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FOSTERING CONCEPTUAL CHANGE THROUGH VALUES *AND* KNOWLEDGE EDUCATION (V*a*KE): THE CASE OF NANOTECHNOLOGY

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Η συγγραφέας Χριστοδούλου Παναγιώτα βεβαιώνει ότι το περιεχόμενο του παρόντος έργου είναι αποτέλεσμα προσωπικής εργασίας και ότι έχει γίνει η κατάλληλη αναφορά στις εργασίες τρίτων, όπου κάτι τέτοιο ήταν απαραίτητο, σύμφωνα με τους κανόνες της ακαδημαϊκής δεοντολογίας.

Υπογραφή:

Ημερομηνία:

To my parents….

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Abstract

The purpose of the present study was to address the knowledge part of the teaching approach V*a*KE (Values *and* Knowledge Education) in terms of conceptual change. Three research questions were examined; (a) whether V*a*KE fosters the same levels of conceptual change, in comparison to an inquiry based teaching in nanotechnology issues (b) whether V*a*KE could sophisticate students' epistemological beliefs and motivate them at the same levels compared to an inquiry based teaching. In addition it was examined (c) whether students participated in a V*a*KE unit could be benefited the most in conceptual understanding regarding their IQ in achieving conceptual understanding.

A quasi experimental design was conducted with pre-, post-, and follow-up measurements. 81 Greek students participated in the study (41 female, M= 11.48 years, SD=.35). Conceptual change was assessed with a generative questionnaire constructed particularly to assess nanotechnology issues, while epistemological beliefs were measured with the Conley, Pintrich, Vekiri, and Harrison (2004) questionnaire addressing the dimensions of source, stability, development and justification. Motivational aspects were examined after the interventions with the Intrinsic Motivation Inventory (Plant & Ryan, 1985). Finally non-verbal IQ was examined with a computerized version of the Raven matrices test.

With respect to the first research question repeated measures ANOVAs revealed that V*a*KE fosters conceptual understanding at the same levels with an inquiry based teaching. Further repeated measures ANOVAs and multiple independent sample t tests, were conducted with respect to the second question indicating that only one dimension of students epistemological beliefs was sophisticated, while one motivational aspect was found statistically significant for the experimental group, namely perceived competence and another one for the control group, namely perceived choice. Finally multiple repeated measures ANCOVAs were conducted for the third research question indicating that students with the lowest IQ were benefited the most for achieving conceptual understanding while participating in a V*a*KE unit.

Although V*a*KE fostered conceptual understanding, all students did not achieve full conceptual change; rather misconceptions and synthetic models were constructed. Nevertheless synthetic models are an intermediate state before full conceptual understanding is achieved. Moreover, synthetic models are dynamic and constantly changing as children's knowledge system develops. Secondly according to contemporary findings framework theories continue to exist with the newly acquired scientific knowledge indicating that domain general abilities, such as executive functions are involved. Furthermore V*a*KE sophisticated students' epistemological beliefs and increased motivation in comparison to an inquiry based teaching, explaining the levels of conceptual understanding.

Keywords: Conceptual change, Values and Knowledge Education (V*a*KE), epistemological beliefs, motivation, nanotechnology, primary education

Περίληψη

Ο σκοπός της παρούσας μελέτης είναι να εξετάσει το γνωστικό κομμάτι της διδακτικής προσέγγισηςV*a*KE (Διδασκαλία Αξιών και Γνώσεων) από την άποψη της εννοιολογικής αλλαγής. Τέθηκαν τρία ερευνητικά ερωτήματα: (α) Αν μπορεί η διδακτική μεθοδολογία V*a*KEνα προωθήσει τα ίδια επίπεδα εννοιολογικής αλλαγής σε σύγκριση με μία διερευνητική διδασκαλία πάνω σε θέματα νανοτεχνολογίας, (β) αν μπορεί να εκλεπτύνει τις επιστημολογικές πεποιθήσεις των μαθητών και να αυξήσει τα κίνητρά τους σε σύγκριση με μια διερευνητική διδασκαλία, (γ) αν το V*a*KE θα μπορούσε να διευκολύνει περισσότερο την εννοιολογική κατανόηση για κάποιους μαθητές σύμφωνα με το IQ τους.

Ένα οιονεί πείραμα σχεδιάστηκε και πραγματοποιήθηκαν μετρήσεις πριν, μετά και σε επανάληψη έπειτα από τρεις μήνες. Στην έρευνα συμμετείχαν 81 μαθητές (41 κορίτσια, M = 11.48χρόνια, SD = 0.35). Η εννοιολογική αλλαγή αξιολογήθηκε με ένα ερωτηματολόγιο παραγωγικών ερωτήσεων το οποίο κατασκευάστηκε ειδικά για να αξιολογήσει θέματα νανοτεχνολογίας, ενώ οι επιστημολογικές πεποιθήσεις μετρήθηκαν με το ερωτηματολόγιο των Conley, Pintrich, Vekiri, και Harrison (2004) Το ερωτηματολόγιο μετρούσε τις επιστημολογικές πεποιθήσεις σχετικά με την πηγή και την τεκμηρίωση του γιγνώσκειν, την σταθερότητα και την ανάπτυξη της γνώσης. Ακόμη εξετάστηκαν και τα κίνητρα των μαθητών με το ερωτηματολόγιο εσωτερικών κινήτρων, IMI (Plant&Ryan, 1985), ενώ τέλος, το IQ των μαθητών εξετάστηκε με μια ηλεκτρονική μορφή του τεστ μη λεκτικής νοημοσύνης Raven.

Όσον αφορά το πρώτο ερώτημα πολλαπλές αναλύσεις επαναλαμβανόμενων μετρήσεων διακύμανσης αποκάλυψαν ότι το V*a*KE προάγει την εννοιολογική κατανόηση στα ίδια επίπεδα με τη διερευνητική διδασκαλία Περαιτέρω αναλύσεις επαναλαμβανόμενων μετρήσεων διακύμανσης και έλεγχοι t-test για ανεξάρτητα δείγματα πραγματοποιήθηκαν αναφορικά με το δεύτερο ερώτημα αποκαλύπτοντας ότι μόνο η επιστημολογική πεποίθηση των μαθητών που σχετίζεται με την ανάπτυξη της γνώσης εκλεπτύνθηκε. Επιπλέον, ο παράγοντας της αυτό-αποτελεσματικότητας κρίθηκε στατιστικά σημαντικός για την πειραματική ομάδα όσο αναφορά τα κίνητρα των μαθητών, ενώ η αντίληψη των μαθητών για τη δυνατότητά τους να επιλέγουν τις δραστηριότητες που θα πραγματοποιούσαν βρέθηκε στατιστικά σημαντική για τους μαθητές της ομάδας ελέγχου. Τέλος οι πολλαπλές επαναλαμβανόμενες μετρήσεις συνδιακύμανσης που πραγματοποιήθηκαν για το τρίτο ερώτημα της έρευνας έδειξαν ότι οι μαθητές που συμμετείχαν στην πειραματική ομάδα με IQχαμηλότερο του μέσου όρου (<95) ωφελήθηκαν περισσότερο για την επίτευξη εννοιολογικής κατανόησης.

Αν και το V*a*KE προώθησε την εννοιολογική αλλαγή πολλοί μαθητές κατασκεύασαν παρανοήσεις και συνθετικά μοντέλα. Μολοταύτα το παραπάνω εύρημα δικαιολογείται αφενός γιατί τα συνθετικά μοντέλα είναι μια ενδιάμεση κατάσταση πριν την επίτευξη πλήρης εννοιολογικής αλλαγής, αφετέρου γιατί σύμφωνα με τελευταία ερευνητικά δεδομένα οι αφελής θεωρίες των μαθητών συνυπάρχουν ακόμη και αν έχει κατακτηθεί η επιστημονική άποψη, αναδεικνύοντας ως σημαντικούς, μηχανισμούς όπως οι εκτελεστικές λειτουργίες. Ενδιαφέροντες συσχετισμοί προκύπτουν ανάμεσα στο γνωστικό κομμάτι της μεθόδου V*a*KEκαι της προσέγγισης της εννοιολογικής αλλαγής.

Λέξεις κλειδιά: Εννοιολογική αλλαγή, Διδασκαλία αξιών και γνώσεων (V*a*KE),επιστημολογικές πεποιθήσεις, κίνητρα, νανοτεχνολογία, δημοτικό σχολείο.

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It has been almost five years since the first time I studied on V*a*KE. It was after a lecture of Jean-Luc Patry in the course of Emotional and Moral Development during my undergraduate studies at the University of Western Macedonia. That was also the time I realized teachers' "double assignment"; to provide students not only with knowledge but with values education as well. However, in my opinion, it is more important for a teacher to provide students with strategies, skills and values which will guide them during life rather than providing them with opportunities on knowledge acquisition. In particular, addressing values education would be the most important assignment for me as a teacher particularly because of the times we live in. V*a*KE changed the way I think of education since it provides the teacher with an opportunity to combine both values and knowledge education.

Cognitive development and in particular conceptual change became equally important for me as a teacher and a learner mainly through my participation in the course of Cognitive Development where the instructor was Dimitris Pnevmatikos, once again during my undergraduate studies in University of Western Macedonia. After this course I personally underwent conceptual change in many domains. Moreover, it became clear to me that organizing newly acquired and pre-existent knowledge in a hierarchical way facilitates not only a better understanding but conceptual understanding as well.

I became familiar with the concept of Nanotechnology through participation, during my post graduate studies in the University of Western Macedonia, in the project of Science Teacher Education (STED) which was an in service teacher training program on science education. Scientific leader of the team, where teachers were trained on Nanotechnology issues was Anna Spyrtou. At this point it is important to thank not only Anna Spyrtou but Leonidas Manou, Ph.D. student, and George Peikos, master student on Nanotechnology at University of Western Macedonia, for guiding me on this newly acquired area of Nanotechnology. Nanoscience and Nanotechnology is quite challenging for primary education but from previous findings it was not impossible to teach and as a matter of fact it proved quite interesting for students. In addition, Nanotechnology was also an ideal subject to address with V*a*KE since it yields many ethical and controversial issues besides its innovative content. Furthermore, Nanotechnology is an appropriate domain for conceptual change since students cannot access directly the unseen nano scale and as a consequence misconceptions are more likely to be created.

I am obliged to Filio Georgiadou, PH.D student at the University of Western Macedonia studying in the field of cognitive psychology, who was the second person helping coding students' answers from the generative questionnaire. Also I would like to mention here, George Kyrianakis, PH.D student in cognitive psychology at the University of Western Macedonia, who facilitated me in estimating students IQ though the computerized Raven test and finally Anjelina Lithoxoidou, PH.D student in Language instruction for examining the text and eliminating any language informalities.

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A Introduction

The current study attempts to deal with the problem of conceptual change addressed as reason behind students' widespread failure to understand counterintuitive concepts mostly in the fields of science and mathematics. An emerging field of interest to science education was chosen for the purpose of the current study, namely that of Nanoscience and Nanotechnology.

Nanoscience and Nanotechnology have extensive implications for the society as they provide it with great advancements in many fields of everyday life. Both benefits and risks concerning applications in the field of Nanoscience and Nanotechnology emerge and as a result education needs to prepare citizens who will be able to make decisions about ethical and societal issues that might arise from Nanoscience and Nanotechnology based on a global and sustainable perspective.

Values and Knowledge Education (V*a*KE) is an instructional approach integrating constructivist knowledge acquisition with constructivist values education through introducing a moral dilemma in order to trigger the discussion among participants. Participants define the missing information needed to answer the problem suggested in the dilemma and by the end of the process a solution is provided. Furthermore, during the discussion participants' moral judgments are challenged to higher levels of moral development. As a result, the provided solution by the end of the process is expected to take into account not only the knowledge acquired but also a more global perspective with regards to the values involved in the dilemma.

Although knowledge is acquired through a V*a*KE process, a question arises of whether participants can also achieve conceptual understanding. Thereafter the main purpose of the current study is to investigate whether V*a*KE is an appropriate teaching approach to promote conceptual understanding, in particular in the field of Nanoscience and Nanotechnology.

The current study is divided in five parts, the theoretical part where the theoretical premises of the study are presented, the parts where the methodology and results of the study are presented and finally a discussion on the findings of the research along. The reader can find the educational material as well as the instruments employed in the research design at the appendices of the publication.

The theoretical part of the study provides an introduction to the conceptual change approach along with the basic principles of the framework theory approach which was followed in the current study, namely that knowledge is acquired in domain-specific, theory-like knowledge structures and that knowledge acquisition is characterized by theory changes. Besides cognitive aspects of conceptual change, motivational and epistemological aspects are also described since it is indicated that facilitate conceptual understanding. In addition, a special reference is being made to the case of Nanotechnology. Firstly, there is a brief introduction to what exactly Nanoscience and Nanotechnology are and why they should be implemented in education. Then the key concepts of Nanotechnology provided in education are presented along with activities integrating these key ideas in formal or informal settings. Finally, students' misconceptions on the concepts of Nanoscience and Nanotechnology employed in the current study are presented. This part of the study is completed with two chapters, one referring to the instructional approach of V*a*KE and the other to the current study. Concerning V*a*KE the theoretical background along with other additional theories supporting the method are introduced. Hence the steps of a prototypical V*a*KE unit, the methods and instruments used for assessment as well as the generalizability of the method, follow. The last chapter of this first part of the study consists of the main idea and purpose of the study, the research questions and hypothesis.

In the next part of the study details concerning the participants of the study are introduced, the design and procedure of the study are described in detail. Also the instruments used to collect the data needed are described and presented. The analysis and presentation of the findings of the current study follows, and the paper concludes with the discussion of these findings in relevance to the hypotheses of the current study and literature; limitations of the study and further research suggestions are also included. In the appendices one can find the educational material constructed for the designed interventions, students' produced material during the interventions as well as a table with the established criteria used for classifying students' knowledge responses regarding the framework theory's approach basic principles.

A.1 An introduction to the theory of conceptual change

Among the most important missions of education is to enable students to understand of the various scientific concepts engaged in scientific areas such as science, mathematics, biology, history and economics. However, this is the assignment schools fail the most, since a profuse body of research has documented persistently students' misconceptions on such scientific domains (Vosniadou, 2007). Some researchers suggest that teachers themselves hold ideas which are not in accordance with the scientific concepts (Duit & Treagust, 2012a) or they are generally uninformed about the recent state of research on teaching and learning neither in science nor on other instructional domains (Duit, Treagust & Widodo, 2013). As a consequence, they fail and lead students to a simple memorization of facts or an enrichment of their misconceptions, whilst what students need, is restructuring their prior knowledge in such a way that is in accordance to the scientific view. This revision of prior knowledge is known as *conceptual change*.

According to Vosniadou (2007) conceptual change in development and learning "is a constructivist approach that rests on certain fundamental assumptions, such as that knowledge is acquired in domain-specific, theory-like knowledge structures and that knowledge acquisition is characterized by theory changes" (p. 48). The term conceptual change was first introduced by T. Kuhn (1962) denoting that concepts immerging from a scientific theory can change their meaning when the underlying theory paradigm changes.

