Science Education International
Vol. 27, Issue 4, 2016, 464-488

Understanding the atom and relevant misconceptions: Students' profiles in relation to three cognitive variables

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ABSTRACT: This work investigates the formation of particular student profiles based on of their ideas relating to basic characteristics of the atom. Participants were secondary students of 8th, 10th and 12th grades from Northern Greece (*n* = 421), with specific cohort characteristics e.g. age, grade and class curriculum, and individual differences, e.g. formal reasoning, field dependence-independence and divergent thinking. Analysis of data from four tasks concerning the characteristics of the atom, linked to identity and behaviour, revealed a significant number of students' misconceptions. A joint dimension reduction and clustering method was applied to outcomes from these four tasks and a four-cluster solution emerged as the most conceptually meaningful. An inspection of the relevant student profiles indicated that three tasks were the most important in the formation of the clusters; one task concerning the understanding of the differences between the atom and other particles of the microcosm and two tasks concerning relations between relevant micro- and macro- characteristics. Furthermore, individual differences could effectively discriminate between student profiles. Generally, students' performance in the above tasks was positively associated to their performance in the three cognitive factors, whereas formal reasoning contributed the most to this discrimination. Although the distribution of student cohort characteristics across student profiles was not clearly different, it seemed that the curriculum also played a noticeable role in the formation of profiles. Relevant implications for the educational practice were also discussed.

KEY WORDS: Atom, Misconceptions, Individual Differences, Student Profiles, Cluster Correspondence Analysis

INTRODUCTION

Students' ideas regarding the characteristics of the atom

Much ink has been spilled in the science education literature on students' ideas of the 'atom' over the last decades, since science researchers have

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approached this concept from several perspectives. Among them, many researchers have focused on students' ideas regarding the characteristics of the atom, such as identity and behavior. Relevant research evidence has suggested that a significant number of misconceptions are held by students from a wide range of ages, from 12 years old to university level (e.g. Griffiths & Preston, 1992; Harrison & Treagust, 1996; Nicoll, 2001; Kikas, 2004; Talenquer 2009; Adbo & Taber, 2009, 2014; Cokelez, 2012). Although it is difficult to put these misconceptions into specific categories fitting all researchers' methodologies, it seems that in general, they can be categorized into two groups:

a. Misconceptions concerning a lack of a distinction between characteristics of substances at the macro-level and those of their atoms at the micro-level; something that seems to be common also for other entities of the microcosm, such as molecules and ions.
b. Misconceptions concerning the differences at the micro-level, between the atom itself such as identity and behavior and other entities, such as the molecule, the ion and/or the cell.

In relation to the former, students often attribute macroscopic characteristics to atoms, for instance, color (Albanese & Vicentini, 1997; Cokelez & Dumon 2005; Talenquer, 2009; Taber & Franco, 2010), physical state and changes of state (Andersson, 1990; Renström *et al.*, 1990; Harisson & Treagust,1996; Adbo & Taber, 2014), or expansion on heating (Renström *et al.*, 1990; Griffiths & Preston, 1992; Kikas, 2004; Adbo & Taber, 2009). As many researchers suggest (e.g. Renström *et al.*, 1990; Kikas, 2004; Talenquer, 2009), this is probably due to the students' core idea that atoms consist of the same substance as the corresponding macroscopic substance. For instance, Renström *et al.* (1990) found, in a relevant study, that upper level school students (13 to 16 years old) believe that '*iron consists of atoms and the atoms consist of iron*'. As a result, students have developed a central way of thinking, in which the atoms, and generally the particles of which a substance comprises, have the same properties as the corresponding macroscopic substance. Talanquer (2009) described this thinking as an '*inheritance assumption'*. Color for instance, is an *inherited* property for the students. Thus, the atoms of phosphorus are thought to be yellow by many students aged 12-16 years old (Andersson, 1990). Similarly, changes of states and expansion during heating are also transferred from a substance to the atoms. Thus, some students 12-16 years old believe that the phosphorus atoms melt when phosphorus melts and that iron atoms expand when iron is heated (Andersson, 1990), whereas similar ideas have been also found in secondary students of older ages (Griffiths & Preston, 1992; Adbo & Taber, 2009); even in trainee teachers (Kikas, 2004).

In addition to the above, students very often ascribe animation to atoms, describing them as entities that they can feel, need, want, require, prefer, try, etc. (e.g. Taber & Watts, 1996; Nicoll 2001; Taber, 2003; Taber & Adbo, 2013; Talanquer, 2013). As many researchers suggest, such an anthropomorphic trend is very common in students of secondary education (e.g. Taber 2003; Taber & Adbo, 2013) and it holds true for a variety of entities. Even in tertiary education, Nicoll (2001) reports that university students describe the atoms as 'wanting' electrons and 'to be happy' when they get a full octet.

This students' anthropomorphic thinking may justify their view that atoms are alive, as well as their confusion between the atom and the cell (e.g. Griffiths & Preston 1992; Harisson & Treagust, 1996; Cokelez, 2012). As Harisson and Treagust (1996) emphatically suggest, students in 8-10 grades describe atoms as living entities, able to reproduce and having a nucleus with functions similar to those of a cell. This is a misconception, which is revealed, as the research stimulus is shifting from the students' confusion between properties of macro- and micro-levels towards the differences between the atom and other entities at the micro-level. However, the most characteristic core idea of the students at the micro-level concerns an overestimation of the atom over the other entities at this level. As Taber (2003) suggests, students give an 'ontological priority' to atoms when trying to understand how our world works at the micro-level, considering atoms as the basic unit of a substance. On the contrary, molecules and ions are not seen as equally fundamental to atom entities, since students consider molecules as combinations of atoms and ions as altered atoms. As a result, the atom is thought to be an entity that is conserved during chemical reactions (Cokelez *et al*., 2008) and it appears to be the starting point for any students' reasoning at the micro-level. For instance, Taber (2003) argues that when students are seeking for an explanation of a chemical reaction, they focus on the reactants' atoms, assuming that these are entities, which are principally involved.

