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# The Role of Some Individual Differences in Understanding Chemical Changes: A study in Secondary Education

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In this study, students' understanding of chemical changes was investigated in relation to four individual differences, related to logical thinking, field dependence/independence, convergence and divergence thinking. The study took place in Greece with the participation of students (n=374) from three grades (8th, 10th and 12th grades) of secondary education. A stepwise multiple regression analysis revealed that the above cognitive variables were statistically significant predictors of the students' achievement, with logical thinking to be the most dominant. Unexpectedly, no statistically important effect was found across ages. Moreover, students' partial achievement scores on understanding the structure of substances and their changes, along with the cognitive variables, appeared to have an effect on their competence in interpretation of chemical changes. Path analyses were implemented to depict these effects. A theoretical analysis that associates the role of cognitive variables with the nature of mental tasks involved when learning chemistry is also presented. Implications for science education are discussed.

*Keywords*: Chemical change; Logical thinking; Field dependence/independence; Convergent and divergent thinking.

## INTRODUCTION

Among the studies conducted in science education during the last three decades, a great number deals with chemical phenomena (e.g. Stavridou & Solomonidou, 1998; Boo & Watson, 2001; Johnson, 2002; Ozmen & Ayas, 2003; Chiu, 2007; Papageorgiou, Grammaticopoulou, & Johnson, 2010; Solsona, Izquierdo & de Jong, 2003; Kingir, Geban & Gunel, 2013). Since the understanding of the idea of a chemical change itself seems to be quite tricky for a wide range of ages, from students of primary education to university students and even further to teachers, the main focus of those studies is on this core topic. Most of the times, relevant research emphasizes students' understanding of the particulate nature of the substances involved in such phenomena and their changes, shedding light on their misconceptions. As a result, a big number of such misconceptions are known today, which seem to be also related to the age (e.g. Stavridou & Solomonidou, 1989; Brosnan & Reynolds, 2001; Papageorgiou et al., 2010).

Students' problems in understanding the nature of substances have as a result the lack of distinction between chemical and physical phenomena (Stavridou & Solomonidou, 1989), since students usually fail to connect the identity of a substance with its properties. Thus, the properties of a product resulting either from a simple mixing or a reaction between substances are not evaluable data for them in order to draw a certain conclusion for the nature of a phenomenon. According to Kingir et al. (2013), this is due to the students' trend to rather memorize information, than to explore concepts and situations in order to generate new ones. As a result, their knowledge on chemical changes comprises a restricted number of reactions, whereas their main criterion for categorizing a phenomenon as chemical or physical is the irreversibility i.e. an irreversible change is chemical, whereas a reversible one is physical.
In this context, students usually identify chemical changes rather as procedures of mixing substances than as interactions between them (Stavridou & Solomonidou, 1998; Boo & Watson, 2001; Talanquer, 2008). When for

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instance, Talanquer (2008) tested 456 university students using a questionnaire, and interviewed 10 of them to enhance the findings, 80% of the former and 40% of the latter considered a chemical reaction rather as an "additive" procedure, than as an interaction between the reactants. The final products of the reaction supposed to be a mixture and not a compound with properties of its own. Similarly Johnson's work (2002) suggested that students have a natural trend to think of the product of a reaction as a mixture of reactants, something that Johnson demonstrated simply in one characteristic pupils' answer "it kind of mixes together…" (p. 1044). This kind of misconception was also revealed in another study of Stavridou and Solomonidou (1998), mainly in students aged 12 to 18. On the basis of 40 students' interviews, three stages of students' conceptions about chemical reactions were identified. In the first stage, a number of students (five aged 14, four aged 16 and only one aged 18) were unable to describe and explain a chemical reaction and for the vast majority of them it just happens as an "event". In a second stage, 14 students (five aged 14, six aged 16, and three aged 18) identified a chemical change rather as a procedure of mixing two substances, than as an interaction between them leading to the formation of new substances. Only in the third stage, five students aged 18 interpreted chemical changes satisfactorily using appropriate terms on the microscopic level.

### The effect of age on understanding chemical change

Studying such findings one can see a differentiation in students' ideas depending on the age of the participants. Generally, the idea of a chemical change is hard even to be grasped by young pupils (ages 11-12) (Stavridou & Solomonidou, 1998; Papageorgiou et al., 2010). With regard to pupils of the 6th grade for instance, Papageorgiou et al. (2010) enhanced previous findings of Stavridou and Solomonidou (1998), suggesting that, the lack of students' ability to think in microscopic terms at that age, hinder their understanding of substances change during a chemical change and thus their interpretation of such phenomena. On the contrary, students attending secondary education seem to be more able to work in microscopic level and to understand chemical changes more sufficiently, although still with many misconceptions. Characteristically, when Solsona et al. (2003) investigated the understanding of a chemical change by students aged 17-18, they identified four different conceptual profiles. Three of them were: the 'incoherent profile' where no coherence appeared in students' explanations, the 'kitchen profile' where students interpreted the phenomenon through macroscopic scale and, for an 8% of the participants, the 'interactive profile' where a chemical change was understood through the change of substances and explanations involved macro- and micro- levels. Interestingly, the fourth 'meccano profile' comprised cases where, although students could work in micro- level frequently using terms like 'atom' and 'electrons', it was unclear whether they could make the connection with the macroscopic properties of the substances and thus, it was uncertain whether they had grasped the concept. Also interestingly, when Calik and Ayas (2005) investigated the level of the understanding of chemical changes by secondary students aged 14 together with their teachers, they found that only a percentage of 12% of the students demonstrated sound understanding of chemical changes. In addition, regarding the change of substances properties, the majority of the participants believed that there was not any alteration during the changes, whereas they mostly focused on physical changes. Both students and their teachers shared such misconceptions, although those of the students were twice as many. Similarly, when BouJaoude (1991) interviewed 20 students of the same age (i.e. 14), eight of them perceived the change as physical, whereas the term 'chemical change' seemed to be memorized only as a phrase.