Posner, Strike, Hewson and Gertog (1982) drew an analogy between the Piagetian approach of accommodation, assimilation and the theory revision proposed by philosophers of science (e.g. Kuhn), in order to promote "accommodation" in students' learning of science in particular (Vosniadou; 2007, 2013, 2014). Posner et al. (1982) describe some fundamental conditions that need to be fulfilled before conceptual change can occur: In the beginning there must be dissatisfaction with the existing concepts, then a comprehensible concept must be perceived as plausible and finally the new conception should suggest the possibility of its use. Posner and colleagues (1982) expect students to think like scientists who will be led to the scientific view when they will become dissatisfied with their existing concepts and realize that some new conceptions are more productive. Furthermore, misconceptions are considered to be incorrect alternative theories to the scientific ones and consequently need to be replaced by the latter. In this context dissatisfaction becomes a prerequisite for conceptual change and cognitive conflict is the major instructional strategy for success. This approach is known as *the classical approach* of conceptual change and became the leading paradigm in science research and instruction for many years (Vosniadou, 2013). Aspects of this approach over the years were under serious criticism (Caravita & Halden, 1994; Hatano & Inagaki, 2003; Pintrich, Marx & Boyle, 1993; Sinatra & Pintrich, 2003; Smith, diSessa & Roschelle, 1993; Vosniadou & Brewer, 1992), and different approaches were developed by researches under the common notion of domain specificity.

At this point it is important to examine what domain specificity is with concern to conceptual understanding. Conceptual change is a domain specific approach examining distinct domains of thought. In particular, many conceptualizations can be applied to the term of *domain specificity* in the field of conceptual change. The first distinction of the term is with regard to Piagetian approaches which are domain general, focusing on principles, stages, mechanisms or strategies that are meant to characterize learning and development. In contrast, in conceptual change approaches distinct domains of thought are examined and learning and development is described within these domains of thought (Vosniadou, 2007). Moreover, some domain-specific approaches focus on the description of development in different subject-matter areas such as physics (Chi, Feltovitch & Glaser, 1981), mathematics (Mayer, 1985; Van Lehn, 1990) or chess (Chase & Simon, 1973). Finally, for some cognitive developmental psychologists, domain specificity is considered through its constraints on learning; whether these constraints are innate as opposed to acquired, whether having representational content or not or by having sociocultural constrains (Vosniadou, 2007).

Nonetheless domain specific approaches should be considered as complementary rather than contradictory to domain general approaches (Vosniadou, 2014). Furthermore, both domain specific and domain general mechanisms apply in learning and development (Keil, 1994), as also indicated by Vosniadou et al. (in preparation) preliminary studies are linking domain specific conceptual organization changes with domain general processes such as executive functions (see Miyake et al., 2000).

A.1.1 The framework theory approach

Framework theory is an attempt to provide a theoretical concept of how conceptual change is taking place when learning science. The main idea behind the framework theory is that young children start the knowledge acquisition process by forming naïve physics, which does not consist of fragmented observations but rather forms a system of observations with the ability to explain phenomena, namely a framework theory. Knowledge is constructed using additive, enrichment types of learning to incorporate the new scientific knowledge to this preexisting naïve physics (Vosniadou, 2013).

Nevertheless in order for knowledge to be constructed in many cases ontological (e.g. the re-categorization of the earth from a physical object to a physical-astronomical object), representational (e.g. the earth appears to be flat from the perspective one has while being on the earth, while at the same time it appears to be spherical from the perspective one has from space) and epistemological (e.g. understanding the differences between appearance and reality) changes are in order (Vosniadou & Skopeliti, 2014).

However, knowledge construction is a slow and difficult procedure during which fragmentation and “synthetic models” can be created.

Next the basic principles of the framework theory approach will be explicated as well as the main differences and similarities with other approaches of conceptual change. The framework theory approach of conceptual change was employed for the present study and is critical for the reader to comprehend its fundamental concepts.

A.1.1.1 Naïve physics and framework theory

There is a need to clarify some terms used in framework theory of conceptual change such as naïve physics, naïve theory and framework theory in order for the reader to fully comprehend the concept of framework theory for conceptual change.

Cognitive developmental research has provided us with evidence that even infants can organize the multiplicity of their sensory experiences under the influence of everyday culture and form relatively coherent domains of thought from an early age (Baillargeon, 1995; Carey, 2009; Carey & Spelke, 1994). This means that young children can be engaged in knowledge acquisition based on their experiences within a specific subject matter. As a consequence, knowledge in the domain of science is formed in the way of naïve physics, where naïve theories are formed, based on beliefs, ideas and explanations of physical phenomena given by children or adults who have not been exposed to science instruction. According to Vosniadou's Framework theory approach naïve theories (2013, p. 13) are considered to be "skeletal structures that ground our deepest ontological commitments in terms of which we understand the world". Therefore, they are considered as framework theories. Despite that, framework theories differ from scientific theories since they are not explicit, well-formed, socially shared constructs; they lack the explanatory power and internal consistency of scientific theories; they are not examined for confirmation or falsification as they are not subject to metaconceptual awareness.

All the above terms – naïve physics, framework theories, naïve theory(and sometimes 'folk physics' or 'intuitive physics') – are used interchangeably and are considered to be tautological. The above terms refer to a principle based system which is characterized by its own ontology and causality and which can be used by the learner in order to predict and explain scientific concepts (Vosniadou, 2007, 2013; Vosniadou & Skopeliti, 2014).

A.1.1.2 The nature of conceptual change in the framework theory approach

Further clarifying the above, a great deal of research has shown that students who have not been exposed to systematic instruction in physics apply their framework theories to describe scientific concepts. For instance, categorization studies in astronomy have shown that young students categorize the "earth" as a physical object opposed to an astronomical physical object and apply to it characteristics of physical objects such as solidity, stability and up-down gravity (Vosniadou & Skopeliti, 2005). In the same way concepts like force, energy and heat are categorized as properties of objects that can be possessed, transferred and disappear (Chi, 2008; Ioannides & Vosniadou, 2002).

Take now the case that students are systematically exposed to physics instruction, and are told that the earth is a sphere without any further explanation. The preexisting framework theories of the students, namely that the earth is flat as well as their belief in an up/down gravity might lead them to form a *synthetic model*, where the new information about the shape of earth will be incorporated to the preexistent naïve theory forming misconceptions (Vosniadou, 2007). These misconceptions are formed because the learner is confronted with a scientific concept which is incompatible with his or her framework theory. Some possible synthetic models to the aforementioned case might be "the dual earth model" where earth is considered to be simultaneously (i) flat, supported and stable so that people could live on, and (ii) a spherical, rotating earth, and (iii) a planet up in the sky; as well as "the disc model" where earth is considered to be flat and round at the same time (Vosniadou & Brewer, 1992).

Synthetic models are being created because students change some of their beliefs about the original concept by incorporating the scientific information to their incompatible prior knowledge, and these synthetic models can still be used by students to provide explanations and interpret scientific phenomena (Vosniadou, 2013; Vosniadou & Skopeliti 2014). Students create synthetic models because they do not have explicit knowledge of their framework theory, and therefore, they understand neither the contradictions between naïve theories and the scientific explanations, nor the misconceptions they eventually create after their exposure to instruction (Vosniadou, 2007). Moreover, synthetic conceptions are dynamic, they are gradually formed and change during development as revealed by a great deal of studies in many scientific domains (Brown & Bryce, 2003; Ioannidou & Vosniadou, 2001; Kyrkos & Vosniadou, 1997; Samarapunganan, Vosniadou & Brewer, 1996).

In any case conceptual change is a gradual approach, it cannot happen overnight, and through the process fragmentation or misconceptions can be created. Fragmentation can be produced when learners use the scientific information in order to enrich their naïve theories without concerning for internal consistency and coherence (Vosniadou & Skopeliti, 2014). For example, children who believe that night is caused because the sun goes behind the mountains, add the scientific information that the Earth turns around itself to their incompatible prior knowledge and provide explanations to the phenomenon which are internally inconsistent and fragmented (Vosniadou & Brewer 1994). On the other hand, misconceptions can be created when the scientific information is distorted and students create synthetic constructions providing incorrect but creative solutions between the incompatibilities of naïve theories and scientific information. The difference is that these synthetic models have some explanatory value and internal consistency. In order to distinguish between fragmentation and synthetic models two criteria must be taken under consideration, internal consistency and explanatory adequacy. The first one is determined by whether students consistently use the same justification to explain the same phenomena like for example that day/night happens because the sun goes behind the mountain. The second one is determined by whether the explanation provided indeed explains the phenomena – even in a very simple way. A synthetic model should have both internal consistency and explanatory adequacy otherwise it should be considered as fragmentation (Vosniadou & Skopeliti, 2014).

For students to avoid creating synthetic models, the ability to make distinctions between "appearance" and "reality" is required (Vosniadou, 2007, 2013). In case students fully comprehend the scientific concept of the earth they are supposed to re-categorize it from the ontological category of physical objects to the ontological categories of physical astronomical objects. This way they are making the desired distinction between "appearance" and "reality" and the prerequisite ontological change. However, this re-categorization of the earth is accompanied with major representational changes, since the earth is a spherical rotating planet in space as opposed to a flat, solid, stable physical object with the sky and planets above its top (Vosniadou, 2007, 2014). Although this representation is often constructed exploiting external models and artifacts, it nonetheless depends significantly on the development of students' perspective taking and epistemological sophistication (Vosniadou, 2013, 2014), namely the ability to make distinctions between "appearance" and "reality" and understanding that things are not always as they appear to be and what seems to be real can be constructed, hypothetical and subject to falsification (Vosniadou& Skopeliti, 2014). Recently a series of empirical studies have found that epistemological beliefs can affect conceptual change performance (Mason & Gava, 2007; Mason et al., 2008; Stathopoulou & Vosniadou, 2007a, 2007b; Kyriakopoulou & Vosniadou, 2014). As a consequence, fundamental ontological, epistemological and representational changes are required for the students to achieve full conceptual change.

Overall the Framework theory is an attempt to provide a theoretical concept of how conceptual change is taking place when learning science. The nature of conceptual change can be described by a distinct line, that of instruction. Before instruction individuals form naïve theories which is knowledge formed from their experience with a specific subject matter. However, after instruction individuals can either undergo full conceptual understanding by acquiring the scientific view, presuming that ontological, representational and epistemological changes have been achieved or form synthetic models, misconceptions or fragmentation while trying to incorporate their incompatible naïve theories to the newly acquired scientific information.

A.1.1.3 The framework theory approach: differences from other approaches

There are three prominent differences between the framework theory approach and the classical approach to conceptual change. First of all, a major distinction is being made between preconceptions and misconceptions. Unlike the classical approach (Posner et al., 1982) (see unit A.1.), the framework theory approach considers *misconceptions* to be synthetic models which result from the student's inaccurate interpretations of the scientific concepts *after* they have been introduced through school instruction. In contrast *preconceptions* are considered to be the initial ideas children form about scientific concepts *before* exposed to any instruction. Secondly, the classical approach states that conceptual change can be achieved with a sudden-gestalt type- replacement of initial conceptions. This replacement presupposes, though, that the learner realizes his or her dissatisfaction from his or her current concepts. On the other hand, as stated earlier, the framework theory approach claims that conceptual change is achieved after radical changes in ontology, epistemological beliefs and representations of the learner's naïve physics. Finally, an important difference between the two approaches is that misconceptions and synthetic models are not regarded as wrong conceptions needing to be replaced by the scientific concepts stated by the classical theory approach; rather they require from the learner to realize that although these synthetic models exist their explanatory power is limited (Vosniadou, 2013; Vosniadou & Skopelliti, 2014). At this point it would be important to elaborate further on what explanatory power means within the Framework theory approach. The explanatory power of a framework theory derives from its ontological and causal structure, consequently when an entity is categorized in an ontological category it immediately inherits all the properties and characteristics of the category. What is crucial is how the learner can be aware of the limited power of synthetic models. Cognitive conflict or a combination of dissonance with knowledge building strategies can prove effective for achieving metaconceptual awareness (Vosniadou & Skopelliti, 2014).

Although Chi and her colleagues (Chi, 1992, 2008; Chi, Slotta & De Leeuw, 1994) express a different argument regarding this latter concept of synthetic models and misconceptions, Chi is not necessarily in contradiction with the framework theory approach. According to Chi (2008) conceptual change is defined as the kind of learning requiring replacing the prior, misconceived knowledge with the new information. In addition, the greatest difficulty in revising misconceptions is that radical ontological reassignments of concepts to their appropriate ontological category are needed (Chi, 2008). This last notion is similar to the description Thagard (2002) provides in order to explain what changes in prior knowledge when conceptual change takes place. On the other hand, the framework theory approach does not deny the necessity of ontological changes but emphasizes on the procedure during which fragmentation, synthetic models can be created as well as the procedure through which ontological, representational, and epistemological changes could take place in order to achieve conceptual understanding.

Another approach of conceptual change is the “Knowledge in Pieces” view, in accordance to which prior knowledge and knowledge emerged from instruction are in continuity. This prior knowledge is composed by many constituent elements with *p-prims* (phenomenological primitives) being one of them and originates to the superficial interpretation of physical experience (diSessa, 1988, 1993). P-prims are organized in a conceptual network and from self-explanatory entities in the beginning are integrated to a larger system of complex structures, such as science laws or justification (diSessa, 1993), so that during the learning process the fragmented knowledge will become coherent due to instruction. That is a difference with the framework theory approach according to which fragmentation to knowledge might result from the instruction *per se*. Another distinction between these approaches is the fact that students cannot always be coherent and theory like speculated by the “Knowledge in Pieces” view, since synthetic models are being formed in order to deal with demands of specific situations and are identified by internal inconsistency and limited explanatory power (Vosniadou, 2013). However according to Brown and Hammer (2008) the differences between these two approaches can disappear with their proposition of the dynamic cognitive structures that could arise from the interactions of smaller conceptual elements.

Additionally, the framework theory and the “Theory Theory Approach of conceptual change appear to have many concepts in line, all of which claim that concepts are considered to be parts of larger theoretical structures and that conceptual change is achieved when a concept is reinterpreted in the context of a new theory (Carey, 1985). “Theory Theory Approach”, though, does not refer to the origins of framework theories or prior knowledge and it rather focuses on older children where systematic instruction is required for the prior knowledge to reorganize (Vosniadou, 2013). Furthermore, according to Carey (2008) conceptual change is not a result of enrichment type mechanisms, rather that of a bootstrapping mechanism, where usually domain specific prior knowledge generates new conceptions (Carey, 2004). According to Carey (2004) bootstrapping is a process underlying the creation of concepts. In the beginning, new concepts are being constructed and related to one another but not to preexisting concepts while subsequently these new concepts are being interpreted by the learner with processes such as analogical mapping, limiting case analyses, induction and abduction (Carey, 2009). Research findings are contradictory with this notion as enrichment type of mechanism appear to be employed (Vosniadou, 2013).

Finally, the framework theory approach has been criticized by sociocultural theorists for focusing only on the individual, internal cognitive processes and not taking into account the social and situational factors that might influence significantly conceptual change (Hatano & Inagaki, 2003). However, the framework theory approach accepts the *cultural mediation hypothesis* (Vosniadou, 2013) according to which individuals in different cultures construct different synthetic models from the possible models, reflecting their cultural experiences (Vosniadou, 1994). The cultural mediation hypothesis has been confirmed in many scientific domains such as astronomy (e.g. Vosniadou, 1994), biology (e.g. Hatano& Inagaki, 1997) and religion (Pnevmatikos & Makris, 2003). Later on, Hatano and Inagaki (2000) suggested that this cultural mediation is more of a sociocultural constrain which is innate domain specific bias guiding learning and development by restricting the possible range of misconceptions leading the learner to select the most appropriate behavior according to his or her cultural experiences. Even though Hatano, as a theorist of the sociocultural approach, claims that understanding is a social approach involving much processing by an active individual mind(1994).Therefore, the individual procedures involved in conceptual understanding cannot be distinguished or be examined apart from the sociocultural procedures engaged in the procedure of knowledge construction.