However, further to the 'ontological priority' of the atom, students in many cases cannot even make the distinction between the 'atom' and the 'molecule' and thus they use occasionally one or the other in similar ways (Nicoll, 2001; Cokelez & Dumon, 2005). As Cokelez and Dumon, (2005) report, for instance, 10-12 grade students refer to hydrogen and oxygen molecules (instead of atoms) when describing the water molecule. Nicoll (2001) also reports that many university students tend to use the term 'molecule', instead of the 'atom' and vice-versa when explaining polarity. This confusion also extends to relations of the atom with other entities of the micro- or/and submicro-level, such as ions, protons or cells. For instance, 12-13 years old students may believe that atoms are made up of cells (Cokelez, 2012) and high school students may believe that atoms and ions have the same size when they have the same number of protons (Eymur *et al*., 2013). Specifically, the confusion concerning the relevant size of the atom is very common and probably originates from a students' trend to conceptualize the atom in terms of its small size. Generally, students specify the atom as something 'very small', 'large enough to be seen under a microscope' or something with a size similar to a 'point of a needle', a 'head of a pin' or a dot (Griffiths & Preston, 1992; Harrison & Treagust, 1996; Cokelez, 2012). However, since other entities at the micro-level have similar sizes, many students, of all grades of secondary education and even university students, make inappropriate comparisons. For example, they present the size of the atom as larger than that of a molecule (Griffiths & Preston, 1992), similar to the cell (Harisson & Treagust 1996; Cokelez, 2012), underestimated when compared to its nucleus (Harisson & Treagust 2000; Adbo & Taber, 2009; Ünlü, 2010), or hardly specified in comparison to the size of the ion (Eymur *et al*., 2013).

Individual differences

Despite commonalities, but looking at the above from another point of view, it seems that a number of parameters, like age and grade, for instance, can play an essential role in the establishment of students' ideas regarding the characteristics of the atom. However, further to those, cognitive factors, such as *Formal Reasoning* (FR), *Field Dependence/Independence* (FDI) and *Divergence* (DIV), have frequently been found to play an important role in the understanding of similar concepts and phenomena (e.g. Tsitsipis *et al*., 2010, 2012; Kypraios *et al*., 2015). In the relevant literature, the meaning and importance of such cognitive factors are explicitly presented, which, in fact, concerns the differences between students as individuals (individual differences). In brief, *Formal Reasoning* (FR), also reported as *Logical Thinking*, refers to the ability of an individual to use concrete and formal operational reasoning (Lawson, 1978), and it is, in fact, a Piagetian concept. *Field Dependence/ Independence* (FDI) refers to the ability of an individual to identify relevant information from a complex context (Witkin *et al.*, 1971) - an ability to separate efficiently the 'signal' from the 'noise'. Generally, field independent students perform better (e.g. Danili & Reid, 2004; Tsitsipis *et al*., 2010; 2012). *Divergence* (DIV) refers to ones' ability to find several equally acceptable solutions to a problem (e.g. Bahar, 1999). Although for many years it was considered as the opposite of *Convergence* - the ability to focus on the one conventionally accepted solution to a problem, *Divergence* is a separate cognitive style. This means that an individual can score high on neither, one, or both of them.

In a recent study of students' representations of the atomic structure in particular contexts, where the effect of such cognitive factors was also examined, *Formal Reasoning* always emerged as an important relevant predictor. However, *Field Dependence/ Independence* was important only in cases where tasks given to the students were independent of any particular context (Papageorgiou *et al*., 2016). Does this also mean that students' ideas regarding the characteristics of the atom can be affected somehow by such cognitive factors? To our knowledge, this has not been under investigation so far.

The atom and its characteristics in Greek secondary education

The Greek secondary education system includes lower secondary education, known as 'gymnasium' (grades 7, 8 and 9), and upper secondary education, known as 'lyceum' (grades 10, 11 and 12). In the 12th grade, students choose one of three directions, namely 'science and math', 'technological' and 'theoretical', according to their interests. The atom and related concepts are taught in both lower secondary education (during 8th grade, age 13-14) and upper secondary education (during 10th grade and the 'science and math' direction of the 12th grade, ages 15-16 and 17-18, respectively), within the context of chemistry, as well as, during all three directions of the 12th grade, in the context of physics.

An outline of the corresponding courses, which last one year, has already been presented in Papageorgiou *et al*. (2016) emphasizing the atomic structure. In the context of chemistry and focusing rather on its characteristics as identity and behavior, the atom is introduced in the 8th grade as the basic unit of a substance, although molecules and ions are also presented later as basic units of the corresponding molecular and ionic substances. The text clarifies that the atom is colorless, despite its colorful representation in the figures of textbooks, as well as, that it is 'very small', comparing the sizes of hydrogen and oxygen atoms with those of a water molecule. An introduction to the Bohr's atomic model also takes place (among others). In the 10th grade, students are taught more in depth the atomic structure based on the Bohr's atomic model, whereas characteristics, such as the size of the atom, are explicitly discussed in relation to its electron configuration and when comparing the atom with other particles of the microcosm. In the 12th grade, lessons relevant to the atom are more specified according to the quantum mechanical model and thus, any other characteristic is connected to this model (e.g. the size of the orbitals determines the corresponding size of the atom). In the context of physics, all 12tg grade students are taught more in-depth concepts related to the Bohr atomic model, including characteristics of the atom, such as for instance, the size of the atom in relation to the atomic number and in comparison to the size of its nucleus and the corresponding ions.

RESEARCH QUESTIONS

Students' ideas regarding the characteristics of the atom as identity and behavior were investigated in the context of a wider study aiming at determining their ideas on the atom and its structure, in general. In the present part of the study, the aim is to focus on misconceptions held by a number of students with specific cohort characteristics, such as age, grade and class curriculum, and individual differences, such as formal reasoning, field dependence-independence and divergent thinking. For this purpose, students' relevant ideas were investigated in relation to these specific features in an effort to answer the following questions:

1. To what extent can students with specific cohort characteristics (grade, age and curriculum) and individual differences, i.e. formal reasoning, field dependence-independence and divergent thinking, understand the characteristics of the atom as identity and behavior and what significant misconceptions do they hold?
2. Which distinct student profiles emerge in relation to their ideas, taking into account their cohort characteristics and individual differences and how these profiles are associated with their misconceptions?