With regard to university students, misconceptions still exist and difficulties also arise (Ahtee & Varjola, 1998; Stains & Talanquer, 2008). Although tertiary education tends to be more focused on specific paths of science and relevant research is conducted on more specific domains, the percentage of students that gave a satisfying explanation for a general concept such as a chemical reaction, was found to be considerably low (Ahtee & Varjola, 1998). A cognitive conflict has been also indentified between micro- and macro- scales when interpreting the phenomena and, concepts like 'substance' or 'atom' were found to be difficult. Furthermore, many university students appeared to base their explanations on phenomenological characteristics (Stains & Talanquer, 2008) and, unfamiliarity with microscopic explanations was found regardless the academic year.

### The effect of the particular characteristics of chemical changes

Looking from another angle, can one see interesting differentiations in such pieces of research concerning the kind of the chemical changes that usually researchers investigated. The vast majority of them focused on combustion reactions (BouJaoude, 1991; Brosnan & Reynolds, 2001; Johnson, 2002; Calik & Ayas, 2005), on the formation of iron rust and iron sulfide (Brosnan & Reynolds, 2001; Solsona et al., 2003), as well as on copper oxidation (Johnson, 2000). Although in all these kinds of changes, researchers investigated the understanding of the idea of 'change' itself, the emphasis was in different point each time. In combustion for example, researchers usually focused on the change of weight during the process, as well as on the role of oxygen and its gaseous state. Much of relevant discussion was concerning low students' ability in perceiving the idea that the oxygen, as a material, possesses characteristics such as mass or weight (Calik & Ayas, 2005).

Due to this peculiarity of chemical changes, different approaches, answers categories and findings interpretations were established by the researchers in each one of the above cases. For example, when Johnson (2002) was studying students' understanding of copper oxidation in a longitudinal study, he introduced three main categories. The first category A included students with a very limited view of the change. In category B, although there was a general grasp of the idea of the chemical change, students had some misconceptions concerning the formation of new substances at the macroscopic and/or the microscopic level. In category C, students had sound understanding of the phenomenon i.e. they described an interaction between two substances leading to the formation of a new substance with its own properties. On the contrary, regarding the understanding of a burning candle, in the same work, Johnson identified six different categories. In the four lower categories, although there were differences in students' understanding of the whole process, there was not any recognition of a chemical change. In particular, in category 1 students simply considered the candle as an object, in category 2 they claimed that there was not any alteration on the amount of wax during the phenomenon, in category 3 some students were trying to explain some loss of the amount of the wax as evaporation, whereas in category 4 students believed that there was not any participation of the oxygen in the procedure and water and/or carbon dioxide seemed to preexist in the wax. Only in the upper two categories there was a partially correct recognition of the process. That is, in category 5 students referred to an interaction of wax with oxygen, although there was confusion on how the reactants form different products, whereas in category 6 students had a coherent set of ideas for the chemical reaction, revealing only some misconceptions concerning the internal structure of wax. From another point of view, when Solsona et al., (2003) investigated the formation of iron sulfide, they introduced the four categories already mentioned i.e. 'incoherent', 'kitchen', 'meccano' and 'interactive', where the emphasis was in the students' conceptual profiles derived from their interpretation ability when connecting micro- and macro- levels.

### The effect of individual differences

Despite the plethora of parameters involved in the understanding of a chemical change, many of the researchers agree that the understanding of the particulate nature of matter is a precondition for this process (Stavridou & Solomonidou, 1998, Johnson, 2002; Papageorgiou et al., 2010). Students are not capable of thinking about substances changes when they have not first understood what a substance is. The latter implies the comprehension of the particle theory and an experience in connecting microscopic scale (interaction of particles) with macroscopic scale (change of properties). This connection ability changes significantly along with the age and varies from student to student. It seems that, although this is a challenge for all ages (Stavridou & Solomonidou, 1998), individual differences play also an important role. As Tsitsipis, Stamovlasis and Papageorgiou (2010) suggested, there is a significant effect of cognitive variables and especially of those concerning *Logical Thinking, Field Dependence/Independence* and *Divergence/Convergence* on the understanding of the particulate nature of matter and therefore, on this ability. Does this mean that they have eventually an effect on the understanding of chemical changes?

From a cognitive point of view, *Logical Thinking* is a cognitive style which comes from Piagetian theory and it is associated with the ability of a person to use 'formal reasoning' when trying to understand concepts that people can understand "not through senses, but through imagination or through their logical relationships within the system" (Lawson & Renner, 1975, p. 348). In literature, a great number of studies emphasize the major role of this cognitive style in students' performance in science (e.g. Lawson & Thompson, 1988; Alick & Atwater, 1988; Niaz, 1996; BouJaoude, Salloum & Abd-El-Khalick, 2004; Tsitsipis et al., 2010).

An also cognitive style refers to a person's ability to separate the significant information from the irrelevant and extra information, known as *field dependence/independence* style (Witkin, Oltman, Raskin & Karp, 1971). Accordingly, Witkin and Goodenough (1981) categorized individuals as *field dependents* or *field independents.* Regardless the scientific field (language, mathematics, social sciences etc.), the prevailing view suggests that, generally, field independent students perform better than the others (Bahar & Hansell, 2000; Danili & Reid, 2004; Tsaparlis, 2005; Tsitsipis et al., 2010).

Additionally, an individual could be characterized by his ability to find either one conventionally accepted solution to a problem (a *converger*) or several equally acceptable solutions to this problem (a *diverger*). These two cognitive styles, i.e. *convergence* and *divergence,* were developed by Hudson (1966). Initially, it was thought that an individual, who scores low in a divergence test, indicates convergence (Bahar, 1999). This idea was challenged by

Hindal, Reid and Badgaish (2009) who suggested that convergence should be examined as a separate learners' characteristic. According to them, a person could achieve high score in either of these characteristics or in neither of them. In the light of their findings, the thought that convergence is the opposite of divergence seems to be overtaken. Regarding the field of chemistry, a diverger seems to perform better than a converger when open-ended questions are used (Al-Naeme, 1991; Danili & Reid, 2006). However, in his work, Hudson (1966) suggested that students' performance in biology was similar for both styles, whereas in the physical science area the hypothesis was that convergers score better than divergers (Marjoribanks, 1978).