A.1.1.4 The “Warming trend” in conceptual change research

From a constructivist point of view, prior knowledge is important for learning since the new acquired knowledge should be built upon what students already know. But as claimed previously this pre-existent knowledge may sometimes serve as a barrier of understanding instead of a facilitator. Thus an interesting learning paradox arises concerning other factors that might after all affect which concepts students will adopt.

Early accounts of conceptual change learning focused on the difference between students’ conceptions and concepts in agreement with the scientific point of view. Due to their focus on rational and cognitive factors these approaches were criticized for excluding any affective, motivational or situational factors and thus labeled as the “cold conceptual change” (Pintrich, Marx & Boyle, 1993). Nevertheless, there is substantial research emphasizing on learner’s characteristics, -namely a “warming trend” in conceptual change (Sinatra, 2005). As this hot aspect of conceptual change will be of great interest for the development of the current study as well, it is essential to refer to its premises and current research evidences.

Theorists on the field of conceptual change suggested that knowledge revision occurs when students realize that their pre-existent knowledge contradicts the newly introduced scientific concepts. However, cognitive conflict and deep engagement are often insufficient to induce change (Pintrich et al., 1993). Furthermore, change might not occur even in situations designed to facilitate conceptual change, because learner's characteristics such as motivation, interest and beliefs are missing (Sinatra & Pintrich, 2003). Although Vosniadou (1999) suggested that perspectives as mentioned above should be integrated in order to make the connection between the internal and external factors more explicit, Sinatra and Pintrich (2003) suggested the introduction of the concept of the *intentional learner* (Bereiter & Scardamalia, 1989). With this concept "the impetus for conceptual change is placed within the learner's control" (Sinatra and Pintrich, 2003, p. 2) and as a result conceptual change depends not only on cognitive factors but also on affective, motivational and metacognitive processes employed by the learner in order to achieve conceptual change (Sinatra & Mason, 2013). Since motivational aspects will be of interest for the current study it is essential to examine briefly the different dimensions of motivation and demonstrate further on with research results the relation with conceptual change.

Motivation has been defined in many ways. However, the main factor regarding motivation is how to get someone to act. Moreover, motivation is an internal process whereby a certain action is instigated rather than a product (Brophy, 2004; Pintrich & Schunk, 2002). Deci and Ryan(1985) with their Self-Determination theory consider motivation as what impels a person at any given time which can be affected by personal interest, satisfaction and enjoyment of an activity. This means that interest rises when students feel that a situation or an issue is important for them and they have control of an activity, namely feeling self-competent or self-efficient. Thus, motivation can be classified as either intrinsic or extrinsic. Intrinsic motivation refers to motivation coming from the inside of an individual rather than from any external person or outside rewards as in the case of extrinsic motivation (Deci, Vallerand, Pelltier & Ryan, 1991; Pintrich & Schunk, 2002). Interest is a powerful form of intrinsic motivation, which refers to doing something because it is inherently appealing and enjoyable for students (Deci, 1992; Ryan & Deci, 2000; Ramsden, 1998). Besides interest, self-efficacy and self-competence experienced along with self-determined behavior, are also positive predictors of intrinsic motivation (Ryan & Deci, 2000). Along with these predictors mastery goals also share some of the characteristics of intrinsic motivation but in most cases are considered specific cognitive goals more situational and context depending (Pintrich & Schunk, 2002). The correlation of motivational aspects and conceptual change is to be demonstrated later on.

A.1.1.4.1 Interest

Interest was suggested by Pintrich et al. (1993) as a potential aspect for conceptual change. If you ask teachers to define motivation an answer referring to interest is more than plausible. Incidents taking place in school life may confirm this notion since in many cases teachers might say that students are not interested in learning, parents will explain their children's lack of motivation and poor performance to lack of interest and finally students will argue that they do not learn because school and classes are not interesting for them (Pintrich & Schunk, 2002). These views depict early research in the middle of the20th century where research was focused on phenomena of interest like attention, curiosity and intrinsic motivation. However, at the last decades of the century there was a renewed interest on “interest”.

According to Hidi and Renninger (2006) interest “as a motivational variable refers to the psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time” (p. 112). To begin with, interest can be distinguished from other motivational variables since besides affective factors, it includes cognitive components as well (Hidi & Berndorff, 1998; Hidi & Harackiewicz, 2000; Hidi, Renninger & Krapp, 2004; Krapp, 2000, 2002; Rathunde, 1998; Renninger, 1989, 1990, 2000). Nevertheless, both the aforementioned components have biological roots (Hidi, 2003) while interest can also be the outcome of an interaction between a person and a specific content (Hidi & Baird, 1986; Krapp, 2000; Renninger & Wozniak, 1985).

Studies on interest draw a distinction between individual and situational interest (Alexander, 1997; Hidi & Baird, 1986; Krapp, Hidi & Renninger, 1992). On one hand personal/individual interest is a personal trait or characteristic relatively stable over time associated with individual’s dispositions, specific objects, activities and domains (Hidi & Renninger, 2006; Krapp et al., 1992; Krapp & Prenzel, 2011). On the other hand, situational interest is associated with environmental stimuli and the interestingness of a particular situation activity, task or text that may or may not last over time (Hidi, 1990: Krapp, 2002: Schraw & Lehman, 2001). The role of topic interest has been investigated in a number of studies. Topic interest can be both individual and situational (Hidi, 2000). It can be an expression of individual interest when a person has positive feelings about the topic, finds it of value and seeks information about it. However, it can also be an expression of situational interest, since the topic might be related to certain characteristics of the situation that triggers individual’s cognitive and affective response.

Baldwin, Peleg-Bruckner and McClintock (1985) were interested in separating topic interest and prior knowledge from reading comprehension; however, results revealed that there were significant main effects for both topic interest and prior knowledge.

Schiefele and Krapp (1996) examined the relationship between topic interest and free recall of expository texts, finding that interest was significantly related to the sequence of recalled ideas, while Schiefele (1996) investigated the relation among topic interest, prior knowledge, verbal ability, quality of experience and text learning, revealing among others that topic interest was negatively related to verbal ability and situational representation and that it could predict quality of experience in the reading phase.

The effects of topic knowledge, topic interest and text coherence on learning were examined by Boscolo and Mason (2003) who concluded to the fact that topic interest increased depending on the learner’s knowledge on the topic. As a consequence, high knowledge and highly interested students performed better than the other groups. Mason and Boscolo (2004) examined high school students’ epistemological understanding and topic interest on their interpretation of a dual expository text about genetically modified food as well as their change on beliefs about the topic. Their findings revealed that students’ topic interest affected their answers to the text arguments and text/based interest. Additionally, after reading, a change in students' beliefs about the topic and their epistemological understanding emerged.

The above are only a few studies revealing a relationship between topic interest and comprehension. Nonetheless, a few have focused on the relationship between interest (individual or situational) and conceptual change revealing that it is a "double-edge sword" and may not always indicate conceptual change (Sinatra & Mason, 2013). In a study of high school students' understanding of genetics, findings were contradictory since students with very low interest on the topic produced either high or very low levels of conceptual change (Venville & Treagust, 1998).

In a series of studies conducted by Andre and Windschitl (2003), a positive effect of interest in intentional conceptual change about electrical circuits was demonstrated. Moreover, interest contributed to conceptual learning not only significantly and independently but also indirectly to conceptual change though prior knowledge. The researchers concluded that interest could affect conceptual change not only directly but indirectly through prior experience and knowledge as well.

Mason, Gava and Boldrin (2008) examined 5th graders' topic interest on conceptual change about light and vision in relation to their prior knowledge and epistemological beliefs. Refutational and traditional texts on the matter were read by the students. Topic interest was found to affect change, as highly interested students changed their misconceptions more than less interested students did.

Interest directs the attentional resources of arousal, selective attention and concentration (Sinatra & Mason, 2013). More interest in a topic can be associated with more attentional resources committed to the learning in a situation (Schiefele & Rheinberg, 1997).

A.1.1.4.2 Epistemic Motivation and Epistemic Beliefs

Epistemic motivation refers to motivation that is not focused on one's self but rather on knowledge as an object and is related to the broader view of motivated social cognition (Kruglanski, 1989). Two of the basic epistemic motivations are seeking closure and avoiding closure. The need for closure refers to the desire for definite knowledge on a task. Motivation towards closure varies on a continuum, where on one end there is the strong *need for closure* while on the other hand there is the need for *avoiding closure* (Kruglanski, 1990). In the first case individuals desire to preserve, or "freeze" their past knowledge to safeguard it for the future which leads to close-mindedness. In the second case avoiding closure refers to the need for "seizing" new knowledge, solving questions or problems, and relates to open-mindedness (Kruglanski & Webster, 1996).

Epistemic motivations are closely related to cognitive styles or dispositions which have been investigated by researchers in the field of conceptual change, such as actively open-minded thinking (Stanovich, 1999) and need for cognition (Cacioppo, Petty, Feinstein & Jarvis, 1996). Sinatra and colleagues (Sinatra, Southerland, McConaughy & Demastes, 2003) have explored how pre-existent knowledge, beliefs and cognitive dispositions relate to college students' acceptance of scientific theories (Sinatra & Mason, 2013). The researchers predicted that those students who believed that knowledge can change and who enjoyed critical and open-minded thinking would be more likely to accept scientific theories such as human evolution unlike students who were less interested in critical and open minded thinking. The results of all three studies revealed that epistemic beliefs and thinking dispositions predicted acceptance of human evolution, but knowledge predicted acceptance of theory only in the cases where students' knowledge was high. Based on the findings, the scientific team concluded that for students with limited knowledge, beliefs and dispositions serve like epistemic motivations. In particular, they play a decisive role for the acceptance of scientific issues that are socially embedded like the human evolution. Furthermore, they claim that these students need to sophisticate their epistemological beliefs on the nature of knowledge in order to accept such scientific theories.

Apart from epistemic motivation, epistemological beliefs concerning the nature of knowledge and knowing have also been correlated with conceptual change (Mason, 2003). Epistemological beliefs as mentioned before are beliefs referring to the nature of knowledge and knowing (Hofer & Pintrich, 1997). An issue under discussion concerning epistemological beliefs is the specificity or generality to certain domains of thought. In the case of domain specificity epistemological beliefs can be applied in specific academic domains such as mathematics, history or social sciences. On the other hand, domain general epistemic beliefs mean that they are applicable across all domains (Schommer & Duell, 2013). For many years, epistemic beliefs were considered as domain general (Baxter Magolda, 1992; Kitchener & King, 1981; Perry, 1968; Schommer, 1990; Schommer & Duell, 2013). However, more recently researchers indicated that epistemological beliefs are both domain general and domain specific (Buehl, Alexander, & Murphy, 2002; Hofer, 2000; Muis, Bendixen, & Haerle, 2006; Schommer-Aikins, 2002). Among the various domains of knowledge, research has focused particularly on epistemological beliefs in science (e.g. Bell & Linn, 2002; Elder, 2002; Hammer & Elby, 2003; Op't Eynde, De Corte, & Verschaffel, 2006, Stathopoulou & Vosniadou, 2007) which will be the domain of interest for the present research as well.

Hofer and Pintrich (1997) proposed four general epistemological dimensions including two dimensions for the nature of knowing, namely certainty and simplicity of knowledge, and two dimensions for the nature of knowing, namely source and justification of knowing. The first three dimensions are parallel with those proposed by Schommer (1990) and Schraw, Bendixen and Dunkle (2002), while the last one is often proposed by researchers taking a developmental perspective to epistemological beliefs (Hofer, 2000; King & Kitchener, 1994). Usually in order to refer to beliefs which consider knowledge as predominantly certain and stable the term "naïve" is being used, while the term "sophisticated" is used to refer to those beliefs which consider knowledge as able to change over time (Kienhues, Bromme & Stahl, 2008).

Although developmental studies focused mostly on older population, like college and high school students, research on the field of Theory of Mind suggested that continuity in development between Theory of Mind and epistemological thinking exists. This view was supported by many researchers such as Smith et al. (2000), Chandler, Hallettand Sokol (2002) who indicated that epistemological thinking begins at an early age, even as young as four years old. From that moment on, changes in primary education students' epistemological thinking were examined (e.g. Conley et al., 2004; Pnevmatikos & Papakanakis, 2009). Moreover, a recent study by Vosniadou and Kyriakopoulou (2014) revealed significant correlations between students' growing of Theory of Mind, development of epistemological thinking and science learning, concluding that Theory of Mind tasks can be used to promote conceptual change.

Another study investigating the relationship between epistemic beliefs and conceptual change in both a constructivist and an objectivist learning environment using simulations on the human cardiovascular system was that of Windschitl and Andre (1998). The results besides the fact that highlighted the constructivist environment as more appropriate to promote conceptual change indicated also that students with more sophisticated epistemological beliefs experienced more changes in their ideas about the human circulatory system, contrary to those considering knowledge to be static.

Mason (2000) investigated the relationship between epistemic beliefs and anomalous data that is, presenting students with evidence that contradicts their pre-instructional theories, on theory change of two topics; the dinosaur extinction and the construction of the Giza pyramids in Egypt. The results indicated acceptance of the anomalous data by the eighth graders contributed the most to conceptual change. Moreover, acceptance of anomalous data was associated with the epistemological beliefs of stability of knowledge and source of knowing. As a matter of fact, students were most likely to change their knowledge when believing that knowledge could change.

Instruction in the criteria of scientific arguments combined with constructivist epistemic beliefs was hypothesized to produce greater learning on physics topics concerning gravity and air resistance (Nussbaum, Mason & Poliquin, 2008). Firstly, the authors found that college students, who were given instruction in the criteria of scientific argumentation, used better criteria and developed better arguments on several dimensions.

Another research investigating epistemological beliefs and their relationship with conceptual change emerged from a refutational text in science topics (confuting students' misconceptions regarding natural selection and biological evolution) was undertaken by Mason and Gava (2007). The results showed that eighth graders with more sophisticated epistemological beliefs, who believed that knowledge is complex and uncertain, gained more in a conceptual point of view while reading the refutational text in comparison to those who didn't have advanced personal epistemologies.

In addition, Stathopoulou and Vosniadou (2007) searched the connection between secondary students' epistemological beliefs on their understanding of Newton's three laws and conceptual understanding. Results revealed that students with more advanced epistemic beliefs did better with physics understanding compared to students with less advanced epistemic beliefs. Furthermore, dimensions of construction, stability and structure of knowledge predicted physics understanding as well. Re-examination of the previous results showed again that construction and stability of physics knowledge predicted better understanding. Although sophisticated epistemological beliefs are necessary for conceptual change in physics, they were not sufficient as well.

Representations of physics concept in text about Newtonian mechanics were also related with individuals' epistemic beliefs in order to explore whether learning was facilitated (Franco et al, 2012). From the result it was indicated that when individuals' epistemic beliefs were consistent with the knowledge representations in the texts students performed better on various measures of learning like processing strategies, text recall and change in misconceptions.

Finally, Trevors and Muis (2014) investigated the relationship between effects of text structure, reading goals and epistemic beliefs on conceptual change. In this research university students participated. They were being identified as evaluativist or not, concerning their epistemic beliefs namely that they could or could not reject objectively certain knowledge recognizing its subjectivity, and who randomly received a traditional or a refutational text. Text structure and reading goals were found to affect cognitive conflict, coherence-building and elaborative processing while reading and promoting conceptual change in the post-assessments but failing to include any misconceptions. Furthermore, students identified as evaluativist engaged in fewer comprehension monitoring processes and were more likely to adopt their coherence-building processes according to their reading goals.