METHODOLOGY

Subjects and Procedure

The present study involved 421 voluntary secondary students of 8th, 10th and 12th grades from Northern Greece. Among them, 189 students were male (44.9%) and 232 female (55.1%). The whole sample can be divided into four cohorts:

- 1^{st} cohort: 127 (30.2%) students of the 8th grade (age 13)
- 2^{nd} cohort: 167 (39.7%) students of the 10th grade (age 15)
- 3^{rd} cohort: 82 (19.5%) students of the 'technological direction' of 12th grade (age 17)
- 4^{th} cohort: 45 (10.7%) students of the 'science and math direction' of 12th grade (age 17)

All students in each one of the cohorts used the same textbook following the National Science Curriculum for Greece (Greek Pedagogical Institute, 2003). Students were from mixed socioeconomic backgrounds and they attended mixed ability classes in regular public secondary schools. Data were collected during the last semester of the school year through four paper-and-pencil tests (one for the characteristics of the atom and three for the corresponding cognitive variables). Prior to the main study, a pilot study (n = 72) was carried out in order to detect and correct possible errors. In that study, the sample consisted of students corresponding to the 1st cohort (n = 24), the 2nd (n = 24), the 3rd (n = 14) and the 4th (n = 10). No errors were detected. Internal reliability was found acceptable, with a Cronbach's alpha of 0.71.

Instruments

A series of paper-and-pencil assessments was created for the purposes of the study. This included an instrument developed to assess students' ideas relating to the characteristics of the atom and three cognitive tests for assessing student individual differences, i.e. formal reasoning and field dependence/independence respectively, and divergent thinking.

Characteristics of the atom

Students' ideas relating to the characteristics of the atom were assessed using the same instrument for all student cohorts, which was developed by the authors taking into account relevant research evidence. Among the instrument items, the four developed on the characteristics of the atom gave an acceptable Cronbach's alpha reliability coefficient (α = 0.73). For each item, students were expected to write down an answer and then explain and/or justify their answers. Table 1 presented a description of these items.

In all items, students' ideas were evaluating and their justifications/ explanations determined for their correctness and completeness in comparison to the scientific view. Their responses were grouped in the following three categories:

- Category A: Scientifically accepted
  (where levels 1, 2, 3 were specified, level 1 was taken as the most scientifically correct and complete)
- Category B: Misconceptions
- Category C: Unclear or No answer

The instrument's coding scheme was validated by two independent researchers and all discrepancies between the two raters were reconciled through discussion until total agreement was reached.

Table 1. Description of the items and possible demands on justifications/ explanations

Items	Description of the items	Possible choices	Demand of a choice on a justification/ explanation
1	Students were asked to explain whether there is any essential difference when using words like ‘atom’, ‘molecule’ and ‘ion’, or is it about the same particle that is differently expressed occasionally	Difference	Explanation of any differences. Description of each one of these particles
		No Difference	Justification of possible reasons to use different words for the same particle
Students were asked to focus on the ‘atom’ for the next items, independently of their beliefs for its possible (or not) relation to ‘molecule’ or ‘ion’			
2	Students were asked to answer whether ‘atoms’ are/ could be alive	Always	Justification of the choice
		Some times	
		Never	
3	After a reference to iron melting, students were asked to compare iron atoms in solid and liquid states	Same	Justification of the choice
		Different	Justification of the choice. Explanation of any possible differences
4	Students were asked to compare oxygen atoms with iron atoms	Same	Justification of the choice.
		Different	Justification of the choice. Explanation of any possible differences

Individual differences

For the assessment of students’ individual differences, the English versions of three cognitive tests were adapted and translated into Greek, in accordance to cross-cultural research guidelines (Beaton *et al.*, 2000).

Already translated versions into Greek (e.g. Danili & Reid, 2006) were also taken into account. The original scoring system was maintained for the translated versions.

The construct validity of the three cognitive instruments was examined in the context of *Confirmatory Factor Analysis* (CFA). Due to the ordinal nature of the test items, the analysis was performed using the WLSMV (Weighted Least Squares with Mean and Variance Adjustment) estimator, implemented in the Mplus software Version 7.31 (Muthén & Muthén, 2012). Model fit was evaluated using the following indices: comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and 90% confidence interval (CI) of RMSEA. According to previous research, CFI and TLI values ≥ 0.95 and RMSEA values ≤ 0.08, were considered as good indicators of model fit (Hu & Bentler, 1999). Internal consistency of all measures was assessed using the Cronbach's alpha coefficient. Composite scores were computed by summing the item scores that constitute each scale.

Formal Reasoning (FR): student ability was measured on the basis of the Lawson paper-and-pencil test (Lawson, 1978), which consisted of the 15 following items:

- conservation of mass (1 item),
- displaced volume (1 item),
- control of variables (4 items),
- proportional reasoning (4 items),
- combinational reasoning (2 items) and
- probabilistic reasoning (3 items).

The students were asked to answer and justify their answers within 45 min. For the present study, a uni-dimensional CFA model demonstrated a good fit to the data ($\chi^2(84) = 105.4$, $p = 0.057$, CFI = 0.99, TLI = 0.99, RMSEA = 0.025 [0.000-0.038]). Cronbach's alpha indicated that the scale exhibited satisfactory internal consistency ($\alpha = 0.77$).

Field dependence/independence (FDI): This ability was measured based on the Group Embedded Figures Test (Witkin *et al.*, 1971), a twenty-item test administered in 20 minutes. in which students dissembled simple figures concealed within ones more complex. Lower scores indicate a field dependent learner; higher scores reflect a tendency toward field independence. The scale was treated as uni-dimensional, a structure which was replicated using CFA ($\chi^2(152) = 313.6$, $p < 0.001$, CFI = 0.98, TLI = 0.98, RMSEA = 0.050 [0.042-0.058]). In the current study, Cronbach's alpha reliability coefficient was found to be high ($\alpha = 0.84$).

Divergent thinking (DIV): To determine this ability, students completed a six-item test designed by Bahar (1999), within 20 min. In item 1, students were asked to generate words with a similar meaning to those given. In item 2, students generated up to four sentences using words in the form given. In item 3, students could draw up to five sketches relevant to a given idea. Item 4 asked students to write as many things that have a common trait as possible. Item 5 asked students to write as many words as possible, that begin with one specific letter and end with another specific one. Finally, item 6 asked students to list all their ideas about a given topic. A uni-dimensional CFA model demonstrated good fit ($\chi^2(9) = 10.45$, $p = 0.315$, CFI = 0.99, TLI = 0.99, RMSEA = 0.020 [0.000-0.059]) and coefficient alpha was acceptable (0.69).

