of the macroscopic world, while if we look at the atom from the point of view of matter, it is part of the microscopic world"; ***c)*** a historical perspective: "the statement is correct, but relative, because in the micro-world of matter ... there are several types of subatomic particles, continuously coming into light thanks to technological development"; ***d)*** the feeling that it is necessary to justify why atoms can be considered matter: "Atoms... have their own weight and their own dimensions; therefore, they can be considered matter".

The students' comments. Ten students write comments in the comments-box in the second questionnaire. The following difficulties are mentioned: ***a)*** not knowing the meaning of some of the words proposed; ***b)*** not being able to remember some of the definitions; ***c)*** not being able to provide explanations ("I am not able to give an explanation of some terms, though I know that I know them and that I have studied them; but I cannot find the words to explain them"; "Though having in mind examples of the description of the world, it was not easy to find precise words"; "Difficulties encountered: the way of expressing concepts, even if they are mentally present"); ***d)*** difficulties related to the identification of the *domains* of the two descriptions, with particular emphasis on the search for suitable examples from every-day life ("I was not very clear about what I was asked to do, because everything {or nearly everything} can be related simultaneously to the two descriptions, since the macroscopic world stems from the microscopic one"; "I encountered many difficulties at finding suitable examples for expressions that are so far from our way of speaking. For some words, the example was easy, because I have an example every day").

An additional survey

In June 1998, after the analysis of the answers presented above was completed, a quick survey was performed with a similar group, i.e., 41 Engineering B.Sc. students at the University of Ancona, taking the first year chemistry course. Due to some time restrictions, only the first and the third questionnaires were distributed, in two consecutive days. They were returned by 35 and 41 students respectively. The analysis of their answers confirms the main features identified in the first survey: the choice of the criteria for the distinction of the two levels (the large majority choosing being or not being "visible to" or "perceivable by" us, or being "small" or "big"); the main trends in the selections to the various entries (Tables 1 and 2); the higher rate of uncertainties in relation to thermodynamic quantities. Only few explanations to the selections were included (67 in total, most of them consisting of very short sentences – 3-6 words) and they do not contribute additional qualitative information. The discussions for the third question of the third questionnaire were, on the average, longer than in the first survey. They also contribute a view that had not appeared previously, i.e., some students stating that the number of particles constituting a macroscopic object is infinite.

A comparison with the study at NUL

One of the objectives of the study in the Italian context was that of enabling a comparison with the outcomes of the study that had been carried out at NUL. The two educational contexts differ mainly for two aspects: NUL students use a second language as medium of instruction, while Italian students use their mother tongue, and Italian students can be considered, on the average, *advantaged* in terms of background secondary school preparation. A sort of automatic allowance for the latter factor derives from the fact that a second year group was involved in the NUL case, while a first year group was involved in the Italian case. The most significant features highlighted by the comparison can be grouped into the three categories discussed in the following paragraphs.

The distinction between the two levels of description. The comparison highlights striking similarities, both for the criteria stated explicitly and for the explanations to the selected assignations. In the survey at NUL, 18 students out of 20 had chosen "being visible" or "not being visible" to the naked eye as the criterion to distinguish between the two worlds; many assignations were made on the basis of this criterion alone (e.g. temperature as pertaining to the microscopic world because "ït cannot be seen, but it can be measured"); a student appeared to think in terms of "macroscopic substances" and "microscopic substances" (Mammino, 1997). In both cases, the fact that the questionnaires had been distributed by the chemistry lecturer did not appear to influence students towards thinking in terms of molecules while searching for criteria identifying the microscopic world.

The correctness of the assignations and the understanding of individual concepts. The trends in the assignations reveal considerable similarities. In particular, the same two areas – thermodynamic properties and the quantum mechanical description of the atom – are associated with the highest rates of incorrect assignations. Is is known that students often experience considerable difficulties in attaining adequate levels of conceptual understanding in these areas (Niaz, 2000; Tsaparlis & Papaphotis, 2002). Therefore, the higher rate of incorrect assignations for entries pertaining to these areas can be ascribed to the combination of the specific conceptual inadequacies and the inadequate familiarity with the distinction of the two levels of description.