A.1.1.4.3 Self-efficacy

Self-efficacy beliefs have been defined as individuals' perception of their specific domain capabilities. Self-efficacy beliefsdo not refer to the will displayed for the fulfillment of a task but they refer to one's perception of ability to complete a certain activity (Bandura, 1977, 1986, 1997).

People's beliefs influence not only the choices they make in life but their effort, their aspirations and their perceived causes of successes and failures, as well. As a matter of fact, people who are self-efficacious tend to attribute failures to their insufficient effort, whereas in-efficacious individuals ascribe their failures to low ability. Moreover, self-efficacy beliefs affect individuals' goals setting, since the more capable people judge themselves to be, the higher the goals are set and their commitment remains (Bandura, 1991). On the other hand, those who doubt themselves more, tend to set lower goals and can be easily discouraged to continue their effort after a failure (Bandura, 1991).

The association between high self-efficacy beliefs, increased effort and persistence in difficult tasks and resilience in the face of obstacles has been offered as a potential explanation of promoting learning through self-efficacy. Furthermore, the self-efficacy effect is hypothesized to activate the process of appropriate knowledge and strategies for new information acquisition (Pintrich et al, 1993; Renninger, 1992; Schunk & Pajares, 2005). Additionally, taking into consideration that a high degree of confidence in one's own capabilities creates a feeling of calmness, while low confidence is associated with anxiety (Schunk & Pajares, 2005), might justify the implications by Pintrich et al. (1993) on the relationship between self-efficacy and intentional conceptual change. The first possible implication is that self-efficacy may cause high confidence in one's capabilities of having a better understanding on a phenomenon, so that conceptual change could be facilitated by self-efficacy, opposing to the case where high self-efficacy could cause higher confidence in a student's ideas. The latter would mean increased resistance to changing ideas (Pintrich et al., 1993).

Conceptual change and self-efficacy, though, have not been studied broadly. Strike and Posner (1992) explored the influence of student's conceptual ecology, while reexamining their previous model on conceptual change. Apart from epistemological beliefs, motivational factors such as self-efficacy and achievement goals were examined as part of a single factor named learning attitude. A significant positive correlation was determined between student's learning attitude and conceptual change in physics. Since in the factor of learning attitude, confidence in one's ability to learn science meaningfully was also included, evidence in favor of the facilitative role of self-efficacy is provided.

Linnenbrink-Garcia, Pugh, Koskey and Stewart (2012) found that although academic self-efficacy, individual interest, and prior knowledge separately were not responsible for differences in conceptual change, varying combinations of these learner's characteristics did differentially account for differences in conceptual change by gender. Along to this research Cordova, Sinatra, Jones, Taasoobshirazi and Lombardi (2014) explored how learners' characteristics such as confidence in prior knowledge, self-efficacy, interest and prior knowledge interact with conceptual understanding of college students on seasonal change. Three profiles emerged, including low (low confidence, self-efficacy, interest, and prior scientific understanding and high prior misconceptions), mixed (high confidence, self-efficacy, and interest, but low prior scientific understanding and high prior misconceptions), and high (high confidence, self-efficacy, interest, and prior scientific understanding and low prior misconceptions). The most efficient profile for conceptual change appeared to be the mixed profile whilst the influence of these learners' characteristics may vary in different learning situations. In any case self-efficacy like interest may appear to have conflicting roles in knowledge reconstruction.

A.1.1.4.4 Achievement Goals

Goal orientation theories were constructed in order to explain children's learning and performance on academic tasks and school settings. The main construct involved in goal orientation theories for achievement behavior is goal orientation which concerns the purposes for engaging in an achievement behavior and in particular *why* and *how* individuals are involved in a task (Pintrich & Schunk, 2002). For instance, in classroom settings one student may be involved in activities because they enjoy learning new things even by making mistakes but another student may be involved because he or she desires high grades. So, both students are engaged in activities but each one has a different goal orientation.

Achievement goals generally have been considered to be cognitive representations rather than implicit needs or drives with an end state that is centered on competence and either developing it (mastery) or demonstrating it (performance) (cf. Dweck & Leggett, 1988; Nicholls, 1984). A mastery goal focuses on the intrinsic value of learning, mastering the task according to self-set standards or self-improvement, developing new skills, improving or developing competence, trying to accomplish something challenging, gain understanding and insight (Ames, 1992; Dweck & Leggett, 1988). On the other hand, a performance goal refers to focus on demonstrating competence or ability, and how ability will be judged relatively to others and their accomplishments. Moreover, it is connected with high performance of an individual in a group and avoidance of incompetence (Ames, 1992; Dweck & Leggett, 1988). Both mastery and performance goals are related to avoidance and approach, so a 2x2 achievement framework was proposed to include these concepts in the construction of achievement goals. As a matter of fact, an individual with performance avoidance goal will not be engaged in an activity where his low abilities will be revealed (Elliot & McGregor, 2001). In addition, Pintrich and Schunk (2002) distinguished similarities between mastery-performance goals and intrinsic-extrinsic motivation.

Achievement goals have been related with outcomes concerning attributions, efficacy, affect, behavior and cognition. Mastery goals have been associated with self-regulation and deeper processing strategies, intrinsic interest and deep engagement, effort, positive affect; whereas performance goals have been correlated with use of more surface learning strategies, negative affect, failure avoidance and poor learning outcomes (Elliot, McGregor & Gable, 1999; Pintrich & Schunk, 2002).

Although research on achievement goals is substantial, its role in conceptual change has not been well documented yet. Nonetheless, research evidence could not be ignored.

Linnenbrink and Pintrich (2002) carried out two studies with college students in order to examine whether deeper levels of engagement with information due to mastery goals engagement could lead students to conceptual change on projectile motion. Results revealed that students adapting mastery goals changed their understanding on the subject matter and in particular those who had low prior knowledge. Performance goals adoption, on the other hand, didn’t promote conceptual change but didn’t facilitate it either. The second study showed that mastery goals were associated with elaborative strategies as well as with a lessening of negative affect.

The positive influence of performance goals was confirmed in a cross-cultural study with American and Chinese high school students (Qian & Pan, 2002). Actually a particularly significant correlation between performance goals and conceptual change learning indicated that students who were willing to change their concepts about projectile motion were also those focused on the self.

Taasoobshirazi and Sinatra (2011) explored the role of achievement goal orientation in conceptual change in physics. Conceptual change was measured with pre and pro administration of the Force Concept Inventory (FCI, Hestenes, Wells & Swackhamer, 1992). Using a structural equation model, results indicated that approach goals had a direct effect on students’ motivation of learning, while motivation influenced both FCI scores directly as well as through course grades indirectly.

Achievement goals may be influenced not only by students’ expectations but by the value they attach to a particular task, activity or subject (Eccles, 2005; Eccles & Wigfield, 2002). The value added to a task may concern its utility and intrinsic enjoyment or its attainment value, namely tasks’ achievement importance. Johnson and Sinatra (2013) explored the relationship between task values, engagement and conceptual change in undergraduate students concerning the common cold. Participants in the utility condition rated their engagement as significantly higher demonstrating the greatest degree of conceptual change after all.

Another study examining the relationship between conceptual change, achievement goal orientations and depth of processing was conducted by Ranellucci et al. (2013). Results revealed that a mastery-approach goal positively predicted deep and shallow processing strategies as well as conceptual change. In contrast, a performance-approach goal orientation did not predict either of the processing strategies and negatively predicted conceptual change. A performance-avoidance goal orientation negatively predicted deep processing strategies and conceptual change. Finally, deep and swallow processing positively predicted conceptual change and mediated relations between mastery-approach goals and conceptual change.

Last but not least Johnson and Sinatra (2014) explored the 2x2 framework achievement theory in relation to students' conceptual change learning for a specific topic in biology, HIV/AIDS. The authors hypothesized that participants with approach goals, both mastery and performance, would display greater post-test conceptual change in their understanding of the HIV/AIDS concept than those with avoidance goals. Results confirmed their hypothesis.

A.1.1.4.5 Emotions

Besides the learner's characteristics mentioned already and which may or may not promote conceptual change, emotions are another variable with increasing interest towards the interaction with conceptual change.

Gregoire (2003) proposed a cognitive affective model of conceptual change according to which moods determine the type of processing involved for conceptual change. In particular, she suggested that positive or neutral emotions would lead to superficial cognitive processing and finally insufficient change, while negative emotions such as fear and anxiety would lead to deeper cognitive processing sufficient required for conceptual change.

On the other hand, Bless (2000) as well as Linnenbrink and Pintrich (2002) suggested that students experiencing positive emotions and good mood would be more willing to engage in contradicting with prior knowledge information and be more open minded to new ideas. Alternatively, students who experience negative feelings, including anxiety or sadness may be less likely to take into consideration new information because it is perceived like a threat or is in contradiction to their prior knowledge (Sinatra, Broughton & Lombardi, 2014).

However, there are still a few empirical studies concerning the relationship between emotions and conceptual change. One of them influenced by Pekrun and colleagues' view on academic emotions (2002), focused on the knowledge of students concerning planets and their attitudes toward the reclassification of Pluto as a dwarf planet (Broughton, Sinatra & Nussbaum, 2013). It was found that emotions predicted students' attitudes prior to instruction, their attitude change as well as their conceptual understanding. Moreover, it was also revealed that negative emotions prior to the instruction became less negative over the course of intervention. It was concluded that negative emotions can inhibit conceptual change but conceptual change intervention could soften the negativity of the emotions and thus open the door for shifts in attitudes and understanding.

In another study Heddy and Sinatra (2013) used an instructional approach called Teaching for Transformative Experiences in Science (TTES) (Pugh, 2002) to facilitate change in college students' conceptions and positive affects about evolution. The results revealed that the experimental group experienced higher levels of transformative experience and greater conceptual change than the control group. Furthermore, the treatment group showed an increase in enjoyment of the evolution content over the course of instruction. This study also supports the findings of Broughton et al (2013) that conceptual change interventions have impact on emotions. However, more research on the field is needed to explore this relationship.

A.1.2 Conceptual change and instruction

The framework of conceptual change has highlighted the importance of prior knowledge in the acquisition of new knowledge. However, this relationship between prior and new knowledge arises additional challenges for instruction (Diakidoy & Kendeou, 2001). Many instructional approaches have been applied in classroom in order to promote conceptual change either combined with other strategies or individually. Such approaches could be the introduction of a refutational text (Sinatra & Broughton, 2011); models and multiple representations (Jonassen & Easter, 2013; Tytler & Prain, 2013) or inquiry based teaching (Duit, Treagust & Widodo, 2013). In this particular section we will refer to models and focus on inquiry based teaching since they were employed in the current study.

Models are considered to be representations of an object, a concept, a process or a phenomenon (Halloun, 2004) but they are also being used in scientific practices such as modeling (NRC, 2012). In addition, they are important part of the scientific epistemological knowledge (Treagust, Chittleborough & Mamiala, 2002) while at the same time they are considered to be facilitators of conceptual understanding and achievements in school. Their importance lies in the fact that they foster metaconceptual awareness, metacognitive skills and intentional learning (Vosniadou, 2010). Although learning, using, revising and constructing models might be the most important actions while modeling (Justi & Gilbert, 2002), recent evidence suggests that developing understanding regarding the nature and role of models are equally important (Treagust et al., 2002). Although during the current research models were engaged in the activities, students were not engaged in modeling activities as described so far. Models were used mostly as representations of the unseen world.

With the term *inquiry* we refer to the diverse ways scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry employed in teaching refers to those activities students are involved in order to develop knowledge and understanding of scientific ideas as well as understand of the way the natural world is studied by scientists (NRC, 2000). Inquiry in teaching can be used both as "inquiry as means" and as "inquiry as ends". In the first case inquiry is mentioned as an instructional approach but in the second case it is considered for the learning outcomes emerging from the instruction (Abd-El-Khalick et al., 2004).

Recent work on inquiry has started framing inquiry through the practices of the inquirers (e.g. Kang & Lundeberg, 2010). During inquiry based activities students are involved in wide range of practices such as developing questions, designing how to answer these questions, designing studies, gathering data, analysing and interpreting data, developing theoretical models using appropriate criteria, communicating finding and theories to others and engaging in reasoned argumentation (Grandy & Duschl, 2007). Inquiry based instructions refer to instruction that engages students in this range of inquiry practices but not necessarily to the full range of all practices (Chinn, Duncan, Dianovsky & Rinehart, 2013). Moreover, inquiry based teaching has been found to interact with factors predicting conceptual change such as motivational factors like interest (Krajcik & Mamlok-Naaman, 2006; Lavonen et al., 2010; Palmer, 2009) and perceptions of autonomy and competence (Lavigne, Vallerand & Miquelon, 2007) as well as with epistemological beliefs (Sandoval, 2005; Sandoval & Reiser, 2004).

With regard to inquiry based instruction it is critical to mention a few exemplars designed to promote conceptual change and conclude to some common characteristics of such interventions. Chinn and colleagues developed a middle school life science program based on model based instructional practices embedded in an inquiry oriented setting (Chinn & Buckland, 2012; Chinn, Duschl, Duncan, Pluta & Buckland, 2008; Pluta, Chinn & Duncan, 2011). PRACCIS aims at promoting reasoning and conceptual change in science. Modelling practices are highly applied in this program. Each lesson was guided by a set of questions (Krajcik, 2001); while students were supposed to decide which model along with explanations would answer these questions the best way. Students were both gathering their own data and data previously processed. Moreover, two kinds of scaffolds were employed, the first one was the development of criteria that could help students' epistemic judgements concerning the nature of models as well as their relationship with the gathered evidence, while the second scaffold directed students into drawing lines between evidence and models as well as arguing about the link drowned between them.

The second case promoting conceptual change focuses on core topics of middle school science such as chemical reactions, natural selection, and ecosystems. It is called IQWST, meaning Investigating and Questioning our World through Science and Technology (Krajcik, McNeil & Reiser, 2008). IQWST is constructed in curriculum units engaging students in inquiry processes prompted once again by driving questions. Some technological tools were also employed like the Finches software which supports students' interactions with a large database of scientific data about the finches of the Galapagos Islands. The curricula constructed for the project aimed at the development of modeling, data gathering, organization and analysis, construction of evidence based explanations as well as design of investigations (Shwartz, Weizman, Fortus, Krajcik & Reiser, 2008). An evaluation study of the program revealed that students along with teachers participating in IQWST curricula gained significantly more knowledge than those included in the control groups (Geier et al., 2008).

Loukomies et al. (2013) examined the way a designed Teaching Learning Sequence could affect students with different motivational profiles aiming at enhancing their interest towards science in general. A Teaching Learning Sequence (TLS) is considered to be a topic-oriented sequence for science teaching in different areas like optics, heat, electricity, structure of matter, fluids, respiration and photosynthesis (M´eheut & Psillos, 2004). This concept is related with a science education research tradition by which teaching and learning are examined at a micro-level (e.g. specific session) or a medium level (e.g. single topic sequence) rather than at the macro-level of a whole curriculum (one or more years) (Kariotoglou & Tselfes 2000). Inquiry based activities were designed while the feelings of autonomy, social relatedness and competence were enhanced through these activities. In particular individuals with different motivation orientations while engaging in science activities that may fulfill their basic psychological needs are expected to develop their motivation towards science. Results revealed that participants' psychological needs (feelings of autonomy, social relatedness and competence) were indeed fulfilled through certain aspects of the designed teaching sequence and as a consequence their motivation was increased according to the Self-Determination Theory (Deci & Ryan, 1985).