### Chemistry in Greek secondary education

In Greek secondary education, physics, chemistry, biology, and geology/geography are taught in a context of distinct courses. Although corresponding specialties of secondary school science teachers are acknowledged, a science teacher could potentially teach all these courses. Chemistry is taught from grade 8 (ages 13-14) to grade 11 (ages 16-17) as a course of the general secondary science curriculum. At grade 12 (ages 17-18), chemistry is taught only in one out of three alternative directions of science curricula, namely the 'science and math direction'. This direction leads students to science, engineering and medical tertiary education.

In lower secondary education, known as 'gymnasium' (which comprises grades 7, 8 and 9), only one tenth of the total lessons on chemical changes that are anticipated for the secondary education take place. In particular, at grade 8, chemistry topics are taught in a one-hour lesson (45 minutes) per week from September to May. Chemical reactions, substances structures and the Bohr atomic model are introduced to students at that grade. They are asked to learn that, in chemical reactions, changes in the structure of the reactants take place, which lead to the formation of new substances with different properties. They are also asked to use properly terms such as 'reactants', 'products', 'atoms', 'protons', 'electrons' etc. At grade 9, where chemistry is also taught for a one-hour lesson per week, the reaction of neutralization is introduced.

Upper secondary education, known as 'lyceum', comprises grades 10 to 12. At grade 10, the chemistry curriculum anticipates two one-hour lessons a week. Chemical reactions, substances structures and the Bohr model are also taught, but in more depth, whereas at grade 11, the basic organic chemistry (also for one hour per week) is introduced to the students. At the final grade of secondary education, quantum chemical concepts such as 'atomic orbitals' and 'electronic clouds' are taught twice a week only to students who have chosen the 'science and math direction'.

### Rationale and research questions

Research has shown that the understanding of the particulate nature of matter acts as a precondition for understanding and interpreting chemical changes (Stavridou & Solomonidou, 1998; Johnson, 2002; Papageorgiou et al., 2010). On the other hand, some individual differences appear to have a significant effect on the understanding of the particulate nature of matter (Tsitsipis et al., 2010). To this end, further worth-testing research hypotheses could be stated concerning the explanatory role of these individual differences on students' understanding of a chemical change, a core topic in chemistry teaching.

Regarding the individual differences in question, the choice was theory driven, taking into account previous research findings as well. A number of Neo-Piagetian cognitive variables are already known as predictors to students' achievement in science (Johnstone & Al-Naeme, 1995; Niaz, 1996; Tsaparlis & Angelopoulos, 2000; Tsitsipis et al., 2010). Among them, logical thinking, field dependence/independence, convergent and divergent thinking were sought as the more closely associated with the mental tasks usually involved in the learning process related to chemistry topics (Tsitsipis et al., 2010; Stamovlasis & Papageorgiou, 2012). Some other variables, such as M-capacity or working memory capacity were not examined, since they are mostly associated with problem solving abilities (Niaz, 1996; Stamovlasis & Tsaparlis, 2005).

The dependent variable investigated in the context of the above questions and, as far as the chemical change itself is concerned, the formation of iron sulfide from its components, iron and sulfur, was chosen among various phenomena. The choice was based on the need for a clear and simple case of a phenomenon, where students' ability to work in microscopic level would be under investigation together with their ability to connect substances characteristics at this level with their properties at the macroscopic level. Cases of chemical changes that could disorient students due to their complex mechanisms or to participation of hardly manageable substances, especially those in the gas state, were avoided. Instead, the complete procedure of the formation of iron sulfide from its components (all in solid state), which would be described in details in the corresponding research instrument, was considered as an appropriate tool in eliciting students' relevant ideas. In addition, for evaluating tasks requiring a higher level of understanding, such as the interpretation of the chemical change, the effect of prerequisite knowledge and abilities like those concerning the understanding of substances structures and their changes was examined. Thus, four research questions are related to the present investigation:

- Are there significant differences in students' understanding of this chemical change across age?
- Can students' partial scores, such as those concerning the understanding of substances structures and their changes, explain the variability of students' competence in interpreting the chemical change?
- To what extent the above cognitive variables could explain variations in students' understanding of the chemical change?
- Which of the above predictors has the most significant effect?

## METHODOLOGY

### Sample

The participants (n=374) were students of 8th, 10th and 12th grades of secondary schools from Northern Greece. All schools were regular public ones, with students of mixed abilities and socioeconomic background. All participants were volunteers and they had followed the National Science Curriculum for Greece (Greek Pedagogical Institute, 2002) using the same textbook in each one of the grades. Data were collected during one school year through five paper-and-pencil tests (one for chemical change and four for the corresponding four cognitive variables). The completion of the tests took place, in any case, at least two months after the last lesson related to the topic of chemical change. Students were always informed about the purpose of the study.

Among the 374 participants, 195 were male (52.1 %) and 179 female (47.9%), whereas the whole sample comprised students of four groups: 91 students of the 8th grade (age 13) fell in the first group, 95 students of the 10th grade (age 15) fell in the second, whereas the students of the 12th grade (age 17) fell in the third and fourth groups, where 97 from them attended the "technological direction" and 91 the "science and math direction". Thus, along with the differentiation of the sample in relation to the age (13, 15 and 17), the option of the 12th grade students to attend chemistry lessons during that year (science and math direction) or not (technological direction) could also be under study.

### Instruments

All paper-and-pencil tests for the four cognitive variables came from relevant previous studies, whereas the test for the chemical change, also a paper-and-pencil one, was an instrument especially designed for the present study. Before the main study, a pilot study (n=77) was carried out in order to detect possible errors in that instrument. All instruments were written in Greek language and collected data were also in Greek. Therefore, all quotations of student responses given in the results are translations from Greek to English language. A brief description of the instruments follows:

*Logical Thinking*: This ability was assessed by the Lawson test of logical thinking (LTh) (Lawson, 1978). The test is consisted of a total of 15 items including: conservation of mass (one item), displaced volume (one item), control of variables (four items), proportional reasoning (four items), combinational reasoning (two items) and probabilistic reasoning (three items). The students had to justify all answers during one school hour (45 minutes) except two items concerning the combinational reasoning. A Cronbach's alpha reliability coefficient of 0.81 was obtained for the present study.

*Field Dependence/Independence*: FDI ability was measured using the Witkin's et al. (1971) Group Embedded Figures Test. This is a twenty-item test in which a student has to locate a group of 'hidden' drawings within a variety of line patterns. It is a timed test of 20 minutes. A Cronbach's alpha reliability coefficient of 0.85 was obtained for the present study.