The language-related aspects. Though the answers provided by the Italian students are, on the average, more sophisticated linguistically, some aspects are very similar, including the use of certain words and the frequent resort to short, syntactically incomplete sentences for the explanations. In general, NUL students experience both the difficulties related to the use of a foreign language as a medium of instruction (Mammino, 1998b) and the difficulties related to inadequate familiarity with the *language of science* (i.e. the mode of expression typical of sciences), while the Italian students experience only the latter. On the other hand, most comments by the Italian students in the second questionnaire mention the difficulties in finding appropriate ways of expression. It appears legitimate to infer that inadequate familiarity with the *language of science* is a major reason of the difficulties in expressing views and explanations (Lahore, 1993), and it is common to both contexts.

Discussion and conclusions

The study presented here was diagnostic in character, with specific focus on students' beliefs and perceptions about the distinction and interplay of the two levels of description in chemistry. Since the two levels and their interplay are an integral part of the entire body of chemistry, the questionnaires utilised covered a considerable proportion of the content of a general chemistry course. The results enable the inference that the design of the questionnaires was apt for the objectives of the study. A comparison between the study at NUL and the study in the Italian context highlights the relevance of the second and third questionnaires for the information to be more complete and detailed. The quick survey carried out in 1998 highlighted the relevance of the second questionnaire to complement the information of the first one – the comparison with the first survey showed that the examples chosen by the students filling the second questionnaire enabled a deeper insight into their "practical" views and their perceptions not only of the individual entries, but of the issue as a whole.

The students' answers highlight insufficient clarity in the perception of the domains of the two levels of description and of the nature of their interplay. Not only the criteria for the identification of the domains appear to be hazy, but the very presence of the two levels of description appears to be largely unfamiliar. A comparison of the answers on the basis of the type of secondary school attended (scientific, humanistic or technical) does not highlight remarkable differences. Moreover, the similarities observed in contexts as widely different as the Italian and the Lesotho ones suggest the presence of similar causes in the two contexts, having a heavier weight than those pertaining to only one of them. For both contexts, the findings show that "the declared knowledge possessed by the students on the particulate model has more limitations than it would be predictable on the basis of official programmes" (Dominguez, De Pro Bueno & Garcia-Rodeja, 1998), and suggest a frequent passive acceptance and/or memorisation of the information, often generated by inadequate attention to the role of contents in reasoning and thought (Duschl, 1995).

The most immediate reflections prompted by the results concern the effectiveness of common teaching-approaches in conveying a sufficiently clear, detailed, convincing and complete picture of the two levels of description and their interplay. Two features of the approach appear most relevant: the extent to which students' attention is attracted towards these aspects and the level of rigour of their presentation. The students' explanations highlight efforts to find plausible answers in a basically tentative way, what shows that the questionnaires asked them to reflect on features that are not specifically or extensively highlighted in their common study-material and that were, therefore, considerably new to them. This suggests the opportunity of attracting students' attention on the presence of the two levels, and on their interplay, since their first approach to chemistry, and of gradually guiding them to a comfortable familiarity with the molecular level and with the way in which microscopic events generate macroscopic phenomena. The secondary school textbook needs to play a major role to this purpose, because it constitutes the first encounter of pupils with chemistry, thus determining conceptions that will often remain dominant, even after more advanced instruction, with a "commanding authority" (Tsaparlis & Papaphotis, 2000) that nearly reaches the character of an "imprinting". The systematisation of the presentation of the two levels of description and their interplay needs to become an important feature of the renovation and upgrading of chemistry textbooks (Mammino, 2003).