Overall, a set of starting questions, model based learning and design of curriculum units are important aspects while promoting conceptual change through inquiry based teaching. Nevertheless, research also accounts for other features which should be taken into account like students' prior knowledge and misconceptions, provision of multiple representations (Chinn et al., 2013), the order, in which each concept will be introduced as well as the motives students will be provided with and their metaconceptual awareness (Vosniadou et al., 2001). Motivation is a feature which should not be excluded while designing inquiry based activities since it does not only increase interest towards science and the activities per se, but also promotes conceptual change as already demonstrated through the current study. Although inquiry based instruction is time consuming and there is a case that students may not undergo conceptual change, teaching in the traditional way might even be less effective. That might happen since students do not engage in active thinking, they do not participate in the investigation process or in "hands on activities" which it is indicated to increase science conceptual change (Minner, Levy & Century, 2010).

A.2 Conceptual change in science education: the case of Nanoscience and Nanotechnology

Even though conceptual change studies have been conducted in many fields so far such as biology (Inagaki & Hatano, 2002), psychology (Wellman, 2002), history (Leinhardt & Ravi, 2008), political science (Voss & Wiley, 2006), medicine (Kaufman, Kaselman & Patel, 2008), environmental learning (Rickinson, Lundholm & Hopwood, 2009), mathematics (Vosniadou & Verschaffel, 2004), and religion (Pnevmatikos, 2002; Pnevmatikos & Makris, 2003, 2010, 2011), science education and physics is the field where conceptual change framework is most frequently adopted.

Nevertheless, not all the aforementioned areas of studies employ the same conceptual change approach. Considering the fact that the present study was conducted based on the framework theory approach in the field of science education, it would be indicative to mention a few exemplars of previous studies providing evidence of the development of knowledge in various areas of physical sciences like observational astronomy (Vosniadou & Brewer, 1992, 1994; Vosniadou & Skopeliti, 2005; Vosniadou, Skopeliti & Ikosipentaki, 2004, 2005; Samarapungavan, Vosniadou & Brewer, 1996), mechanics (Ioannides & Vosniadou, 2002),geology (Ioannidou & Vosniadou, 2001), biology (Kyrkos & Vosniadou, 1997) and mathematics (Vosniadou & Verschaffel, 2004; Vamvakoussi, Vosniadou & Van Dooren, 2013). The current research in particular, is an attempt to apply the framework theory approach in the emerging field of nanoscience and nanotechnology [1](N-ST).

As already mentioned research has shown that students come to science classes, with resistance to change, pre-instructional concepts and ideas about those phenomena that are to be taught and which consequently do not comply with scientific views (Duit & Treagust, 2012). The field of N-ST could not be excluded. Although still a few studies focus on the misconceptions students bring along in science classes, these ideas should be taken seriously into consideration while designing an intervention aiming at conceptual change (Vosniadou et al., 2001). Before presenting these ideas though, it would be important to clarify, what N-ST is, why it is an essential concept to be introduced in education and finally how this introduction can be carried out.

A.2.1 Nano: A short word with great applications and risks

To begin with, the prefix “nano” originates from the Greek word “νάνο” which is another word denoting to dwarf (Ratner & Ratner, 2003). In science however “nano” means one billionth. In particular 1 nanometer is equal to 1/1,000,000,000 m. or 10^{-9}m and refers to nanoscale. To get a sense of the nanoscale a human hair is approximately 80,000 nm wide and a red blood cell approximately 7,000 nm wide, while an atom is below 1 nm size (Dowling et al., 2004).

[1] From now on, instead of using the terms Nanoscience and Nanotechnology the abbreviation N-ST will be adopted.

Nanotechnology relates to a multi-disciplinary field including chemistry, biology, material science, and engineering (Ernst, 2009; Gardner & Jones, 2009; Gardner, Jones & Falvo, 2009; Ghattas, 2012). According to the European Commission (2004) nanotechnology should be introduced as an "umbrella" term incorporating all fields in N-ST. Sweeney (2006) defines nanotechnology as "the emerging capability of human beings to observe and organize matter at the atomic level" (p. 437). This definition is in line with Bhushan (2010) where "nanotechnology encompasses the production and application of physical, chemical, biological systems at scales ranging from individual atoms or molecules to submicron dimensions, as well as the integration of the resulting nanostructures into larger systems"(p. 1). These definitions reveal the main idea of the term of nanotechnology which is the ability to manipulate materials at the atomic level and as a consequence to display different properties in the macro- or microscale.

The first one talking about nanotechnology, without making any explicit reference to the word nanotechnology, was R. Feynman in 1959 with his speech entitled "*There is plenty of room at the bottom*". With his speech he predicted the manipulation of atoms and molecules, even the manufacture of new objects and machines (Ghattas, 2012). Further on, he stated (Feynman, 1960, p. 36) that "atoms on a small scale behave like nothing on a large scale, for they satisfy the laws of quantum mechanics". The term Nanotechnology was used for the first time by a Japanese researcher N. Taniguchi. By using this term, he referred to the ability to engineer materials at the nanoscale (1974) (Dowling et al., 2004; Fanfair, Desai & Kelty, 2007). Feynman's ideas were elaborated and advanced by Drexler (1981) who discussed the possibility of molecular manipulation as a progress of manufacturing objects with specific atomic requirements using designed protein molecules. These ideas were furthered on his book "Engines of Creation: The Coming Era of Nanotechnology" (1986) (Fanfair, Desai & Kelty, 2007). In the meantime the first microscope making nanoscale accessible and Drexler's ideas reality was invented by Binnig and Rohrer (1981) called STM (Scanning Tunneling Microscopy). Later on another invention followed, the AFM (Atomic Force Microscope) on 1986 which clearly opened the doors to the nanoworld (Fanfair, Desai & Kelty, 2007; Gerber & Lang, 2006; Singh, Tiwari & Tawaniya, 2013). Finally, with these two achievements the first molecular manipulation took place in 1989 by Eigler who wrote the initials of the company he worked (IBM) using 35 xenon atoms on a nickel surface (Fanfair, Desai & Kelty, 2007). The 21st century seems to be embracing the era of Nanotechnology, albeit the educators and (science) teachers still have great challenges to overcome.

Scientists developed two ways (Figure 1) in order to reassemble atoms and molecules and subsequently fabricate new materials and objects as well as conceptualize their new properties. The first approach is the "top-down" where larger structures are reduced in size to the nanoscale (e.g. miniaturization) (Hingant & Albe, 2010; Sanchez & Sobolev, 2010; Stevens et al., 2009). The second approach used is the "bottom-up" technique. Essentially molecules and atoms are being manipulated in order to create bigger objects. The "bottom up" approach is otherwise called assembly or "self-assembly" (Hingant & Albe, 2010; Sanchez & Sobolev, 2010; Stevens et al., 2009) (see also unit A. 2.2.2.1.6.).

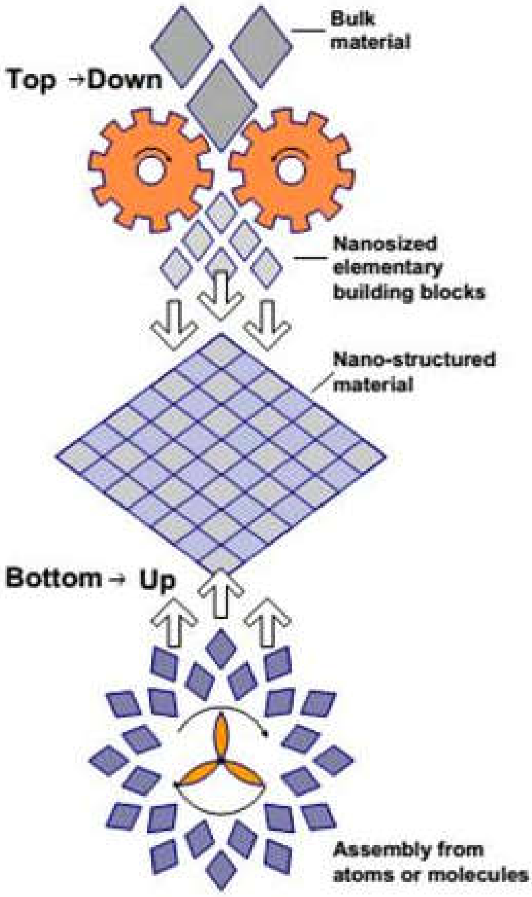

Figure 1: Illustration of the "top-down" and the "bottom-up" approaches in Nanotechnology

The applications of nanotechnology in everyday life are unprecedented and advancements in research, new discoveries and new ideas occur constantly. Mentioning all the possible applications in N-ST would sidetrack the reader from the purpose of this chapter. However, it is critical to realise the benefits provided from N-ST as well as its risks.

Perhaps the most important applications of N-ST are in the field of *medicine*. The applications can be distinguished in three broader categories: drug delivery systems, tissue engineering, sensors and diagnostics (Jones et al., 2013). In the first case of drug delivery systems, the idea is to replace the well-known chemotherapies, which are used as cancer treatment, with artificial systems at the size of nanoparticles. These systems will deliver drugs specifically to the malignant cells, reducing significantly for instance the side effects of the drugs (e.g. Farokhzad & Langer, 2009; Ferrari, 2005; Sinha, Kim, Nie & Shin, 2006; Suri, Fenniri & Singh, 2007). In the second case, material based methodology is used to produce artificial biocompatible tissues and potential organs. New materials are being fabricated exploiting the bottom-up approach developed for the advancement of new materials in Nanotechnology (Bronzino & Peterson, 2010; Chen, Sato, Ushida, Ochiai & Tateishi, 2004; Ma, Kotaki, Inai & Ramakrishna, 2005; Shi, Votruba, Farokhzad & Langer, 2010). The last case mentioned was sensors and diagnostics. The smaller the sensor, the more sensitive it is. Nanosized mechanical and chemo-electronic sensors are fabricated with the bottom up approach for detecting pathogens in blood or noxious species in the environment (Cheng et al., 2006; Ilic et al., 2001; Jain, 2003).

The second field where one can find major applications of N-ST is *advanced material* (Jones et al., 2013). A lot of new materials with new properties have emerged from N-ST, generating a set of different uses for these materials as well. Furthermore, there are many cases where advancements to existing materials were made for their improvement and expansion of their usages. Superhydrophobic surfaces and materials that clean themselves (Benedix, Dehn, Quaas & Orgass, 2000; Koch & Barthlott, 2009; Parkin & Palgrave, 2005) or remain waterproof when used under the water (Koch & Barthlott, 2009). Moreover, eco-efficient (Pacheco-Torgal, 2014) or super strong materials (Zhu, Bartos & Porro, 2004) are being used in construction.

Other applications of N-ST could be found in nanoelectronics (Lu & Lieber, 2007; Waser, 2012) as well as in everyday life with products using nanoparticles like anti-aging cosmetics or sunscreens (Müller, Petersen, Hommoss & Pardeike, 2007; Nohynek, Lademann, Ribaud & Roberts, 2007) or more resistant sports equipment (Esawi & Farag, 2007). Another application can be found in environmental protection with nano sensors detecting pollution (Zhang & Fang, 2010). An online inventory established by the STIP[2] at the Woodrow Wilson International Center for Scholars, in collaboration with the Virginia Tech Center for Sustainable Nanotechnology, examines the ways Nanotechnology is entering the marketplace (Project on Emerging Nanotechnologies, 2013). The list of products is endless and only advocates the previous examples of N-ST applications.

Despite all the developments and the applications in the field of N-ST, it is becoming clear that using nanomaterials can oppose potential risks concerning human health and the environment (Dunphy Guzman, Taylor & Banfield, 2006; Macoubrie, 2006; Planinsic & Kovac, 2008; Shatkin, 2012; Sweeney, 2006). Thereafter a focus on ethical issues related to Nanotechnology seems necessary. Leweinstein (2006) identified a range of potential ethical and social issues related to Nanotechnology. He described the potential risks separating them in broader categories. Thus, he identified environmental issues, associated with toxicity, resources and pollution, issues in labour markets, educational issues concerning introduction of interdisciplinarity into curricula and the training of teachers and students and also issues of privacy with regard to access control over databases and private data. Another category of socio-ethical issues is in regard to national policy or intellectual property issues (patents), while the most important type has reference to the enhancement of human beings, as the borders between treatment and change can be easily trespassed.

Another classification of socio-ethical issues is reported by Sandler (2009). His typology involves five main types of N-ST related implications and although it does not differ much from Leweinstein's typology it is considered to be more elaborated. The first classification is related to *social issues* such as "unequal health care, inequalities in education, unequal access to technology, inadequate information security/privacy protection, inefficiencies in intellectual property systems, unequal exposure to environmental hazards and inadequate consumer safety protection" (p. 7). The second type identified is the *contested moral issues* which in the public

[2]Science and Technology Innovation Program

opinion are issues that should be prohibited to deal with. Examples of contested moral practices involve “synthetic biology, construction of artificial organisms, biological weapons development, stems cell research and genetic modification of human beings” (p. 7). The third category of issues is the *Technoculture issues*. These issues emerge from the interaction of technology and society. Problems which can be included are the overreliance on technological fixes to manage problematic effects, rather than address the causes behind these effects, overestimation of our capacity to predict and control technologies and finally technological mediation of our relationship with nature. The fourth aspect identified as a socio-ethical issue is the *form of life* issues, which means that Nanotechnology might have impact in the way we understand what being human means and which is our relationship with the environment. For instance, if life trajectory thanks to Nanotechnology becomes extended, family norms and structures as well as social and political institutions might need restructuring. The last set of issues arising from Nanotechnology is related to *transformation*. Nanotechnology can be combined with other fields such as biotechnology, computer science, cognitive science and robotics. This collaboration of disciplines might lead us to transformation of the creatures we are (self-aware and artificial intelligences), or the environment we live in. These ethical issues could be integrated into discussions regarding the nature of science. An educationally viable medium for this implementation could be the relation of moral and ethical decisions referring to the development of scientific discoveries in the field of N-ST (Ghattas, 2012).

In conclusion N-ST might seem a challenging topic to integrate in science curriculum, nevertheless its interdisciplinarity could increase students’ positive attitudes towards science education (Chang, 2006) since interest in these studies has declined due to the disconnection between school science and students’ curiosity (Osborne, 2007).

A.2.2 Introducing Nanoscience and Nanotechnology in primary education

A.2.2.1 Why is it important to introduce Nanoscience and Nanotechnology in the class?

Nanotechnology has been described as the defining technology of the twenty-first century, with the ability to carry us into the next industrial revolution (Ho, Scheufele & Corley, 2010). The emerging fields of N-ST promise to have extensive implications for the society, as they provide it increasingly with advancements in drug delivery (Petros & DiSimone, 2010), treatments and preventive measures for disease (Panyala, Peña-Méndez, & Josef, 2009), better materials (Falvo et al., 1997) and more efficient electronics (Stix, 2001). Life expectancy will grow and life quality will be improved.

However, one of the challenges for N-ST, if not the most difficult one, is the field of education “which is looming as a bottleneck for the development of the N-ST field and particularly for its implementation” (Roco, 2003, p. 1247). The above statement highlights the need and importance of the N-ST implementation in education; otherwise the rapidly evolving development on the field will be delayed. As the N-ST field continues to cultivate the education of a new generation of technicians, scientists, developers, policy-makers, regulators and educators seems mandatory. Furthermore, it is important that this new generation of citizens should be aware of the impact N-ST could have in their lives. Every year the number of nano products appearing on the market increases expeditiously (Jones et al., 2013). Roco (2003) predicted that by 2015 the approximate number of workers needed in various areas would be 0.8–0.9 million in the US, 0.5–0.6 million in Japan, 0.3–0.4 million in Europe, about 0.2 million in the Asia-Pacific region excluding Japan and 0.1 million in other regions. This clarifies the need of a nano-education as suggested by Healy (2009) or Malsch (2008).