*Convergency and Divergency:* As already mentioned, convergence and divergence had to be measured separately. Regarding divergence (DIV), a six-item test designed by Bahar (1999) was used. It is a timed test of 20 minutes. Each item constituted a mini-test: Test 1 asked students to generate words with similar meaning to those given. Test 2 asked students to construct up to four sentences using words in the form as given. Test 3 asked students to draw up to five different sketches relevant to an idea given. Test 4 asked them to write as many things that have a common trait as possible. Test 5 asked to write as many words as possible, that begin with one specific letter and end with another specific one. Finally, test 6 asked students to list all their ideas about a given topic. This test was used to Greek students firstly by Danili and Reid (2006) and recently by Tsitsipis et al. (2010). A Cronbach's alpha reliability coefficient of 0.75 was obtained for the present study.

In order to assess convergence (CONV), a five-item test, which was introduced recently by Hindal et al. (2009), was used. It was translated into Greek language with modifications to some words and ideas in order to fit Greek idioms, in accordance with published guidelines for translation of instruments in cross-cultural research (Hambleton, Merenda & Spielberger, 2005). In line with these guidelines, the test was translated into Greek independently by two native speakers, who then agreed upon a version. It contained five timed sub-tests and students were asked to answer each question separately within a specific time (20 minutes totally). Test 1 asked students to find two patterns that link to a group of words given (question 1), to form two words from letters given (question 2) and to write down the number missing from three sequences given, justifying their response (question 3). Test 2 asked students to read a text and classify three main ideas in a diagram given. Test 3 asked students to pick out a different object from a group of four, explaining the reason for their selection. Test 4 asked students to write two things that are true for all four graphs given. Test 5 asked students to mark a route on a map given and describe it in a few words. A Cronbach's alpha reliability coefficient of 0.60 was obtained for the present study.

*Chemical change*: Students' understanding of a chemical change was assessed with an instrument developed for the needs of the present study and it was the same for all ages. This included 11 items, which could be grouped into three distinct tasks. Task 1 concerns understanding of the substances structure (*Structure understanding*), task 2 concerns recognition of the substances change (*Change recognition*) and task 3 concerns interpretation of the substances changes (*Interpretations*). A description of all the tasks and items is shown in Table 1. The instrument also contained a number of macroscopic pictures which provided students with more information for the experimental process of the synthesis of iron sulfide from its components, including mixing and hearing. The Cronbach's a reliability coefficient of the instrument was 0.79.

For the evaluation of the chemistry test a marking scheme of a 4 level Likert-type scale was used for each item. The score '3' was assigned to correct answers that included explanations at the sub-microscopic level to the expected degree according to what students had been taught in each group. The score '2' was assigned to partially correct answers, the score '1' was assigned to partially incorrect answers including misconceptions of any kind, while no answers or irrelevant answers were marked with '0'.

The marking scheme was applied to both students' descriptive written answers and their drawings. For example, an answer was considered to be a correct one when a student referred for task 2 to a heterogeneous mixture of two components before their heating and (s)he described the formation of a new substance with different structure and properties after the heating. On the contrary, the score '1' was assigned for task 3 to the student's answer: "*Iron melted, it became a liquid and after that, sulfur was covered and mixed with iron. Afterwards, this material became cold and it turned into a stone*". Also, Figure 1 shows an indicative student's drawing representing iron structure in a correct answer for task 1. The sum of items scores was used as the dependent variables for the total and partial scores (task1, task 2 and task 3).

## RESULTS

Table 2 shows the means, standard deviations, and Cronbach's alpha reliability coefficients for the four cognitive variables, as well as the total score for the test on chemical change. One can have thus, a first idea for the students' competences and a general view of the results prior to proceed to the specified analysis presented below.

### Effect of the age cohorts

The analysis focused first on the effect of the age cohorts to investigate a possible progress in students' understanding of chemical phenomena, as it is expected by the curriculum and teaching. Table 3 presents the mean scores of cognitive variables and achievement in chemistry tests across ages. A gradual increase of the mean of all cognitive variables is observed as the age increases. Analysis of variance (ANOVA) with age-group (cohort) as independent variable showed that this increase is statistically significant ($p<0.001$) indicating, expectantly, that age has an effect on the psychometric variables. However, this is not observed in the case of students' understanding of the chemical change. With the exception of Lyceum-Sci cohort, there is no statistically significant difference across aged-groups. That is, only in this group, a specialized one, the effect of teaching on this matter has a manifested effect. This will be discussed later in the discussion part.

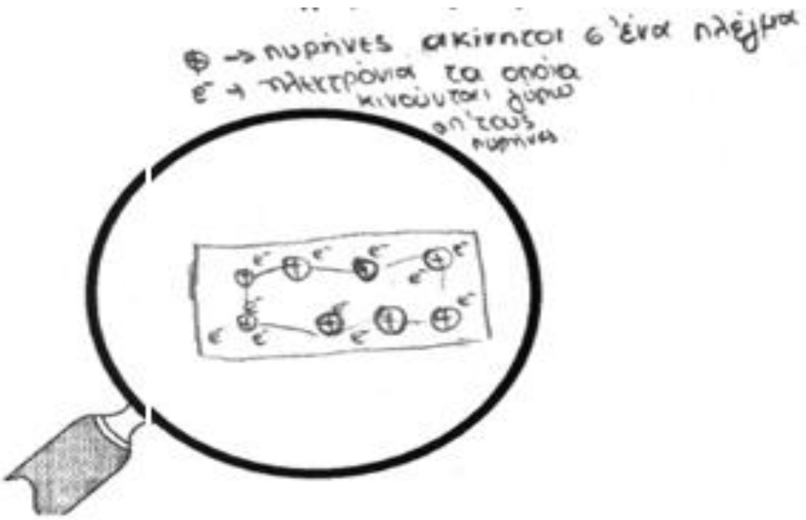

**Figure 1.** An indicative student's drawing representing iron structure in a correct answer for task 1. The student specified that it is about a giant structure (a lattice) where nucleuses of iron atoms remain stable, whereas outer electrons are moving around.