The fact that some terms denoting concepts, and expressions denoting properties or events, may be utilised only within one of the two levels, and others within both levels, is closely related to the conceptual features of the distinction and interplay between the two levels. Thus, the accurate selection of the wording of definitions and explanations, so that they are fully consistent with the physical models, becomes an optimal instrument to highlight such features. This is in line with the opportunity of enhanced attention to the role of rigour in the presentation of information and as a pedagogical tool (Mammino, 1998c), up to a critical re-consideration of a number of traditional statements and habits (Bradley, Brand & Gerrans, 1987). An illustrative example is offered by a traditional definition of *molecule* as "the smallest part of a compound that maintains the properties of that compound" (a definition still widely utilised in a number of contexts, including some in the Southern African region). Besides the fact that it excludes the molecules of elements from its domain, the definition contributes to uncertainties in the perception of the distinction between the two levels of description, by talking of properties being *maintained* (Mammino, 2000). When asked to list the properties of a substance, students usually start with colour, density, melting point, boiling point and other physical properties, none of which is maintained by the individual molecule. It is therefore important to utilise a different definition, clearly expressing to the nature of molecules as particles pertaining to the microscopic description.

The fact that several students try to find the *macroscopic*-case examples only from everyday life can be associated with the common statement that *macroscopic* refers to the "world around us", such an expression being easily related to what we experience commonly, out of the investigation scope of science. This suggests the potential relevance of the incorporation of epistemological aspects into chemistry teaching, to enhance students' familiarity with the scope of science as well as with the role of models.

Because the study was aimed at obtaining an overview across the major themes of a general chemistry course, the findings interface with a number of relevant investigation-themes in chemical education, from students' understanding of thermodynamic quantities to their beliefs and perceptions about the structure of atoms, chemical bonding, the nature of solutions, the differences between the various phases of matter, etc. Discussing each interface individually would require much more space than that of a single article. For each theme, the discussion would unavoidably extend from the detailed consideration of the conceptual features to issues like:

- The extent to which these same conceptual features can be introduced at secondary school level, without overtasking pupils and without compromising rigour (i.e., by finding a reasonable balance between the need for simplification and the need to avoid excess simplification or loss of rigour);
- The best modes of presenting them to students;
- The degree of rigour (or rigour inadequacies) of current textbooks;
- The extent to which chemistry teachers are confident with the distinction and interplay of the two levels of description.

Some of these issues are the objects of separate on-going studies.

Finally, it is worth mentioning that the study had an immediate "fallout", since the analysis of the students' answers provided a number of suggestions for classroom work, aimed at clarifying the corresponding concepts. In this way, the administration of the questionnaires was incorporated into the ongoing teaching activity, with the questionnaires serving as an introduction to explanations and discussions, by priorly attracting students' attention on the variety of features related to the two levels of description. The only limitation of the option is the fact that the analysis of questionnaires of this type is considerably time-demanding, because they involve both examples and explanations, what implies the analysis of one or more sentences for each entry. Thus, they can be considered viable only for small or medium-size groups of students.

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Резюме

ИЗУЧЕНИЕ ПОНИМАНИЯ СТУДЕНТОВ ВЗАИМОДЕЙСТВИЯ МЕЖДУ МИКРОСКОПИЧЕСКИМ И МАКРОСКОПИЧЕСКИМИ ОПИСАНИЯМИ ПО ХИМИИ

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Представления о различие и взаймодействии между понятиями и моделями, принодлежащими к описанию микроскопического уровня и тем, принодлежащими к описанию макроскопического уровня является ключевым фактором, широко определяющим концептуальное понимание в химий. Поэтому информация о ширине и ясности таких представлений могут быть важной для предложения и оптимизаций подходов к преподаваний основной и общей химий.

В статье представляются результаты исследования по этому вопросу, проведённого с помощью трёх наборов специально изготовленных вопросов, заданных группе первокурсников, изучающих курс по общей химий. Обсуждение рассматривает концептуальное и практическое влияние исследуемых представлений и включает предложения для работы в течение занятий и для общих подходов к преподавании химии.

Ключевые слова: микроскопическое описание, макроскопическое описание, общие курсы химии.

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