The nations around the world have already invested excessive amount of money and effort in fostering educational programs improving the N-ST development as well as proliferating their financial resources. The U.S. government created the National Nanotechnology Initiative (NNI) which is a long term research and development program that began in fiscal year 2001 and now coordinates 25 departments and independent agencies. The total investment in fiscal years from 2001 to 2005 was over $ 4 billion with an increase beginning at $270 million in 2001 to $ 1,2 billion in 2005 (Roco, 2007).

In Asia-Pacific countries including Japan, the research and development projects represent around 30% to 40% of the worldwide distribution (Roco, 2001). Japan appears to be the most prominent country among the Asia-Pacific countries concerning the amount of money spent on research and development in N-ST field and the second worldwide (Hullmann, 2007). Asia Nano Forum is one of the many initiatives undertaken in Asia-Pacific countries engaging almost 13 countries in N-ST research and development (Maclurcan, 2005).

In 2004, the European Commission highlighted the need to “promote the interdisciplinary education and training of R&D personnel together with a strong entrepreneurial mindset” (EC, 2004). As a consequence, the upcoming European Action Plan (2005) included several measures to foster interdisciplinary human resources for N-ST. About €2.4 billion was spent in Europe, including a third from private sources until the year of 2005 (Malsch, 2008). In 2007, Nanoforum published an analysis of three types of nano education recorded in Europe: type A offering a limited supplement of short specialised modules to graduates or students type B consisting of Master degree programmes, and type C providing full nanoscience education programmes for undergraduates (Malsch, 2008). These circumstances reveal the need of Europe to pursue the development in the field as well as the universal status.

As a result of the N-ST research and development and mostly of the “invasion” of nanotechnology products worldwide, educating a new generation of scientists and workforce appears to be crucial. However, nano-education is rather important with reference to societal and ethical issues, so another matter of its educational significance is connected with scientific and technological literacy. In many cases nanotechnology involves both benefits and risks about the environment and public health, so the need for N-ST education has also been discussed with reference to sustainable development (Schwarz, 2004; Berne, 2008). Furthermore, these risks highlight the need to enable citizens to make intelligent and independent decisions about N-ST related ethical and societal issues (e.g. Roberts, 2004; Sabelli et al., 2005; Zenner & Crone, 2008). Last but not least, the need for this new literacy (nanoliteracy) will allow meaningful participation in the field of nanotechnology, critical to national development (Yawson, 2012).

According to the PISA definition, scientific literacy is the ability to form opinions and make reasoned decisions about personal as well as societal issues related to science and technology (Laherto, 2010). This definition emphasises on three aspects: the personal, the social and the global, and is in accordance with the OECD (2007) definition of science literacy. A scientific literate citizen must be able to identify scientific issues, explain phenomena scientifically and using scientific evidence (OECD, 2007). On the other hand, technological literacy is "the ability to use, manage, understand and assess technology" (ITEA 2000, p. 242).

Nevertheless, nanotechnology is an interdisciplinary field combining not only physics but chemistry, biology, material science, medicine and engineering as well. Because of this interdisciplinary nature of N-ST, it has been stated that even though a nanoliterate citizen may not have the knowledge of how each product or application works, which are the risks and benefits, but it is proposed that an individual should be literate enough to ascertain the risks and benefits emerging from the use of nanoproducts (Yawson, 2012). Additionally Vandermoere, Blanchemanche, Bierberstein, Marette and Roosen (2010) suggest that although research has shown that nanoliteracy has no direct impact on attitudes towards nanotechnology, if public's self-estimated knowledge is high, then it would be more likely for them to perceive the benefits and risks of N-ST.

According to Yawson (2012) the multidisciplinary nature of N-ST requires a new proposed framework, encompassing science, technology and society literacy, while providing nanoeducation. Any curriculum developed for N-ST education should be based on good theoretical foundations and a balance of knowledge competences drawn from all the disciplines incorporated in N-ST field (Yawson 2010). Within this framework all literacies converge in nanoliteracy.

The foregoing conveys the impression that an education concerning N-ST is mandatory as the scientific and technological development advances rapidly both for technological and scientific development and for literate citizenry.

A.2.2.2 How do I introduce Nanoscience and Nanotechnology in the class?

The USA National Science Foundation in 2006 funded a workshop where scientists gathered in order to reach consensus on the concepts and learning goals of N-ST that should be integrated in primary education (7-12 grades). The key concepts were nine and addressed as "the Big Ideas of Nanoscience and Engineering". Each "Big Idea" was suggested to be integrated not as a different subject in primary education but as an integration in the curriculum of each subject matter (Stevens et al., 2007). In this case a challenge like the one addressed by Murday (2009) concerning the establishment of specific standards of learning for the implementation of N-ST in science curricula is being clarified.

A.2.2.2.1 The Big Ideas of Nanoscience and Engineering

A.2.2.2.1.1 Size and Scale

Factors related to size, shape, proportions, scale and dimensions help describe materials and predict the way they behave. Size is defined as the extent of bulk amount of something. Every object has a size that can be defined in either one, two or three dimensions. Usually, we compare objects to other objects or with reference to its dimensions (length, area, volume). In accordance to this comparison it is useful to divide materials into “scales” or “worlds” (e.g. macro-, micro-, nano-, atomic) (Stevens et al., 2007, 2009).

Each scale is characterized a) by specific objects included in this scale (e.g. proteins and DNA are typical objects of nanoscale) (Tretter et al., 2006), b) by the tools used to enable visibility to these objects (e.g. the optical microscope has a resolution limit approximately 0.2 μm or 200 nm, so smaller objects cannot be measured by this microscope), c) models that describe the behavior of matter at that scale. Although it is useful to divide the size into scales, we must consider these worlds as a continuum, because the limits of one to another are not easily defined (Stevens et al., 2007, 2009). Shape also affects the proportionality between surface area and volume and according to each scale, the forces which dominate the interactions between materials can differ. As a consequence, scientists can predict the behaviour of an object based on its scale and size (Stevens et al., 2007, 2009). This is also the main reason why size and scale is considered among the Big Ideas of nanotechnology.

A.2.2.2.1.2 Structure of Matter

Atoms interact with each other and form molecules. Molecules interact with atoms or molecules to form nanoscale structures and so on. Materials consist of blocks forming hierarchies of structures. To understand the properties and behaviour of matter across scales one must understand the structure and the properties of its building blocks. That is the main reason why structure of matter is considered to be among the Big Ideas of nanotechnology (Stevens et al., 2007, 2009).

The type of atoms and their arrangements determine the identity and affect the properties of a material. Some of the interesting properties of the nanoscale are related to specific properties of the atoms constituting the material (e.g. carbon allotropes) (Stevens et al., 2007, 2009).

A.2.2.2.1.3 . Forces and Interactions

On each scale the interactions between the particles are described by four forces, gravitational, electromagnetic, strong and weak nuclear forces. On the macroscale gravitational force usually dominates. On the nanoscale the electromagnetic forces prevail, while on the atomic and subatomic the strong and weak nuclear forces. Furthermore, electrical forces on the nanoscale dominate the interactions not only between atoms and molecules but between structures and assemblies on the nanoscale as well (Stevens et al., 2007, 2009).

Nanotechnology takes advantage of these unique interactions on the nanoscale to rearrange atoms and create newly functional materials. However, it is critical to understand how materials are built and which forces hold them together in order to proceed with the rearrangement of the atoms, molecules, structures and assemblies (Stevens et al., 2007, 2009).

A.2.2.2.1.4 Quantum Effects

As materials become smaller and enter nanoscale, quantum effects become more important. Matter exhibits both wave-like and particle-like characters. This implies that we cannot simultaneously determine the position and momentum of a particle. Only discrete amounts of energy may enter or exit certain systems, because energy is quantized. Because of the nature of the particle we cannot predict exactly what will happen to matter in smallest scales. Instead only the probability of a given outcome can be measured. This has implications for the electron behaviour (Stevens et al., 2007, 2009).

Quantum mechanics effects are important in the cases that classical mechanics cannot predict accurately the behaviour of materials. Since in the nanoscale electrical sources prevail, the students need to understand how atoms and molecules are being influenced by using the quantum mechanical model rather than the classical (solar system) model (Stevens et al., 2007, 2009).

A.2.2.2.1.5 Size-Dependent Properties

Another key concept considered as a Big Idea in the N-ST field is the properties materials can display directly linked with their size. At the case of nanoscale objects, where materials transit from the bulk form to atoms and molecules, exhibit different properties than those in the macro- or microscale, which can also be very unpredictable (Roduner, 2006; Cortie, 2004).

Properties are those qualities or characteristics that determine the nature of a material as well as their functionality. For instance, gold nanoparticles exhibit some interesting optical properties in nanoscale (Stevens et al., 2009). When the diameter of nanoparticles is between 10 to 30 nm, they no longer seem gold but red. The smaller, they get the more their colour changes (Haiss et al. 2007; Link & El-Sayed 1999; Handley 1989). Gold nanoparticles because of their change in properties while in the nanoscale were used in the Middle Ages to achieve some of the rich red colours found in stained glass used in that period of time (e.g. the Lycurgus cup: Daniel & Astruc, 2004).

Furthermore, surface to volume ratio increases dramatically when an object becomes smaller and smaller. Cutting a material in smaller pieces results in a more exposed area, which translates to more atoms on the surface and therefore a higher energy level as well as quicker oxidation. Moreover, the melting and dissolving points of objects can range dramatically (Stevens et al., 2009). Absorption is another surface dependent property. For example, super absorbent polymers on account of the high surface area to volume ratio absorb up to 500 times their weight (Kabiri et al. 2003). Other size depended properties is bumpiness, stickiness and shakiness (Taylor, Jones & Pearl, 2008). Bumpiness refers to the surface of materials, like the lotus leaves, which although appear to be smooth at the macroscale, they are composed of micro and nanocrystals on the nanoscale, enhancing the surface with its roughness and making it superhydrophobic. Stickiness as a property refers to the electromagnetic forces influencing atoms and molecules and in conjunction with surface to volume ratio increase objects become very sticky in the nanoworld (e.g. gecko).Finally, shakiness concerns the perpetual movement of molecules due to thermal forces and temperature changes.

The properties mentioned are not the only ones changing while entering the nanoscale. Scientists are examining materials in size of nanoparticles in order to understand these unique and unexpected properties. One of the fundamental concepts in science education is identifying the properties and characteristics of materials. Younger students begin with colour, shape, size, weight and the material from which an object is being made. Later on they are being introduced to properties like density, melting and boiling point, solubility which do not change and are independent to the amount of the material. However, what students are missing is that properties do not differentiate to intensive and extensive properties but they can all change according to the objects size (Stevens et al., 2007, 2009).

A.2.2.2.1.6 Self-Assembly

Under specific conditions, some materials can rearrange their structures and form new more organized forms. This self-assembly process of matter in the nanoscale can be fully exploited by scientists in order to create new materials and object. Essentially they are trying to manipulate atoms, molecules, nanoscale assemblies and structures by placing them in a certain environment where particles can self-assemble on their own and form new organized structures. Only specific “building blocks” are capable of self-assembling, as they must be under specific circumstances such as concentration of components, temperature, polarity, and acidity of solvent and demonstrate specific characteristics (e.g. shape, charge, composition) (Stevens et al., 2007, 2009).

The phenomenon of self-assembly in the nanoscale has been exploited widely in the fabrication of super hydrophobic and self-cleaning surfaces mimicking the surface of the lotus leaf (Lin, Chu, Chiang & Tsai, 2006; Song, Zhai, Wang & Jiang, 2005). The industrial applications of the lotus effect have received a great deal of attention (Lin et al., 2006; Wu, Zheng & Wu, 2005).

A.2.2.2.1.7 Tools and Instrumentation

The development in tools and instruments used in research fields always works in favour of scientific progress. Tools help scientists to detect, observe, weight, manipulate and fabricate nanoscale matter with exceptional accuracy. These instruments are really important for students and knowledge construction, as they try to comprehend objects and matter which in most cases are unseen (Stevens et al., 2007, 2009).

The field of N-ST was improved and supported by the development in technology and the invention of new microscopes that helped scientist detect and observe particles that were only speculated to exist. The scanning electron microscope (SEM) uses a focused beam of electrons instead of a visible light to scan a sample. Then an image of the sample is generated from the pattern of back scattered electrons. This microscope has made objects in nanoscale accessible and objects in microscale further appreciated (Stevens et al., 2007, 2009). Another important microscope was the atomic force microscope (AFM) which allowed scientist to see objects smaller than 10nm even to identify the type of element of a single atom (Sugimoto et al., 2007). These are only two of the most important technological breakthroughs of the 21st century.

A.2.2.2.1.8 Models and Simulations

As mentioned before objects, materials, processes, systems and phenomena are really difficult to comprehend while on the nano- or even the microscale, mostly because they are not accessible by the human eye. For the integration of these issues in primary education, beside tools and instruments other teaching techniques must be undertaken to facilitate students' knowledge construction. Models and simulations are usually used to help students visualize, predict, hypothesize about structures, properties, behaviors and phenomena.

A model is a representation of an idea, object, event, process, system or phenomenon (Gilbert & Boulter, 2000), used to describe, explain and predict phenomena (Van Driel & Verloop, 1999) that cannot be directly perceived. Models can represent an abstract idea or a concrete object. The type of model used depends on the purpose and the target. Models can be physical or computer based, static or dynamic. It must be able to represent most but not particularly every aspect of the target. A model can also have limits concerning some elements of the target unable to be displayed. The nature of models is multifaceted, as they can be mental models, consensus, hybrid, historical, pedagogical, teaching and scientific (Gilbert, Boulter & Elmer, 2000).

A simulation is any attempt to mimic a real or imaginary environment or system (Alessi & Trollip, 1991; Reigeluth & Schwartz, 1989; Thurman, 1993). It can be employed in a computer and then it would be a computer simulation which contains a model of a system (natural or artificial, e.g., equipment), or a process (De Jong & Van Joolingen, 1998). Simulations serve both scientific and educational purposes and they are usually used in cases where inherent difficulties (e.g. costs, danger) exist. Moreover, they provide the opportunity for the user to make predictions or make decisions based on the changes of different variables of the simulation (Rieber, 1996).

In the N-ST field, models appear to be critical as in many cases the targets are inaccessible or scientists are working to understand the novel structures and properties of matter observed at the nanoscale. Since computer science has advanced, models and simulations can be controlled trough the computer with wider possibilities than in the past. As a consequence, they can play an important role in the development of new materials and objects on the nanoscale in favor of many scientific fields, such as drug design and engineering (Stevens et al., 2009).

A.2.2.2.1.9 Science, Technology, and Society

The final concept considered to be among the Big Ideas of nanotechnology and engineering is the notion that science and technology can not only advance human life but can also raise ethical questions.

Students should be familiarized with the idea that Nanoscience advancement would provide solutions to a series of worldwide difficulties and problems like sustainable energy, water quality or cancer cure. However, this advancement will be facilitated by technological development and vice versa. Technologies that humans create can affect positively or negatively not only other humans but the environment and animals as well. Furthermore, the solution to a problem can create other problems, so one should think who will benefit and at what cost. In this way society is engaged and should be prepared to make decisions always considering the risks and deciding in light of social perspective and sustainable solutions (Stevens et al., 2007, 2009).