Statistical Analysis

Data analysis in the current study was based on a combination of dimension reduction and cluster analysis in order to find a meaningful allocation of students to groups with respect to their responses on the set of four tasks, related to the characteristics of the atom's identity and behavior. In particular, *Cluster Correspondence Analysis* (Cluster CA) was used, seen as recently proposed method suitable for categorical data, combining Correspondence Analysis with *k*-means clustering (van de Velden *et al*., 2016). The advantages of Cluster CA over alternative approaches have been demonstrated via a simulation study (van de Velden *et al*., 2016). Cluster CA yields optimally separated clusters and a low-dimensional approximation of the cluster by variable associations. Low-dimensional coordinates are obtained for clusters (as represented by their cluster mean) and variable categories in such a way that the between-cluster variance is maximized, whilst the within-cluster variance is minimized. While cluster solutions ranging from two to seven clusters were considered, the number of dimensions ranged from two to six. Cluster CA was applied in the present study using the software package *clustrd* in the *R* programming language (Markos *et al*., 2016).

Differences in cognitive factor scores among the clusters were evaluated using one-way ANOVA, followed by Tukey's multiple comparison tests. Partial eta-squared was used as a measure of effect size. A partial eta squared (η^2) value of 0.01, 0.06, and 0.14 corresponds to a small, medium, and large effect size, respectively (Richardson, 2011). In addition, chi-square tests were used to evaluate differences among the clusters in task scores and student cohort characteristics.

Table 2. Percentage (%) distribution of students' performance concerning the characteristics of the atom in tasks 1 to 4 by student cohort

Task	Cohort	Category A			Category B	Category C
		Level 1	Level 2	Level 3		
1	1st	25 (19.7%)	19 (15.0%)	26 (20.5%)	42 (33.1%)	15 (11.8 %)
	2nd	29 (17.4%)	44 (26.3%)	36 (21.6%)	43 (25.7%)	15 (9.0%)
	3rd	15 (18.3%)	21 (25.6%)	13 (15.9%)	32 (39.0%)	1 (1.3%)
	4th	15 (33.3%)	16 (35.6%)	2 (4.4%)	11 (24.4%)	1 (2.2%)
	Total	84 (19.9%)	100 (23.7%)	77 (18.3%)	128 (30.4%)	32 (7.6%)
2	1st	39 (30.7%)			59 (46.5%)	29 (22.8%)
	2nd	54 (32.3%)			76 (45.5%)	37 (22.2%)
	3rd	31 (37.8%)			34 (41.5%)	17 (20.7%)
	4th	28 (62.2%)			10 (22.2%)	7 (15.6%)
	Total	152 (36.1%)			179 (42.5%)	90 (21.4%)
3	1st	1 (0.8%)	1 (0.8%)	70 (55.1%)	33 (26.0%)	22 (17.3%)
	2nd	9 (5.4%)	5 (3.0%)	86 (51.5%)	46 (27.5%)	21 (12.6%)
	3rd	10 (12.2%)	4 (4.9%)	47 (57.3%)	14 (17.1%)	7 (8.5%)
	4th	1 (2.2%)	7 (15.6%)	29 (64.4%)	6 (13.3%)	2 (4.4%)
	Total	21 (4.9%)	17 (4.0%)	232 (55.1%)	99 (23.5%)	52 (12.3%)
4	1st	29 (22,8%)	0 (0.0%)	34 (26.8%)	36 (28.3%)	28 (22.0%)
	2nd	33 (19.8%)	9 (5.4%)	36 (21.6%)	64 (38.3%)	25 (15.0%)
	3rd	18 (22.0%)	15 (18.3%)	15 (18.3%)	24 (29.3%)	10 (12.2%)
	4th	16 (35.6%)	9 (20.0%)	4 (8.9%)	13 (28.9%)	3 (6.7%)
	Total	96 (22.8%)	33 (7.8%)	89 (21.1%)	137 (32.5%)	66 (15.7%)

RESULTS

Preliminary analyses

Table 2 presents the distribution of student scores in the four tasks by student cohort. Although relevant misconceptions are present throughout the four tasks, students in the total sample seem to recognize 'atoms', 'molecules' and 'ions' as separate particles (task 1) to a significant degree, since more than 60% of them fall into categories A1 to A3. Some examples of such students' answers are, for instance in task 1: *It is about different particles, because molecules can be found free in nature and consist of atoms that are basic units of matter without charge. The atom consists of electrons, protons and neutrons. The ion is a charged particle, which can be a cation, if an atom loses electrons, or an anion, when an atom receives electrons* (A1). *Molecules consist of atoms and are thus not about the same particles. Ions are particles with positive or negative charge* (A2). *A molecule consists of atoms. When atoms are the same, it is a molecule of an element, whereas when atoms are different, it is a molecule of a compound* (A3).

On the contrary, results for task 2 seem to verify the evidence concerning students' confusion between the atom and the cell. Across all tasks, the percentage of students having misconceptions (category B) in this task is the highest (42.5%), whereas the same holds true for category C, where task 2 appears to have the highest percentage of students providing unclear answers, or no answer (21.4%). The results also suggest the presence of misconceptions relevant to an atom regarding the relation between properties of macro- and micro-levels. When students are asked to imagine atoms of substances in various states, the percentages of their misconceptions (category B) in tasks 3 and 4 are found to be 23.5% and 32.5% respectively. An overview of the most frequent students' misconceptions across the four tasks is presented in Table 3.

With regard to differences in performance by student cohort, the percentage of students providing scientifically accepted answers tends generally to increase moving from the 1st to the 4th cohort, whereas misconceptions and unclear answers tend to decrease. The most notable differences are those among students in the 4th cohort (12th grade, 'science and math direction') and those in the other three cohorts. The fact that there are such differences even between this cohort (4th) and the 3rd (12th grade, 'technological direction'), especially in tasks 1 and 2, supports the probable notion that the curriculum plays a significant role.

Table 3. An overview of the students' misconceptions across the four tasks

Task	Students' misconceptions
1	There is not any essential difference among atoms, molecules and ions, because: • Molecules and ions are alternative forms of atoms • They are about synonyms There are differences: • The atom consists of molecules; the ion consists of atoms and/or molecules • The atom is the smallest particle that can be found as an individual entity in nature
2	Atoms are/ could be alive: Always • The atom is the smallest living organism, since cells consist of atoms. • The atom has biological functions, since it is the basic unit of living organisms • They are living organisms, since they can feel. During chemical reactions, the atoms make choices and decide how and with what they will bond. • Their movement, as well as the movement of their electrons, can explain why they are living organisms Sometimes • Living organisms consist of living atoms, whereas non-living materials consist of non-living atoms • Living cells consist of living atoms, whereas dead cells consist of non-living atoms
3	Iron atoms of the solid state are solid and iron atoms of the liquid state are liquid because: • Atoms have, in general, the same properties as those of the corresponding substance; they can melt, expand and /or evaporate. • The electrons of an atom move more freely in the liquid than in the solid state • As the state changes, the number of electrons changes accordingly (the solid state has less electrons than the liquid one and thus, solids expand during melting) They are the same, because: • The atom is so small that it cannot be seen