**Table 1.** Tasks and items concerning chemical change

| Task | Description of the task | Description of the items per task |
|---|---|---|
| 1 | *Understanding* of the substances structure | i. Students are asked to draw the structure of iron and sulfur grains when they observe them using a hypothetical magnifying glass.<br>ii. Students are asked to explain their previous drawings.<br>iii. Students are asked to draw the structure of the material after the heating of the mixture, if they can observe it using a hypothetical magnifying glass.<br>iv. Students are asked to explain their previous drawings. |
| 2 | *Recognition* of the substances change | i. Students are asked to explain what happens when the two compounds are mixed together.<br>ii. Students are asked to describe the material that is formed after the heating of the previous mixture and its transformation to a stone.<br>iii. Students are asked to justify their previous responses concerning descriptions and/or pictures. |
| 3 | *Interpretation* of the substances change | i. Students are asked to answer if the material after the heating contains iron and/or sulfur. They are also asked to justify their answer.<br>ii. Students are asked to explain how the components of this new material are connected to each other justifying its properties.<br>iii. Students are asked to describe what happens to this material when it started to glow.<br>iv. Students are asked to describe what happens to this material during the heating and before it started to glow. |

**Table 2.** Mean score standard deviations of cognitive variables and total achievement in chemistry test

| Variables | Max score possible | *n* | Mean | Standard deviation | Cronbach's alpha |
|---|---|---|---|---|---|
| LTh | 60 | 374 | 31.18 | 13.44 | .814 |
| FDI | 20 | 374 | 6.45 | 4.29 | .847 |
| DIV | 100 | 374 | 42.96 | 11.88 | .754 |
| CONV | 25 | 374 | 14.57 | 4.52 | .599 |
| CHEMICAL CHANGE | 33 | 374 | 14.99 | 6.97 | .792 |

**Table 3.** Mean score and standard deviations of cognitive variables and achievement in chemistry test per task across age cohorts

| | Gymnasium (8th grade) | | Lyceum A (10th grade) | | Lyceum Tech (12th grade) | | Lyceum Sci (12th grade) | |
|---|---|---|---|---|---|---|---|---|
| | **mean** | **sd** | **mean** | **sd** | **mean** | **sd** | **mean** | **sd** |
| LTH | 22.68 | 12.52 | 27.4 | 12.7 | 33.89 | 11.45 | 40.75 | 9.77 |
| FDI | 4.86 | 3.39 | 5.6 | 4.03 | 6.76 | 4.04 | 8.59 | 4.73 |
| CONV | 12.07 | 5.04 | 14 | 3.97 | 15.07 | 3.98 | 17.12 | 3.51 |
| DIV | 37.97 | 14.08 | 40.75 | 10.6 | 43.46 | 9.92 | 49.73 | 9.35 |
| Task 1 | 5.32 | 4.23 | 3.93 | 3.8 | 3.64 | 3.69 | 7.77 | 4.82 |
| Task 2 | 5.74 | 2.12 | 4.4 | 2.19 | 5.06 | 2.23 | 6.14 | 1.87 |
| Task 3 | 4.85 | 3.05 | 4.14 | 3.17 | 4.7 | 2.98 | 7.89 | 2.86 |
| Total Score | 15.9 | 7.46 | 12.46 | 6.95 | 13.4 | 6.77 | 21.8 | 7.38 |

### Effect of individual differences

Table 4 presents the correlation matrix with Pearson correlation coefficients of all variables used in this study. All the cognitive variables correlate significantly with all the dependent variables ($p < 0.01$). In particular, LTh, FDI, DIV and CONV correlate significantly with the main dependent variable that is the total understanding of chemical change (0.44, 0.22, 0.38, and 0.39, respectively, $p < 0.01$) as well as with all the other dependent variables: structure understanding, recognition of chemical change and interpretation of the change.

Especially, the *interpretations* correlate significantly with the four cognitive variables LTh, FDI, DIV, and CONV (0.40, 0.19, 0.37, and 0.36, respectively, $p < 0.01$) as well as with the structure understanding and the recognition of chemical change (0.47 and 0.44, respectively, $p < 0.01$).

The correlation analysis suggests that merely linear correlation exists between the two variables when, however, the presence of the others is ignored. Thus, a multiple linear regression was applied in order to provide linear models, which relate the dependent variables with the predictors through stochastic equations (Anderson, 1984). In other words, with the presence of all other variables, these models propose the existence of a statistically significant effect of a predictor.

In order to determine which cognitive variables have an effect on the dependent variables given that the other variables are present, four multiple regression analyses were performed; one multiple regression analysis for each dependent variable. The results are summarized in Table 5.

Also importantly, the application of hierarchical Linear modeling across ages showed that the effects of the cognitive variables on the dependent variables -their coefficients (betas)- do not change across cohorts. This justifies our choice to analyze and present the results for the whole sample with multiple regression analysis.

The first stepwise multiple regression analysis revealed that only LTh was statistically significant predictor of *students' understanding of the structure* scores. This predictor accounted for 12.3% of the variance.

In the other three multiple regression analyses, the three out of the four cognitive variables, that are LTh, DIV and CONV, were determined to be significant predictors of the *understanding of chemical change*, *interpretation of chemical change* and the *total* score. All the three predictors together accounted for 15.7% of the *understanding of the structures*, 21.5% of the *interpretation of the chemical change* and finally, 24.1% of the *total scores*.

Two more multiple regression analyses were applied to determine: (1) Which out of six total variables, namely the four cognitive (LTh, FDI, DIV and CONV) as well as the *understanding of the structure* and the *understanding of the chemical change*, have predictive power on the *interpretation of the chemical change.* (2) Which out of six variables, namely the four cognitive (LTh, FDI, DIV and CONV) as well as the *understanding of the structure of substances* and *their changes,* have predictive power on the *interpretation of the chemical phenomena.*

**Table 4.** Pearson's correlation coefficients

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *Independent variables* | | | | | | | | |
| 1. LTh | 1.00 | | | | | | | |
| 2. FDI | .49* | 1.00 | | | | | | |
| 3. DIV | .47* | .42* | 1.00 | | | | | |
| 4. CONV | .54* | .38* | .55* | 1.00 | | | | |
| *Dependent variables* | | | | | | | | |
| 5. Structure understanding | .33* | .14* | .23* | .25* | 1.00 | | | |
| 6. Recognition of chemical change | .32* | .22* | .33* | .33* | .38* | 1.00 | | |
| 7. Interpretation of chemical change | .40* | .19* | .37* | .36* | .47* | .44* | 1.00 | |
| 8. TOTAL | .44* | .22* | .38* | .39* | .83* | .70* | .81* | 1.00 |