A.2.2.3 N-ST based activities for formal and informal education

Integration of N-ST activities in education does not come without any challenges. Teachers might be interested in this new science field but also in most cases they are inhibited to include such activities in their courses, as they feel pressured by the science standards and curricula or they lack availability in materials, ready to use text books or they even lack teaching experience on N-ST issues (Drane et al., 2009). Additionally, an in service training for science teachers is at least important (Jiao & Barakat, 2011; Planinsic & Kovac, 2008) in order to conceptualize the size matter and be able to help their students restructure their thinking in macro-, micro-, nano-level (Jones et al., 2011; Jones, Tretter, Taylor & Oppewal, 2008; Meijer, Bulte & Pilot, 2009). However, besides these challenges one can find many studies referring to N-ST implementation both in formal and non-formal education; therefore, it is a predominant reason to present some representative school activities, which are in most cases integrated in formal education and particularly in secondary education.

Taylor et al. (2008) provide us with a set of activities illustrating the concept of different material properties depended on the size. As a matter of fact, materials in the nanoscale have different bumpiness, shakiness and stickiness. In order to explain the bumpiness property teachers could conduct the lotus effect experiment, where students could realize that different surfaces cause different behaviors. Teachers could then introduce to students' applications that utilize the lotus effect like self-cleaning buildings. The property of shakiness could be demonstrated with the help of different sized sugar (e.g. powdered sugar, granulated sugar and sugar cubes). Furthermore, providing the students with an idea of how “geckos” take advantage of the Van der Waals forces to cling on surfaces would help students understand the property of stickiness.

Another interesting set of activities available for use both inside and outside of school were designed by Duncan et al. (2010) employing art and stained glass techniques in order to teach Nanotechnology. The activities could be separated into three basic categories. The first one was the introduction to the connections between science and art, specifically between nanotechnology and stained glass techniques. The second one was the synthesis of nanoparticles solutions containing poly vinyl alcohol (PVA) and the last one concerned the use of the nanoparticle PVA solutions or the dried solid shapes to create art. These activities were used in a variety of setting and audiences from children aged 2 years old along with their caregivers as well as to general public with senior citizens.

Simonneaux, Panissal and Brossais (2013) experimented on Nanotechnology with the perspective of citizenship education. They used the SAQ strategy according to which after training on Nanotechnology issues, a socially acute question was addressed to students. After the debate students’ arguments concerning their perception of risk on Nanotechnology were evaluated and two tendencies were observed. The first one reflected an individualistic use of nanotechnology and the second a critical and humanistic vision of the use of nanotechnology and science. The theme of the project was related to an undergoing project in the area about “an optical device that uses diffraction of light by an array of molecules to detect specific antigen/antibody interaction” (p. 2386).

Blonderand Sakhnini (2012) developed a Nanotechnology module to teach basic concepts. The first one was about size and scale and the second one was about surface area-to-volume ratio (SA/V). A variety of teaching methods, including game-based learning, learning with multimedia, learning with models, project based learning, storytelling and narratives were implemented for the instruction. Students’ interviews and final projects were analysed to learn how this variety of teaching methods influenced students’ understanding of basic nanotechnology concepts. Moreover, the study examined which methods enhanced this understanding and which it did not.

As mentioned before N-ST activities could be implemented for enhancing not only formal but non-formal learning as well. Nanoyou (Nano for Youth) is a project aiming at informing students around Europe about Nanotechnology and encourage them to engage in debates concerning socio-ethical issues of Nanotechnology. Students between the ages of 11 to 18 could participate in Nanoyou within formal education, while students between the ages of 18 to 25 could participate in Nanoyou within non formal science institution. The content of the Nanoyou project is with regard to medicine, the environment, energy issues and ICT (Filipponi & Sutherland 2009).

NanoAventura exhibition was planned by an informal science museum, particularly utilizing computer games and videos in order to help students conceptualize the idea of size and scale. Students at the age of 9 to 12 could be engaged in activities about nanomedicine or self-cleaning surfaces but mostly about size and scale (Murriello, Contier & Knobel, 2006).

In Taiwan, Nanotechnology has entered elementary and secondary Taiwanese text-books (Chao, Hsiung & Yu, 2011); however the results of a nanoliteracy survey indicated that Taiwanese elementary students lack awareness of Nanotechnology (Huang, Hsu & Chen, 2011). Lin, Wu, Cho & Chen (2015) designed a nanotechnology-based popular science education promotion teaching (NPSEPT) program. The program took place at the campus of Ilan University in Taiwan, as an edutainment camp for students. Undergraduate students were trained as teachers during the program. The subject matters of the activities included the definition, properties and application of nanotechnology both in nature and engineering. In addition, an experiment on lotus effect was displayed and an exhibition of daily products of nanotechnology was visited.

Finally, another application of Nanotechnology will be presented so that the reader would fully appreciate the range of activities, teaching methods, tools and content developed. The Nanoscale Informal Science Education Network (NISE Net) is a national community of researchers and informal science educators dedicated to fostering public awareness, engagement and understanding of nanoscale science, engineering and technology. The provided activities could be completed by all levels of education. One major purpose of the exhibition is to engage participants in tasks concerning the size, the properties and the new technologies related to the nanoscale (NISE Net, n. d.).

A.2.2.3.1 Integrating N-ST in the Greek Science Curriculum

In Greek education, aspects of N-ST have not yet been integrated in science curriculum, neither in primary nor in secondary education. However, there is currently a pilot project in primary education focusing on the integration of some of the Big Ideas of Nanoscience and Engineering mentioned in the new science curriculum. Research has revealed, though, that not all of the Big Ideas of Nanotechnology and Engineering can be integrated in the new science curriculum in Greek primary education (Manou & Spyrtou, 2013). However, in many cases the learning outcomes suggested from the new science curriculum are in accordance with the key concepts of N-ST. The following table (Table 1) presents briefly the Big Ideas of Nanotechnology and Engineering correlated with the new science curriculum in Greece.

Table 1: the Big Ideas of N-ST and the correlation with the new Science Curriculum in Greek Primary Education (adapted from Manou & Spyrtou, 2013 in Greek)

Big Ideas of N-ST	**5th Grade**	**6th Grade**
Size & Scale	Unit 1.1: Living Matter - Life around us	
Size dependent properties	Unit 1.2: Materials and technological objects around us - Raw materials	
Structure of matter		

Forces & Interactions		Unit 4: Creating with forces
Self-assembly		
Tools & Instrumentation	Unit 1.1: Living Matter - Life around us	
Models & Simulations	Unit 1.2: Materials and technological objects around us - Raw materials	
Science, Technology & Society	Unit 1.2: Materials and technological objects around us - Raw materials Unit 2.5: Technological applications - Protection Unit 3.2: Using less energy for the same needs and desires	Unit 1: Human body – Knowing my body Unit 2.6: Effects of modern technological achievements in human hearing
Quantum effects		

Some key-concepts of the present study that will be presented below were based on the pilot study of Peikos, Manou and Spyrtou (2014) who integrated some of the Big Ideas of N-ST in a primary school of the Greek city, Florina in the region of Western Macedonia. Taking into account the science curriculum in primary education the concepts implemented concerned a) the size and scale, b) the size dependent properties, c) tools and instrumentation, d) models and simulations, e) forces and interactions, f) science- technology-society. The Teaching Learning Sequence (TLS) was designed based on students' misconceptions on these Big Ideas and an inquiry approach was designed and followed by the instructor. The TLS included activities introducing "nano" to the students, the distinction between the scales (macro-, micro-, nano-), applications of nano in nature and technology as well as their benefits for the society (lotus effect, geckos, shark' s scales, water filtration). The TLS lasted ten hours and for the instruction a variety of teaching methods were applied, like using tools and instruments, learning with multimedia and learning with models.

A.2.2.4 Students' misconceptions on N-ST concepts

Although N-ST is an emerging field of inquiry, quite enough studies aim at mapping beliefs and opinions of the public or special interest groups such as middle and high school students, college students or teachers (for a review Bryan, Magana & Sederberg, 2015). However fewer are the studies with regard to primary education students' pre-existing ideas and misconceptions which are of special interest to the present study. Thus the content of these studies does not vary since most of them focus on a few of the Big Ideas of N-ST such as the size and scale, tools and instrumentation, structure of matter along with models and simulations.

The Big Ideas of N-ST included and directly taken into account in the design of the current study are those of *Size and Scale* and *Size dependent properties*. Nevertheless indirectly, another set of Big Ideas of N-ST was implemented such as *Tools and Instrumentation* and *Science, Technology, Society*. As a consequence, students' misconceptions which were taken into consideration during the design of the instruments along with the content and the material for the study's interventions address to these four fundamental concepts of N-ST.

Concerning *size and scale* students prior to sixth grade seem unable to make a distinction between the smallest thing they can see and the smallest thing they can imagine (Castellini et al, 2007; Waldron, Spencer, Batt, 2006). For instance, small macroscopic items like ants or grains of salt are smaller than atoms and cells (Castellini et al, 2007). This idea is in line with Holladay (2005) who found that early elementary students believe that the smallest thing they can think of is one they can actually see with their eyes or one belonging to the macroscopic scale. Tretter, Jones, Andre, Negishi and Minogue (2006a) explain that objects unseen with a naked eye cannot be experienced and manipulated directly, making it difficult for students to build robust understanding of small things. Hence students tend to believe that all those objects belonging to the unseen world have roughly the same size, although their size might vary greatly (Tretter, Jones & Minogue, 2006b).

In order to conceptualize size, individuals tend to create distinct categories of spatial distances and tend to perceive objects as being similar in size and relative to conceptual landmarks with the most common landmark being of one's self (Tretter et al, 2006a; Jones, Tretter, Taylor & Oppewal, 2008). According to the previously stated researchers these categories increase with age, grade level and experience. So among students of 5th, 7th and 9th grade, gifted seniors, and doctoral students, students up to 9th grade identified only one category of objects smaller than themselves (small), while gifted students identified three (small, very small, microscopic) and doctoral students five (small, very small, barely visible, many atoms and atomic) (Tretter et al., 2006a). Additionally, students up to the 9th grade seem to be more accurate while ranking macroscopic objects at the visible realm and less accurate when ranking objects at the invisible realm (Tretter et al., 2006b). Furthermore, Tretter et al. (2006a) reported that middle-school students do not demonstrate an adequate understanding of concepts of scale and size on the micro- and the nano-level and as a result when asked to rank objects on these levels ranked some of the macroscopic objects as the smallest objects from the given set.

Building on the previous reports on size, research has also demonstrated that students have difficulties conceptualizing the atom and the nature of matter. Therefore, students have difficulties understanding the difference between the relevant size of atoms, molecules, viruses, cells and bacteria and consequently distinguishing between the micro- and the nano-world (Magana, Brophy & Bryan, 2012). These results were also consistent with a study carried out by Nakhleh, Samarapungavan and Saglam (2005) which found that middle school students pose fragmented ideas on the structure of matter while believing that atoms and molecules could be seen under an optical microscope in the same way they could see microbes.

Misconceptions on the idea of *size dependent properties* seem to be unmapped. However, the most important thing found was that students believe that the properties bulk materials exhibit, can be attributed to the individual atoms or molecules (Albanese & Vicentini, 1997; Ben-Zvi, Eylon & Silberstein, 1986; Krajcik, 1991). For instance, students may believe that gold atoms have gold color as in bulk form.

With regard to the Big Idea of *tools and instrumentation,* research revealed that students may believe that it is possible to see nanoscale objects, atoms and molecules with a light microscope (Griffiths & Preston, 1992; Harrison & Treagust, 2002). According to Stevens et al. (2009) students might face difficulty in understanding that scanning probe microscopes do not work similarly with optical microscopes, thus reinforcing Harrison and Treagust (2002) who found that students assume that the images produced by the scanning probe microscopes are the same as seeing something through an optical microscope.

Finally, the pre-existing ideas of students about the Big Idea of *Science, Technology & Society* would mostly concern students' perception of risks about N-ST. Stevens et al. (2009) argue that students would consider new products and technologies as better than the old ones. In addition, Cobb and Macoubrie (2004) found that approximately 20% of their participants believed that risks of nanotechnology are greater than its benefits. However, this perception was highly correlated with participants' limited knowledge on the subject matter.

During the interventions described below an attempt was made to confute those misconceptions known from the literature review as well as those that emerged after the administration of a questionnaire with generative questions with regard to *size and scale* and the *size dependent properties* of hydrophobicity and absorption.

Generative questionnaires are constructed to provide information on students' underlying conceptual structures. As a matter of fact, through these questions phenomena which cannot be directly observed, could be explained, revealing at the same time what exactly students understood on a subject matter. Consider for example the questions "If you were to walk for many days in a straight line, where would you end up?" "Would you ever reach the end or edge of the earth?" and "Does the earth have an end or an edge?" In order for these questions to be answered students cannot rely only on the earth's shape. They will have to create a mental representation of the earth including the information about its shape and then answer the question (Vosniadou, 2002; Vosniadou, Skopeliti & Ikospentaki, 2005). In other words these questions do not aim at examining whether students have been exposed to the scientific view, because they have been, on the contrary these questions provide information showing[you can't prove in our field] whether the scientific view is fully comprehended.

A.3 Integrating ethical issues and values in science education through VaKE

As 21st century unfolds, the ultimate aim of education is formulated with the slogan "learning to be" as suggested back in 1972 by Faure et al. Faure had a vision of a lifelong education which could produce the complete person who would be acquiring knowledge during his lifespan and not once and for all as suggested until then (Faure et al. 1972, p. viii). Science and technology are becoming core parts of any curriculum enclosing the idea of developing scientific humanism (Pnevmatikos et al., 2015). Scientific humanism is considered as the wholeheartedly commitment to scientific methods which one extends even to any kind of moral and social problems (Otto, 1943). More specifically it means that one knows the scientific methods, the rules of objectivity, the relativity of knowledge, the ability to dialectic thoughts while at the same time one is sensitive to the ethical and social dimension of scientific and technological activities (Pnevmatikos et al., 2015).

From an educational perspective the sensitivity described above regarding the ethical and social dimension of scientific and technological issues has emerged from the Science-Technology-Society tradition in science teaching (Kolstø, 2001). Discussions on socio-scientific issues focus on empowering students to consider how science-based issues reflect, in part, moral principles and elements of virtue that encompass their own lives, as well as the physical and social world around them (Zeidler, Sadler, Simmons & Howes, 2005). When exploring socio-scientific issues students link their science knowledge and knowledge from other academic and social domains, with their citizenship values and reflect on the way this knowledge is used in society (Keast & Marango, 2015).

Although science is not value-free; an interesting question arises on whether teachers feel confident and competent enough to administer ethical and moral issues in their science courses. According to Gruber (2009) moral education seems to be excluded by teachers who are unaware of methods, goals or topics for its implementation. Moreover, teachers fear that values education might interfere with value systems of parents, or administration or other stakeholders and eventually they avoid its implementation. Furthermore, pressure resulting from the curriculum, exams and students' evaluation can also be an obstacle for values education demonstrating that teachers give more emphasis on knowledge than on moral education.

However, teachers are obliged by the curricula to integrate values education, although in most cases this is a requirement to be seen only in the premises of the curricula as no particular suggestion for moral and values implementation is stated. This is also the case for Greek curricula which however suggest that values education should integrate all subject matters; they still do not provide any suggestion on how teachers could effectively achieve this aim (Pnevmatikos & Patry, 2014).

Values *and* Knowledge Education (V*a*KE) is an approach aiming at overcoming the problem described above combining values and knowledge education as well as meeting the premises of *learning to be* (Pnevmatikos et al., 2015). The approach was introduced by Jean-Luc Patry and his colleagues at the University of Salzburg. In particular V*a*KE (Patry, Weyringer & Weinberger, 2007) is a teaching method integrating constructivist values education and constructivist knowledge acquisition using a moral dilemma to trigger the discussion. V*a*KE can be applied in every subject and course in school apart from science, like religion, language or biology (Weinberger, Patry & Weyringer, 2009). Accordingly, the main aspects of the method will be discussed.