(Table 3 continues)

Task	Students' misconceptions
4	Oxygen atoms are different compared to iron atoms, because: • Atoms have in general the same properties with those of the corresponding substance; an atom of oxygen is in the gas state, whereas an atom of iron is in the solid state; an atom of oxygen is lighter/ softer compared to that of iron • The electrons of the oxygen atom are moving faster and are at larger distances from nucleus compared to that of iron (thus, oxygen is a gas, whereas iron is a solid) • Bonds between oxygen atoms are stronger compared to those between iron atoms (confusion between bonds and intermolecular forces) They are the same, because: • All atoms are the same, independently of the substance in which they can be found

Since the emphasis in the present study is on students' misconceptions, rather than on their correct answers, task categories A1 to A3 were combined for simplicity reasons into a single category (A) for subsequent analyses, summarizing scientifically accepted answers.

Cluster Correspondence Analysis

The results of Cluster CA indicated that a four- cluster solution in two dimensions provided the most meaningful interpretation. Cluster differences in task response frequencies (Table 4), student cohort characteristics (Table 5) and cognitive factors (Table 6) were all found to be statistically significant. Formal reasoning always emerged as a significant predictor, having the highest effect size. A detailed description and characterization of each cluster was as below.

Cluster 1 (Student profile: High-performers): This cluster, which comprises roughly one-third of the sample (32.5%), expresses a student profile that contains 137 students who exhibit the highest scores on all four tasks. More specifically, all participants in this cluster (100%) provide scientifically accepted answers to tasks 1 and 4, 83.9% of the participants provide scientifically accepted answers to task 3 and 51.1% to task 2. Cluster 1 contains students from all four cohorts who score significantly higher on all three cognitive factors than students of the other clusters.

Table 4. Task response frequencies across the four clusters

Cluster		Task 1			Task 2			Task 3			Task 4			
		A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**Total**
C1	Freq.	137	0	0	70	46	21	115	7	15	137	0.0	0	137
	%	100.0	0.0	0.0	51.1	33.6	15.3	83.9	5.1	10.9	100.0	0.0	0.0	100.0
C2	Freq.	0	103	0	34	44	25	81	10	12	52	42	9	103
	%	0.0	100	0.0	33.0	42.7	24.3	78.6	9.7	11.7	50.5	40.8	8.7	100.0
C3	Freq.	96	11	0	31	52	24	50	53	4	19	88	0	107
	%	89.7	10.3	0.0	29.0	48.6	22.4	46.7	49.5	3.7	17.8	82.2	0.0	100.0
C4	Freq.	28	14	32	17	37	20	24	29	21	10	7	57	74
	%	37.8	18.9	43.2	23.0	50.0	27.0	32.4	39.2	28.4	13.5	9.5	77.0	100.0
Total	Freq.	261	128	32	152	179	90	270	99	52	218	137	66	421
	%	62.0	30.4	7.6	36.1	42.5	21.4	64.1	23.5	12.4	51.8	32.5	15.7	100.0

Note: Freq. = Frequency. Task 1 ($\chi^2(6) = 489.26$, $p < .001$), Task 2 ($\chi^2(6) = 21.23$, $p < .01$), Task 3 ($\chi^2(6) = 117.1$, $p < .001$), Task 4 ($\chi^2(6) = 465.54$, $p < .001$)

Table 5. Student cohort frequencies across the four clusters

Cluster		Student cohort 1st	2nd	3rd	4th	Total
C1	Freq.	38	46	20	33	137
	%	27.7%	33.6%	14.6%	24.1%	100.0%
C2	Freq.	27	36	11	29	103
	%	26.2%	35.0%	10.7%	28.2%	100.0%
C3	Freq.	29	54	11	13	107
	%	27.1%	50.5%	10.3%	12.1%	100.0%
C4	Freq.	33	31	3	7	74
	%	44.6%	41.9%	4.1%	9.5%	100.0%
Total	Freq.	127	167	45	82	421
	%	30.2%	39.7%	10.7%	19.5%	100.0%

Note: Freq. = Frequency. $\chi^2(9) = 28.6$, $p = 0.001$, Cramer's $V = 0.261$.

Table 6. Mean (SD) differences in cognitive factors across the four clusters

		FR		DIV		FDI	
Cluster	*N*	Mean	SD	Mean	SD	Mean	SD
C1	137	33.23[a]	11.96	43.95[a]	8.34	9.74[a]	4.51
C2	103	27.64[b]	12.06	42.18[b,c]	8.18	8.44[b,c]	4.64
C3	107	28.05[c]	11.50	41.03[b,c]	7.83	8.31[b,c]	4.49
C4	74	23.22[d]	11.44	40.15[d]	9.41	7.08[d]	4.29
Total	421	28.78	12.25	42.11	8.47	8.59	4.58

Note: FR = Formal reasoning ($F(3, 420) = 12.463$, $p < 0.001$, $\eta^2 = 0.082$), DIV = Divergent thinking ($F(3, 420) = 4.152$, $p = 0.006$, $\eta^2 = 0.029$), FDI = Field dependence-independence ($F(3, 420) = 5.913$, $p = 0.001$, $\eta^2 = 0.041$). Mean values denoted by the same letter do not differ significantly ($p > 0.05$; Tukey's multiple comparison test).

Cluster 2 (Student profile: Mid-performers with misconceptions): This cluster contains 103 students (25.4%), all of them holding misconceptions in task 1 (100%). Furthermore, the majority of this student profile provide scientifically accepted answers in tasks 3 (78.6%) and 4 (50.5%), respectively. A significant percentage of students in this cluster (28.2%) are in the 4th cohort (12th grade, 'science and math direction'). Moreover, cluster 2 is the second highest, after cluster 1, in formal reasoning, divergent thinking and field dependence-independence.

Cluster 3 (Student profile: Mid-performers with misconceptions): This cluster contains 107 students (25.4%), who have misconceptions in tasks 3 and 4 (82.2% and 49.5%, respectively), whereas the vast majority provide scientifically accepted answers in task 1 (89.7%). Therefore, in comparison to cluster 2, this cluster also expresses a student profile with misconceptions, but with opposite performance patterns (see Table 7). Moreover, as shown in Table 4, about a half of the students (50.5%) in this cluster are of the 2nd cohort (students of the 10th grade). With regard to cognitive factors, the participants in cluster 3 have significantly lower scores than those of cluster 1, but significantly higher than those of cluster 4. Also of note is that the students in this cluster do not perform significantly different in divergent thinking and field dependence-independence than those in cluster 2.