* Correlation is significant at the 0.01 level

**Table 5.** First set of regression analyses: Regression slopes, *t*-tests, model fit and $R^2$

| **Model** | | **Adj $R^2$** | **% of variance explained** | **b** | **Beta** | **t** | **F** |
|---|---|---|---|---|---|---|---|
| **Structure** | | .123 | 12.3 | | | | 12.950*** |
| | *LTh* | | | .075 | .285 | 4.513*** | |
| **Change** | | .157 | 15.7 | | | | 17.222*** |
| | *LTh* | | | .025 | .153 | 2.476* | |
| | *DIV* | | | .033 | .177 | 2.938** | |
| | *CONV* | | | .069 | .141 | 2.271* | |
| **Interpretation** | | .215 | 21.5 | | | | 25.284*** |
| | *LTh DIV* | | | .061 | .272 | 4.560*** | |
| | *CONV* | | | .050 | .196 | 3.369*** | |
| | | | | .092 | .137 | 2.288* | |
| **Total** | | .241 | 24.1 | | | | 30.685*** |
| | *LTh DIV* | | | .161 | .312 | 5.341*** | |
| | *CONV* | | | .109 | .185 | 3.254*** | |
| | | | | .214 | .139 | 2.378* | |

* p < 0.05, ** p < 0.01, *** p < 0.001

Table 6 demonstrates that: (1) only four out of the six variables were statistically significant predictors of students' interpretation scores. The predictors were the following: *Understanding of the structure*, *understanding of the chemical change*, LTh and DIV. All four predictors together accounted for 35.4% of the interpretations variance. (2) Only two variables were statistically significant predictors of students' *understanding of chemical change*: the *understanding of the structure* and the *interpretation of the chemical change* accounting together for 25.9% of the variance.

According to Bryman and Cramer (1990), the standardized regression betas of the regression analyses can be used as path coefficients. Thus, two path analyses were employed. Path I diagram (Figure 2) shows that LTh has a

**Table 6.** Second set of regression analyses: Regression slopes, *t*-tests, model fit and $R^2$

| **Model** | | **Adj $R^2$** | **% of variance explained** | **b** | **Beta** | **t** | **F** |
|---|---|---|---|---|---|---|---|
| **Interpretation** | | .354 | 35.4 | | | | $35.090^{***}$ |
| | *LTh* | | | .035 | .154 | $2.788^{**}$ | |
| | *DIV* | | | .034 | .132 | $2.477^{*}$ | |
| | *STRUCTURE* | | | .252 | .295 | $6.345^{***}$ | |
| | *CHANGE* | | | .302 | .220 | $4.649^{***}$ | |
| **Change** | | .259 | 25.9 | | | | $22.781^{***}$ |
| | *STRUCTURE* | | | .121 | .195 | $3.786^{***}$ | |
| | *INTERPRETATION* | | | .184 | .253 | $4.649^{***}$ | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

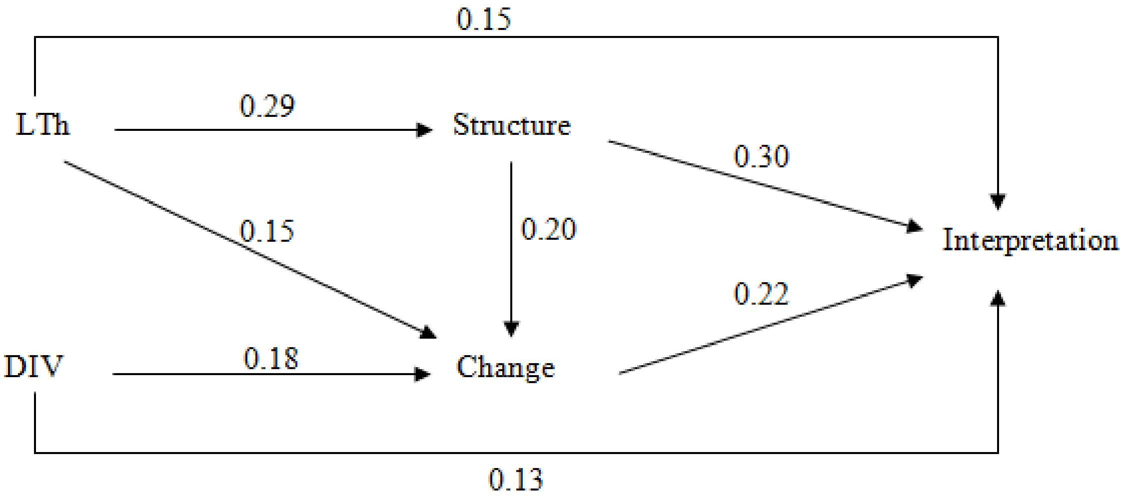

**Figure 2.** A path analysis for hypothesized relationships between the two cognitive variables (LTh and DIV) and the dependent variables (*understanding of structure*, *understanding of chemical change* and *interpreting change*). The total causal effect is 0.45

significant direct effect (0.15) on *interpretation of the change* and an indirect effect via *understanding of the structure* (0.29 × 0.30 = 0.09), via *understanding of the change* (0.15 × 0.22 = 0.03) and both via *understanding of the structure* and *understanding of the change* (0.29 × 0.20 × 0.22 = 0.01). LTh has a total effect of (0.15+0.09+0.03+0.01) 0.28. DIV has a direct effect (0.13) on *interpretation of the change* and an indirect effect via *understanding the chemical change* (0.18 × 0.22 = 0.04). DIV has a total effect of (0.13+0.04) 0.17.

Path II diagram (Figure 3) shows that *understanding of the structure* has a significant direct effect on *interpretation of the chemical change* (0.30) and also indirect effect via *understanding of the change* (0.20 × 0.22 = 0.04). A total causal effect of 0.34 was calculated.