Cluster 4 (Student profile: Low-performers): This cluster is 74 students and is the smallest cluster in size (17.6%). A significant majority of students in this cluster provide unclear answers, or no answer (Category C) to most of the tasks. More specifically, 77% scored C in task 4, 43.2% in task 1 and 28.4% in task 3. About half of the students in this cluster (44.6%) are of the 1st cohort (8th grade), but this is also the cluster having the fewest students of the 4th cohort ('science and math direction') and the lowest scores on the three cognitive factors, compared to the other clusters.

A visualization of the four clusters in two dimensions can be seen in Figure 1. In the graphical display of Figure 1, which constitutes a biplot (Gower & Hand, 1996), the origin depicts the average student profile in terms of their performance in the four tasks and all other points depict deviations from this average profile. The display depicts two clearly separated clusters, with cluster means C2 and C4, and two central clusters, with cluster means C1 and C3. To interpret the solution, we consider individual tasks, i.e. a combination of a task, T1 to T4, with a category, A, B, C (e.g. T1.B, T4.A, etc.), and the positions of the cluster mean points relative to these. The cluster mean (C1) is located on the left part of the horizontal axis in Figure 1 and it is related to the response category A (scientifically accepted answers) for all tasks. The cluster mean (C2) is located on the bottom left part of the map and is related to category B (misconceptions), especially for tasks 1 and 4. The cluster mean (C3) is located near the origin, below that of cluster 1, and close to the average profile. The cluster mean (C4) is located on the right part of the horizontal axis and is related to category C (unclear answer or no answer), especially for tasks 1 and 4. Overall, tasks 1 and 4, followed by task 3, appear to be the most discriminating tasks that differentiate the four clusters.

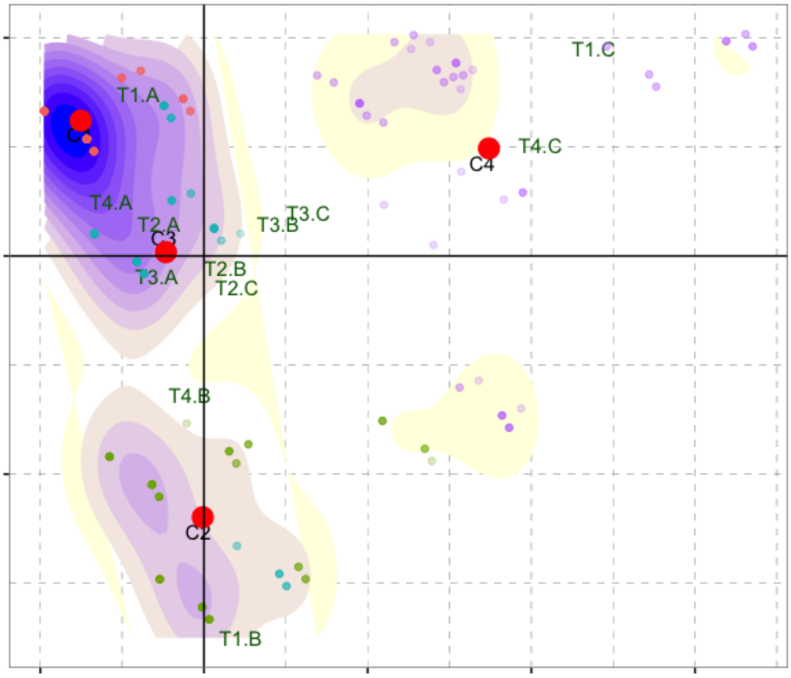

Figure 1. Cluster Correspondence analysis biplot with four clusters in two dimensions. Attribute labels correspond to the categories of tasks 1 through 4 with category numbers added (from T1.A to T4.C). Cluster means are labelled C1 through C4. Cluster points are shown in different colors. The contours show the density of the data points relative to each of the cluster means.

Discussion and Conclusions

Preliminary analyses showed that there are significant students' misconceptions regarding the characteristics of the atom such as identity and behavior in all cohorts, including the 4th cohort, where grade, age and corresponding curriculum could probably predispose us to the opposite. Although students' performance in the 4th cohort was significantly higher compared to the other cohorts, misconceptions were also present to a significant degree. Generally, misconceptions found throughout the sample are in accordance with the existing research evidence, regarding both the relation of characteristics between macro- and micro-levels and the differences at the micro-level in-between atoms, molecules and ions as identities and behaviors. In the present study, the former misconceptions referred to the presence of an '*inheritance assumption'* in students' thinking (Talanquer, 2009), whereas the latter indicated a lack of distinction between the atom and other particles of the microcosm (Nicoll, 2001; Cokelez & Dumon, 2005; Eymur *et al*., 2013), rather that support for the 'ontological priority' that students gave to atoms (Taber, 2003). However, in the context of this '*inheritance assumption'*, it seemed that students in the sample had more relevant misconceptions when manipulating atoms of different substances found in different states under normal conditions (task 4), rather than atoms of the same substance in different states (task 3). Probably, although such an 'inheritance' thinking could affect responses in both tasks, students had strongly connected in their minds each substance with a particular state (the state in which this substance appeared in normal conditions), that this was more effective when thinking at the micro-level in task 4.

Taking into account both preliminary analyses and the results of Cluster CA, a number of interesting findings emerged for discussion. First, a confusion between characteristics of the atom and those of the cell was quite apparent. This was demonstrated by the high percentages in relevant misconceptions (task 2) throughout the sample, as shown in Tables 2 and 4. Although the presence of such misconceptions was lower for the students in the 4^{th} cohort compared to those in the other three cohorts, this difference did not reach statistical significance, and therefore performance in task 2 did not seem to differ between clusters. This meant that students' confusion concerning atom and cell characteristics was present in a similar proportion across all student profiles that were identified in the present study. What might be confusing for the students, was probably a fuzzy location of the cell characteristics between the macro- and micro-levels in the 'chemical triplet', i.e. the macroscopic, microscopic and symbolic levels, introduced by Johnstone (1993). Usually, science teachers included the cell in the micro-level and, additionally, they did not manipulate properly these levels during the teaching/learning procedure (Treagust *et al*., 2003). As a result, students were poorly assisted in differentiating the cell characteristics over those of the other particles at the micro- level. However, as Talanquer (2011) suggested, there were many faces and interpretations of this triplet, which could lead to its transformation into a multi-dimensional space that included different scales/levels, dimensions and approaches. Based, for instance, on such a separate scale/level, the cell could be more effectively differentiated from atoms, molecules and ions.

Focusing on the contribution of individual differences in the formation of the student profiles, results revealed that they play a significant role. In accordance to relevant research evidence (e.g. Tsitsipis *et al*., 2010, 2012; Kypraios *et al*., 2015), students' high performance in the corresponding tests was associated with their presence in cluster 1 (High-performers), whereas their low performance was connected to their presence in cluster 4 (Low-performers). Also, clusters 2 and 3 (Mid-performers with misconceptions) were characterized by a corresponding mid-performance in cognitive tests. Although the distribution of the four cohorts of students, across the four clusters, did not differ (despite clusters 3 and 4 being characterized by a significant presence of the 2nd cohort (50.5%) and the 1st cohort (44.6%), respectively), the role of individual differences in the formation of the student profiles seemed to be more important than those of cohort characteristics.

Further to the above, an interesting finding considers the distribution of students in the two mid-performing clusters in the four-cluster solution, where students' performance in cognitive tests do not significantly differ and thus, individual differences do not play a discriminating role. Cluster 2 corresponds to a profile, in which it seems all students have misconceptions in differentiating atoms, molecules and ions, but this is not an obstacle for the majority of them when comparing characteristics of such particles with properties of the corresponding substances. Again, this is more obvious in task 3 than in task 4. Taking into account that approximately one third are students of the 4th cohort, it is possible that this is connected with the corresponding curriculum, at least, to a certain degree. For instance, an assumption that can be made is the following: as the curriculum of the 4th cohort focuses on the atomic structure through the quantum mechanical model, students' attention is possibly distracted from the characteristics of the atom as identity and behavior. Thus, these particular students may be used to work in a procedural way that possibly allows them to relate micro- and macro-levels, without entirely realizing the differences between the atom and the other particles of the microcosm.

On the contrary, in cluster 3, one can notice a reverse distribution, which means that, for the students of this profile, the knowledge of the particle characteristics at the micro- level is not enough for drawing a clear picture regarding relations of micro- and micro- characteristics. Taking into account that these students do not have significant differences concerning the cognitive factors and that about half of them are students of the 2nd cohort, it is possible that again the curriculum has an impact. As already reported, in this cohort the characteristics of the atom, in comparison to the other particles of the microcosm, are discussed explicitly. Thus, it is possible that the emphasis for these particular students is placed on these characteristics, rather than on any further implications for the relations between macro- and micro-levels.

IMPLICATIONS FOR SCIENCE EDUCATION

Taking into account all the above on the basis of the discriminating role of tasks 1, 4 and 3 in the formation of the relevant student profiles, it seems that students' understanding of the differentiations in-between atoms, molecules and ions are not necessarily associated with the relations between micro- and macro-characteristics, and vice-versa. What seems to be more likely in educational practice is that students can successfully relate micro- and macro-characteristics when they have just understood the behavior of the particles of the microcosm as a whole (in contrast to the properties of substances at the macro- level), without necessarily identifying differences in-between the behaviors of atoms, molecules and ions. This aspect has also been addressed by Johnson and Papageorgiou (2010) who introduce a simple particle model in order to explain what are a substance and its states. When the main objective of a teaching/learning procedure is the explanation of the properties of a substance and a number of its physical changes, according to this model, the key point is the understanding of the behavior of the particles of microcosm rather than how they appear. On the contrary, when the objective is the explanation of chemical phenomena, the understanding of the atom itself as identity and behavior, as well as its differences from the other particles of the microcosm, is a fundamental precondition. In other words, the findings of the present work do not underestimate the importance of the atom as a fundamental identity and idea in general, but they rather specify the degree to which the knowledge relevant to the atom is associated with a realistic connection between macro- and micro-characteristics.

However, the students' understanding of the behavior of the particles of microcosm, the atom itself and both the physical and chemical phenomena is also strongly associated with the role of the curriculum, the relevant textbooks and the teaching practices. Since the curriculum seems to play a noticeable role in students' achievements, the identification of misconceptions needs to activate curriculum and textbooks designers to realize what is going wrong. When students even in the 4^{th} cohort, who have spent much time studying topics relevant to an understanding of the atom, hold significant misconceptions, then the whole situation seems to be quite problematic. Of course, the role of the teacher and the teaching practices are also important. As many researchers suggest (e.g. Jarvis *et al*., 2003; Papageorgiou *et al*., 2010; 2013) long term in-service training programs could significantly improve teachers' pedagogical content knowledge and make them more capable to manipulate such difficult science concepts and be more effective in the classroom, even for students with low cognitive abilities.

LIMITATIONS

Despite the interesting findings, a number of limitations arise when interpreting the results of this study. The sample was convenient and originated from a specific geographic region, using a self-report instrument and a specific coding scheme. This provides a potential source of measurement error using a single method at a single time (cross-sectional design). A longitudinal design would further determine the stability of the obtained clusters over time. Therefore, the results should be treated as exploratory, and not as conclusive, given the limited scope of this study.

Nevertheless, the intention of data analysis through Cluster Correspondence Analysis was not to identify the one and only perfect clustering solution, but rather to determine naturally occurring groups of students based on certain variables for which meaningful interpretations can be proposed and supported. Through this approach, four meaningful groups emerged that lead to a better understanding of how students perceived the characteristics of the atom, as well as to a deeper understanding of their misconceptions.

REFERENCES

Andersson, B. (1990). Pupils' conceptions of matter and its transformations. *Studies in Science Education*, *18,* 53-85.

Bahar, M. (1999). *Investigation of biology students' cognitive structure through word association tests, mind maps and structural communication grids*. Ph.D. thesis: University of Glasgow.

Adbo, K., & Taber, K. S. (2009). Learners' mental models of the particle nature of matter: a study of 16-yearold Swedish science students. *International Journal of Science Education, 31*(6), 757–786.

Adbo, K, & Taber, K. S. (2014). Developing an Understanding of Chemistry: A case study of one Swedish student's rich conceptualisation for making sense of upper secondary school chemistry. *International Journal of Science Education*, *36*(7), 1107-1136.

Albanese, A., & Vicentini, M. (1997). Why do we believe that an atom is colourless? Reflections about the teaching of the particle model. *Science and Education*, *6*(3), 251-261.