## DISCUSSION

In relation to the main research questions concerning students' understanding of the chemical change, there is no doubt that, independently to age, it is very difficult for a student to grasp the core idea. Further to any verification of relevant findings from previous studies (e.g. Stavridou & Solomonidou, 1998; Boo & Watson, 2001; Johnson, 2002; Ozmen & Ayas, 2003; Papageorgiou et al., 2010; Solsona et al., 2003; Kingir et al., 2013), this study clearly demonstrates a major difficulty for a regular student of Greek secondary education to follow the progress of a chemical phenomenon and to interpret such a phenomenon. The mean total score of all participants is fallen below the one half of the maximum possible score; this is true for all grades, except the students of the Lyceum-Sci

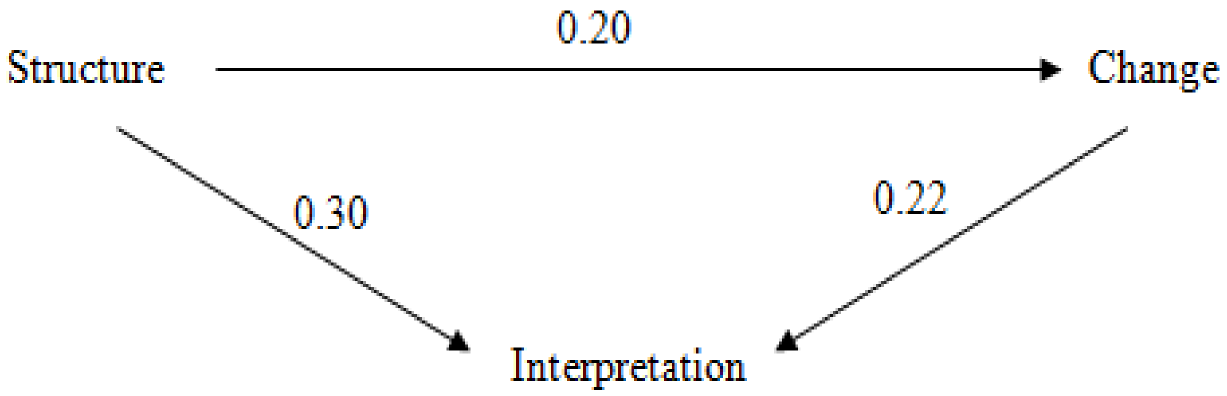

**Figure 3.** A path analysis for hypothesized relationships between students' *understanding of the structure*, *understanding of the change* and *interpreting the change*. The total effect is 0.34

cohort. So, one could agree with those arguing that the understanding of chemical changes is a challenge for all ages (e.g. Stavridou & Solomonidou, 1998; Brosnan & Reynolds, 2001); but is 'age' really a key factor?

The statistical analysis showed that, although age has a significant effect on the cognitive variables, there is no such an effect of age on the dependent variables. An age cohort represents the grade level and it is essentially an indirect evaluation of the curriculum and teaching efficiency. Since the test was the same for all grades, one would expect a better performance as age increases. However, there was not any verification of this expectation. Given that the effects of cognitive variables are statistically significant and constant across cohorts, a potential factor expected to contribute to the explained variability is the school grade level. The expected improvement can be noticed only in the case of 'science and math direction', which is the only direction of the 12th grade where chemistry is taught twice a week. This probably means that, the understanding of chemical changes is related rather to the fact that students at higher grade levels have the opportunity to acquire more knowledge, and therefore they are more able to answer relevant questions, than to a knowledge development due to the age factor itself. Thus, a curriculum and teaching issue might arise here.

The importance of this issue has recently discussed by Jaber and BouJaoude (2012), when they studied the effect of a particular teaching scheme involving macro, micro and symbolic levels on the conceptual understanding of chemical reactions. According to them, students should be first taught these three levels in order to be familiar with them, and then they could be trained to acquire the ability to shift between them. However, if students learn the relevant chemical concepts working separately at these three levels in a discrete manner, they will be probably led to a fragmented kind of knowledge. On the contrary, a student-centered teaching method, that gives emphasis on the interplay between the three levels, along with a students' involvement in an epistemic discourse about the nature of relevant knowledge, can have as a result their conceptual understanding of chemical phenomena.

The findings of the present study advocate the suggestions of the above teaching proposal. Indeed, participants' understanding of a chemical change appears to be associated with their ability to work at the micro- level, to understand the structure of the substances and their changes, as well as to connect them with their properties at the macro- level. In accordance with many researchers' suggestions (e.g. Stavridou & Solomonidou, 1998; Brosnan & Reynolds, 2001; Johnson, 2000, 2002; Solsona et al., 2003; Othman, Treagust & Chandrasegaran, 2008; Stains & Talanquer, 2008; Papageorgiou et al., 2010) the understanding of the structure of the substances and the recognition of their changes are proved to be significant predictors of the students' ability to interpret a chemical change. Among them, the understanding of the structure seems to be the basis of the whole idea of the chemical change, since it has a significant direct effect on the interpretation of the chemical change and also an indirect effect via the recognition of the change. This emphasizes the importance of teaching the relevant to particulate nature of matter topics timely in science education curriculum. As Papageorgiou et al. (2010) suggested, despite the difficulties of young students to understand the idea of a chemical change, there is evidence that they can use particle ideas to interpret such phenomena even from the age of 11/12. Interestingly, for those the ability to use particle ideas was high, an also high ability to interpret chemical phenomena was noted. Besides, the students' understanding of the particulate nature of matter has been found to be significant predictor for the understanding of physical phenomena and in particular, of changes of states (Tsitsipis et al., 2010). That also was a case of young students (age 14-15) advocating the significance for secondary science education of this topic in understanding both physical and chemical phenomena.

However, the ability of a student to use particle ideas, to elaborate micro-situations and to make connections with the corresponding macro- level in order to interpret a chemical change prerequisites the development of formal reasoning. That derives from the Piagetian and Neo-Piagetian theories and it is also found to be true through the findings of the present study. Among the four individual differences under study, LTh appears to play to most important role in understanding a chemical change. This finding is also consistent with those of other previous studies reporting the supremacy of LTh as a predictor of students' science competence (Lawson & Thomson 1988; Alick & Atwater, 1988; Kang, Scharmann, Noh & Koh, 2005; Tsitsipis et al., 2010; Stamovlasis & Papageorgiou, 2012). In this study, LTh proved to be a significant predictor for every dependent variable. This means that the development of a student's formal reasoning determines to a significant degree the beginning of a process following by certain steps concerning his/her ability to work on substances structures (in order to grasp the idea of a 'substance'), to understand the changes in substances structures and the relevant consequences in their properties in real world and thus, to interpret a chemical change. However, this does not necessary mean that students' developmental constraints predetermine the final learning outcome concerning chemical changes in secondary education. As already reported elsewhere (Stamovlasis & Papageorgiou, 2012), there is a lot of discussion on this matter. Despite the controversial aspects, there are many studies suggesting that the teaching content together with the corresponding teaching methods and the whole design of the science curriculum play the central role in this story. Some of them for instance, claim that an appropriate teaching scheme for particle ideas can change those predetermined series of steps and build the preconditions for the understanding of chemical changes (Wiser & Smith, 2008; Tsitsipis et al., 2010).

As far as the role of the rest individual differences in the understanding of the chemical change is concerned, both CONV and DIV proved to be also significant predictors of the total students' achievement, the understanding of the substances change, as well as of the interpretation of change. However, DIV seems to play a more important role and divergent students appeared to have a better ability in interpreting a chemical change. Although this is not in line with the results of other studies suggesting that those who mostly show aptitude for science are convergers (Hudson 1966), the finding was expected to a certain degree. That is, although usually research questions in the field of science demand unique solutions clearly obtainable from the information available, which would favor convergent students, in the present study students' work at the micro- and macro- levels included tasks that needed more complex mental processes. Similarly, when Tsitsipis et al. (2010) investigated the effect of divergent thinking on students' understanding of the particulate nature of matter and the changes of state, they found a better competence of the divergent students.

On the contrary, although FDI appears to play a significant role on the understanding of chemical change when it is correlated in absence of the other independent variables, this role seems to be degraded when these variables are present. This might be due to multicolinearity effects with convergence and divergence when using multiple regression analysis. Nevertheless, the effect of FDI in interpreting chemical changes should not be underestimated, since many previous studies support that field independence is a significant factor effecting students' competence in science (Bahar & Hansell, 2000; Danili & Reid, 2004,2006; Kang et al., 2005; Tsaparlis, 2005; Stamovlasis & Tsaparlis, 2005; Tsitsipis et al., 2010; Stamovlasis & Papageorgiou, 2012). In a recent relevant study in younger students (aged 11/12) for instance (Stamovlasis & Papageorgiou, 2012), FDI found to be a significant predictor of the interpretation of chemical changes. Literature has shown that the role of FDI appears to be diminished when it is examined along with the effects of other variables, especially in low demand tasks, while its effect appears to be significant in tasks that are more complex and difficult for the students (Tsaparlis et al., 1998; Stamovlasis, 2010, 2010). This might explain the low effect of FDI in the present research in comparison to the results of a study on elementary school students. Taking into account that in the present study the average of students' age is higher and there is a significant improvement in the students' mean scores in relation to the age, it is possible that this is an indication that the role of FDI is more efficient in younger ages, where the tasks seem to be more difficult. In other words, a possible explanation could be that the advantage of a field independent student to separate readily the significant information from its context (Witkin & Goodenough, 1981) is of great importance for the understanding of chemical changes when the micro- situations where (s)he is working on are unfamiliar to him/her. In upper grades, when the ability to recognize and manipulate particle identities has been developed due to experiences provided through the science curriculum, these situations are more familiar and the advantage possibly partially fades, without however stop playing a noticeable role.

Overall, evaluating the effect of all the selected cognitive variables, it is concluded that they can explain a significant part of the students' competence variance and all the related model-parameters are statistically significant. Thus, the findings of the present research are of paramount importance, because they shed light on the factors effecting students' understanding of chemical changes, emphasizing the important role of the individual differences.

The latter could help in the design of relevant teaching schemes concerning this highly important particular domain, fostering strategies that overcome barriers set by these individual differences.

## IMPLICATIONS FOR SCIENCE EDUCATION

The implications concern science educators, but also all those involved in the design of curricula or educational materials such as textbooks or software. Science educators should be aware of the significant role of individual differences, not only in the understanding of the idea of chemical change, but also in the learning process generally. Cognitive styles that describe the way a student approaches a learning task, also determine the learning strategies that should be followed (Sternberg, 1997; Riding & Rayner, 1998). A teacher could help students with insufficient formal reasoning to overcome barriers and obstacles existed due to their limited relevant ability, by applying appropriate teaching methods that make abstract concepts more accessible even through concrete thinking. As also discussed elsewhere (Howe & Durr, 1982; Zeitoun, 1984; Stamovlasis & Papageorgiou, 2012) these methods could include illustrations, diagrams and models that constitute more perceptible entities under study in order to pay attention on critical attributes of abstract concepts. In addition, it would be clear for the science teachers that a constructive teaching concerning the idea of chemical change, as well as any relevant science domain, should not adopt only a single correct way, plan or solution.

Curriculum designers should be aware not only of all the above, but also of the factors shaping an appropriate content in each grade. The lack of progress in understanding chemical phenomena across the three grades of this study might probably designate that the content is not the most appropriate, although causes should be further investigated. Even though the sample was not representative in order to generalize for the whole student population, we consider that it might be indicative for the Greek curriculum and teaching approach deficiencies. Generally, a science curriculum might start studying observable materials involved in chemical changes and then continue giving the opportunities to students to facilitate interpretations of chemical changes by the introduction of particle ideas. All this progress should take place within an explanatory context and not within the logic of the discipline of chemistry as perceived by the experienced chemist (Danili & Reid, 2004). Although the timing of introducing particle ideas is a matter of a wider discussion, Johnson and Papageorgiou (2010) for instance suggested that, they might be included quite early in the science curriculum (probably after the stage of studying observable materials), since this is a prerequisite for the understanding and interpreting any phenomenon, physical or chemical, and therefore, adequate time should be available for studying the phenomena themselves in the following grades.

In any case, when science education is for all, consequences of the role of individual differences in understanding phenomena such as chemical changes, should be taken seriously into account by any one is engaged in this process. To that extent, any further research that fosters this role could also help to a better science education.

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