Beaton, D. E., Bombardier, C., Guillemin, F., & Ferraz, M. B. (2000). Guidelines for the process of cross-cultural adaptation of self-report measures. *Spine*, *25*, 3186-3191.

Cokelez, A. (2012). Junior High School Students' Ideas about the Shape and Size of the Atom. *Research in Science Education*, *42*, 673–686.
Cokelez, A., & Dumon, A. (2005). Atom and molecule: upper secondary school French students' representations in long-term memory. *Chemistry Education Research and Practice, 6*(3), 119–135.
Cokelez, A., Dumon, A., & Taber, K. S. (2008). Upper secondary French students, chemical transformations and the "Register of models": A cross-sectional study. *International Journal of Science Education*, *30*(6), 807-836.
Danili, E., & Reid, N. (2004). Some strategies to improve performance in school chemistry, based on two cognitive factors. *Research in Science and Technological Education*, *22*, 201–223.
Danili, E., & Reid, N. (2006). Cognitive factors that can potentially affect pupils' test performance. *Chemistry Education Research and Practice, 7*(2), 64-83.
Eymur, G., Çetin, P., & Geban, O. (2013). Analysis of the alternative conceptions of preservice teachers and high school students concerning atomic size. *Journal of Chemical Education*, *90*(8), 976-980.
Greek Pedagogical Institute. (2003). *National Program of Study for Primary and Secondary Education: Science*. Athens (Greece): Greek Pedagogical Institute Publications.
Gower, J., & Hand, D. (1996). *Biplots*. Chapman & Hall/ CRC: London.
Griffiths, K. A., & Preston, R. K. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching*, *29*(6), 611–628.
Harrison, A. G., & Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: implications for teaching chemistry. *Science Education*, *80*(5), 509–534.
Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: a case study of multiple-model use in grade 11 chemistry. *Science Education*, *84*(3), 352–381.
Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modelling*, *6*, 1–55.
Jarvis, T., Pell, A., & Mckeon, F. (2003). Changes in primary teachers' science knowledge and understanding during a two year in-service programme. *Research in Science and Technological Education, 21*(1), 17–42.
Johnson, P.M., & Papageorgiou, G. (2010). Rethinking the introduction of particle theory: a substance-based framework. *Journal of Research in Science Teaching*, *47*(2), 130-150.

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response to changing demand. *Journal of Chemical Education*, *70*(9), 701–705.

Kikas, E. (2004). Teachers' conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching*, *41*(5), 432-448.

Lawson, A. E. (1978). Development and validation of the classroom test of formal reasoning. *Journal of Research in Science Teaching*, *15*, 11-24.

Markos, A., Iodice D' Enza, A., & van de Velden, M. (2016). clustrd: Methods for joint dimension reduction and clustering. R package version 1.0.0. url: http://cran.r-project.org/package=clustrd.

Muthén, B., & Muthén, L. (2012). *Mplus User's Guide* (7th ed.), Los Angeles, CA: Muthén and Muthén.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education, 23*(7), 707-730.

Papageorgiou, G., Markos, A., & Zarkadis, N. (2016). Students' representations of the atomic structure - The effect of some individual differences in particular task contexts. *Chemistry Education Research and Practice, 17*(1), 209-219.

Papageorgiou, G., Stamovlasis, D., & Johnson, P. (2010). Primary Teachers' Particle Ideas and Explanations of Physical Phenomena: The Effect of an In-Service Training Course. *International Journal of Science Education*, 32(5), 629-652.

Papageorgiou, G., Stamovlasis, D., & Johnson, P. (2013). Primary Teachers' Understanding of Four Chemical Phenomena: Effect of an In-Service Training Course. *Journal of Science Teachers Education*, 24, 763-787.

Renström, L., Andersson, B., & Marton, F. (1990). Students' conceptions of matter. *Journal of Educational Psychology*, *82*(3), 555.

Richardson, J. T. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review*, *6*(2), 135-147.

Stamovlasis, D., Kypraios, N., & Papageorgiou, G. (2015). A SEM Model in Assessing the Effect of Convergent, Divergent and Logical Thinking on Students' Understanding of Chemical Phenomena. *Science Education International, 26*(3), 284-306.

Taber, K. S. (2003). The atom in the chemistry curriculum: Fundamental concept, teaching model or epistemological obstacle? *Foundations of Chemistry*, *5*(1), 43-84.

Taber, K. S., & Adbo, K. (2013). Developing chemical understanding in the explanatory vacuum: Swedish high school students' use of an anthropomorphic conceptual framework to make sense of chemical phenomena. In *Concepts of matter in science education* (pp. 347-370). Netherlands: Springer.

Taber, K. S., & García-Franco, A. (2010). Learning processes in chemistry: Drawing upon cognitive resources to learn about the particulate structure of matter. *Journal of the Learning Sciences*, *19*(1), 99-142.

Taber, K. S., & Watts, M. (1996). The secret life of the chemical bond: Students' anthropomorphic and animistic references to bonding. *International Journal of Science Education*, *18*(5), 557-568.

Talanquer, V. (2009). On cognitive constraints and learning progressions: The case of 'structure of matter'. *International Journal of Science Education*, *31*(15), 2123-2136.

Talanquer, V. (2011). Macro, Submicro, and Symbolic: The many faces of the chemistry "triplet". *International Journal of Science Education*, *33*(2), 179-195.

Talanquer, V. (2013). When atoms want. *Journal of Chemical Education*, *90*(11), 1419-1424.

Treagust, D., Chittleborough, G., & Mamiala, T. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, *25*(11), 1353-1368.

Tsitsipis, G., Stamovlasis, D., & Papageorgiou, G. (2010). The effect of three cognitive variables on students' understanding of the particulate nature of matter and its changes of state. *International Journal of Science Education*, *32*(8), 987-1016.

Tsitsipis, G., Stamovlasis, D., & Papageorgiou, G. (2012). A probabilistic model for students' errors and misconceptions in relation to three cognitive variables. *International Journal of Science and Mathematics Education*, *10*(4), 777-802.

Ünlü, P. (2010). Pre-service physics teachers' ideas on size, visibility and structure of the atom. *European Journal of Physics*, *31*(4), 881.

van de Velden M., Iodice D'Enza, A. and Palumbo, F. (2016). Cluster correspondence analysis.Psychometrika (in press) DOI: 10.1007/s11336-016-9514-0

Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). *Embedded figures test, children's embedded figures test, group embedded figures test: manual*. Palo Alto, CA: Consulting Psychologists Press.