A.3.1 Description of the theoretical background supporting V*a*KE

As mentioned before V*a*KE (Patry et al., 2007; Patry, Weinberger, Weyringer & Nussbaumer, 2013) is a teaching method integrating constructivist values education (e.g. Blatt & Kohleberg, 1975) and constructivist knowledge acquisition (e.g. von Glasersfeld, 1995) using a moral dilemma to trigger the discussion between participants. According to Kohlberg (1984) moral dilemma discussions foster the development of moral judgment and can also generate questions on the content and challenge students' knowledge on the matter under discussion. However, V*a*KE is the case where additional theories are employed and critical multiplism is applied (Figure 2).

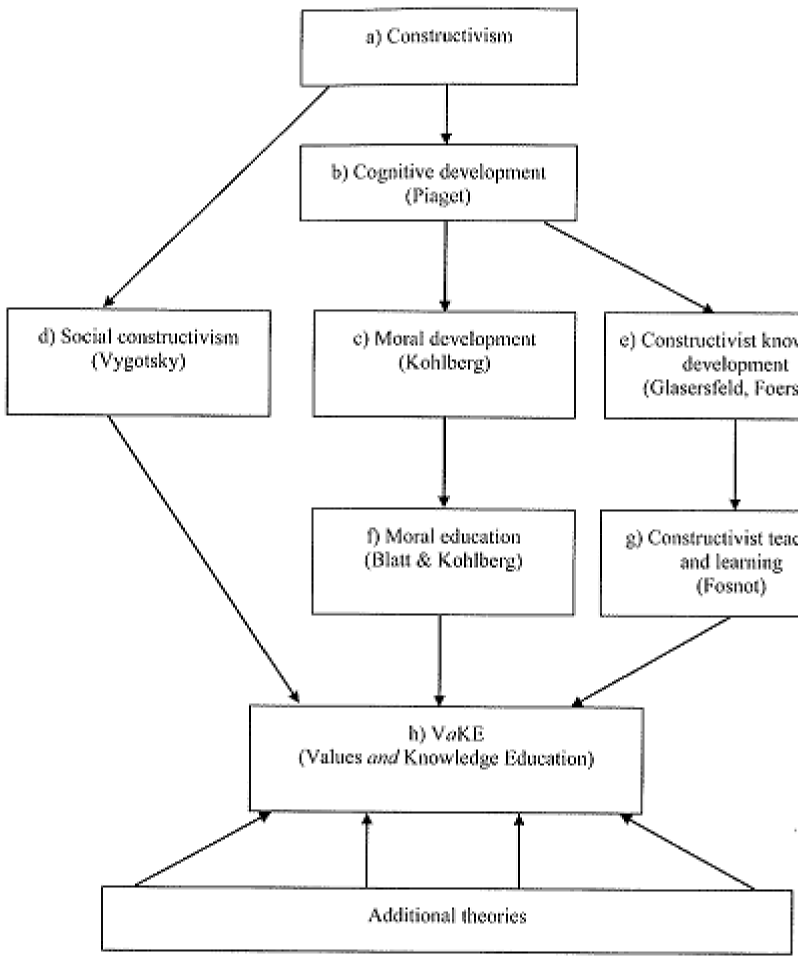

Figure 2: Background theories and their interaction for the development of V*a*KE (Patry et al., 2013, pp. 566).

A.3.1.1 Constructivist Knowledge acquisition

Concerning the constructivist knowledge acquisition V*a*KE is based on the theoretical findings of Jean Piaget, Lev Vygotsky, and Ernst von Glasersfeld. According to Piaget knowledge acquisition is defined as a physical or mental activity where recognition of an object means its adaption to existing cognitive schemata. The adaption of the object permits the individual to maintain the *equilibrium* between his inner representation and the perceived stimuli. This adaptation though, can take place under two different processes known as *assimilation* and *accommodation* (Piaget, 1950; Piaget & Inhelder, 1969).

In the first case of *assimilation*, the new information is perceived as known and compatible with the existing schemata and so it can be integrated into them without causing any change. In the second case of *accommodation*, a change to the preexisting schemata takes place in order to integrate the new information. In this case the new information is incompatible with preexisting schemata and that causes disequilibrium to the individual, namely a cognitive conflict that arouses both positive and negative emotions for the person. In order for the individual to solve this conflict older schemata are reconstructed or reorganized in such a way that the new information can be included. In this case the disequilibrium is solved but in the case where the disequilibrium is not balanced, the accommodation as a process includes reflective thinking and meta-cognition (Piaget, 1950; Piaget & Inhelder, 1969).

Ernst von Glasersfeld (1995, 1998), from his point of radical constructivism, suggested that the construction of a reliable base of knowledge depends on its viability, meaning that our actions, knowledge and cognitive operations are viable only if they fit to our experience and pass the viability check otherwise if the individual does not create a new schema to integrate the new information, it will be pushed aside as it would have failed the viability check. Patry (2014) distinguish eight types of viability checks the learner is able to perform during a V*a*KE process.

The concept of the zone of proximal development suggested by Vygotsky (1978) also seems to be important in knowledge acquisition in the case of V*a*KE since social interaction is inevitable not only in the case of a V*a*KE course but in everyday life as well. According to Vygotsky (1978) ZPD is the distance between the actual development level as determined by independent problem solving and the level of potential development as determined by problem solving under adult guidance or in collaboration with more capable peers. The range of skills one can develop with adult guidance or peer collaboration exceeds what can be attained alone. Additionally, the partners in the learning group should be on different developmental levels. In any case full development of the ZPD relies on full social interaction of the individual.

A.3.1.2 Constructivist moral education

Piaget besides cognitive development also worked on constructivist moral development formulating one of the first theories on moral development. In accordance to his theory (Piaget, 1997) moral development occurs through social interaction. Piaget in his studies examined how children develop moral reasoning with regard to their understanding and observance of rules in games and their judgment concerning good or bad actions. Therefore, he proposed two stages of moral development. Since students in elementary school think that rules are fixed and absolute, their actions are obedient to authority (e.g. parents, teachers), hence this stage was called "heteronomous morality". Older students (10 or 11 years old) have a relativistic view of rules and they understand that rules can change after agreement and in this case Piaget called this stage "autonomous morality".

Kohlberg elaborated on Piaget's work on moral development, using moral dilemmas (e.g. Heinz dilemma) to challenge both children and adolescents' moral arguments. Kohlberg (1984) based on his analysis of these arguments suggested that six stages of moral reasoning could be found, where the higher the stage the more differentiated moral reasoning and understanding of the world are. Intercultural studies revealed that these six stages of moral development could be found elsewhere as well. Kohlberg classified the six levels in three major levels each of which consists of two levels.

The first level is the *pre-conventional level* where the individual is not able to understand the rules, expectations and conventions of the society. The moral judgments on the first stage of this level are based on obedience and punishment. Children behave according to rules and norms imposed by some authority. The second stage is characterized by an instrumental view, where children realize that different persons can have different opinions and benefits but they still decide depending on their best interest.

At the second level, the *conventional level* the individual gains an understanding that rules and norms are important to sustain society but the person still is unable to reflect critically these norms. The right behavior is based on what the group decides to be right. At the first stage (3) of this level, the expectations of the peers are important and individuals' moral judgments are taking into account the expectations and beliefs of the people close to them. At the next stage individuals' perspective focuses on the society as a whole and the arguments are driven by the laws so that societal order is upheld.

The final level is the *post conventional level* where reasoning is characterized by a way of thinking that critically reflects norms of the society. Reasoning at this level is with priority to society and its principles although sometimes these principles can be in conflict with norms of the society or peers. At the fifth stage people believe in the social contract consisting of basic human rights such as the fact that democratic process can improve society. The moral arguments at the last stage of the post conventional level emphasize on individual principles of justice. These principles respect human dignity and they have universal validity. However, at this stage Kohlberg did not find enough empirical support, so he suggested it as a theoretical stage.

People pass the stages one at a time but the procedure is slow and someone without social interaction combined with cognitive development can remain at the same level for many years. Most children at the age of ten can be found in stage 2, while most adolescents (18 years old) reach stage 3. The majority of adults remain in the conventional level of moral development (Colby & Kohlberg, 1987).

Kohlberg proposes as the most appropriate method for moral development the introduction of a moral dilemma that would challenge students' moral judgements (Blatt & Kohlberg, 1975). Through the dilemma discussion students will encounter different points of view on the matter and as a consequence a person's moral reasoning can shift into higher stages due to cognitive conflicts in the current moral stage they are on.

A.3.2 Additional Theories supporting V*a*KE

V*a*KE is an approach grounded on many constructivist concepts as mentioned earlier (units A.3.1.1 & A.3.1.2.) but also has a close relationship or capitalizes on other theories as well. Furthermore, since it is one of many methodological tools that can be applied in teaching, theories of learning and instruction as well as classroom management can be addressed in the V*a*KE theory (Patry et al., 2013). In that context a concrete meta-theoretical concept is needed in order to develop and test theories. V*a*KE is underlined by Dewey's opinion on *warranted assertibility* (1938) which is best done when followed by *critical multiplism* (Cook, 1985; Patry, 1989, 2005, 2010, 2013).

Warranted assertibility means that the better a statement is supported by arguments, the more one can accept it. Although a scientific approach might have different types of arguments, someone following one concept does not have to reject arguments from another concept since they may even be better that the original ones (Patry, 2010,2012). Critical multiplism means using multiple approaches in a critical way in order to rule out the biases each approach could introduce (Patry, 2005, 2012). Two dimensions of critical multiplism are distinguished; Thoughtfulness versus Thoughtful research and single vs multiple methods. "Critical multiplism refers to rational multiplism well aware of the problems and biases and theory driven" (Patry et al., 2013, p. 568). More precisely biases one theory may have, are compensated by using another theory.

Besides the constructivist theories on which V*a*KE is grounded, research has revealed that V*a*KE is based on additional theories as well. Among these theories one can find problem solving and problem based learning, theory of care, theory of discursive learning, subjective theories, critical thinking, learning in groups, the interaction between formal, non-formal and informal learning, personal development and identity, discourse ethics, culture and wisdom, motivation, pedagogical tact. From the above theories, results will be presented for those which an empirical relationship to the method has been established.

Theory of care. Kohlberg's theory of moral development is oriented in justice excluding also female reasoning from his experiments and for that many colleagues criticized his work and findings. Gilligan, one of Kohlberg's students proposed that care is another important criterion for moral judgment adding in that way a female perspective on moral issues (1982). However, Lyons (1983) and Walker (1984) have shown that among gender and moral judgments there is not a one to one relationship. Moreover, Döbert and Nunner-Winkler (1986) have also demonstrated that gender is less important than concern. Actually if an individual feels emotionally concerned by the dilemma or attached to the main characters of the story then it is more possible that they will judge based on care rather on justice which might be the case when the individual feels emotionally distant.

These findings are in line with V*a*KE research. Patry and Schaber (2010) assessed whether participants in a V*a*KE course felt concern with the protagonist of a dilemma story and whether they judged being more focused on justice or on care. Care and justice judgments did not correlate, while the subject's gender played no role at all. Concernment on the other hand was positively correlated with care and negatively correlated with justice. This shows that participants in V*a*KE use judgments of both types and that their priority depends on their level of concern. Nevertheless, it is essential to mention that dilemma construction in the case of V*a*KE approach takes into account the special characteristics of participants and tends to personalize and increase concern as much as possible unlikely to dilemmas used by Kohlberg like the famous Heinz dilemma where concernment is avoided (Patry et al., 2013).

Theory of discursive learning. In V*a*KE, argumentation is important in order to find who is in favor of and who is against the dilemma's options. Moreover, it is important for moral and cognitive development as stated already, since each argument whose viability is acknowledged provides deeper learning for the participants. Miller (2006) made an attempt to define the framework for analyzing the structure of group argumentation. In this framework argumentation in a V*a*KE process can also be analyzed.

Miller (2011) analyzes the specific way ("logic") in which arguments are stated in a group argumentation referring to the correlations and relationships developed behind argumentation. In that concept an argument is considered as a sequence of statements logically related. Arguments result deductively but also inductively while in both cases specific rules apply. According to Miller's framework argumentation is represented in a structure tree (Figure 3). Each statement is represented with a different box while the last concluded box represents an effective argument, providing a solution to the problem under discussion. The logic of an argument refers to the principles used in the transitions from one statement to the other.

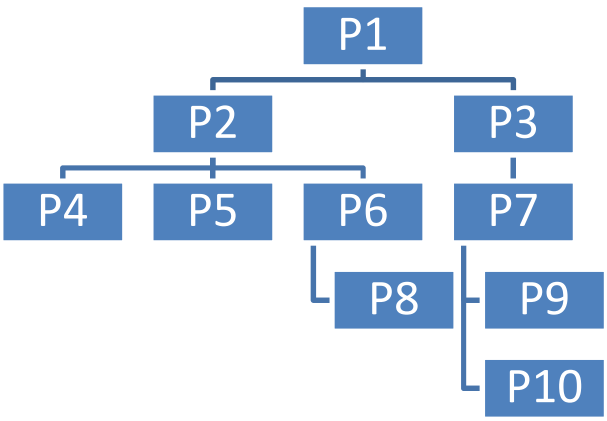

Figure 3: Example of Miller's structure tree

In the case of a V*a*KE argumentation two trees are needed: one for the statements in favor with a positive conclusion and another against a certain dilemma decision with a negative conclusion. Miller's structure trees were successfully used in order to describe participants' argumentation in a V*a*KE process (Kircher, 2008; Nussbaumer, 2009). Furthermore, the arguments can be classified on whether they belong to the morality domain or to the subject matter domain. The structure tree of argumentation can provide information on whether students commit the naturalistic fallacy. Although only in a few cases was accepted by the participants (Nussbaumer, 2009).

Theory of problem solving and problem based learning. Essential characteristics of problem based learning (Barrows & Tamblyn, 1980) are consistent with V*a*KE principles. Students are supposed to answer a problem, which might be fictional or real, by searching for the appropriate information. Students are setting their personal learning goals, are responsible for finding the resources needed for the inquiry as well as checking their learning achievements. The problem employed in a V*a*KE unit is the dilemma story which is structured stimulating participants to form questions and consider the possible solutions and approaches.

Furthermore, students are cooperating in order to solve the problem, discuss the information emerging from their inquiry and finally present their solution. In problem solving the teacher is also a facilitator of the process. Interdisciplinarity is also facilitated in V*a*KE (Patry, Weinberger & Weyringer, 2010) since students should integrate knowledge from different disciplines relevant to the process of solving the problem.

Inquiry-based learning is a student-centered, active learning approach focused on questioning, critical thinking, and problem solving. Considering the close relationship between *problem based learning* and *inquiry based learning* it is crucial to mention that V*a*KE is also consistent with this instructional approach. Inquiry-based learning activities have a question as a starting point (see also unit A.1.1.5 of the present paper) followed by investigation concerning the solutions. New knowledge is gained as information is gathered and understood, while discussing discoveries, experiences, and reflecting on newly acquired knowledge (Savery, 2006). Inquiry-based learning is frequently used in science education.

Motivation. Frewein (2009) examined academic performance and motivation comparing students in a V*a*KE process and in a mix type of instruction with both frontal teaching and group work. The results indicated that although there wasn't a significant correlation between the teaching method and the groups, better academic performance was observed by the V*a*KE group with which the variable of motivation was also significantly correlated.

A.3.3 Steps in a prototypical V*a*KE unit

V*a*KE is an approach based on problem solving using moral dilemmas stories and the discussion of related issues to trigger participants' moral judgments while it simultaneously triggers questions on the content. The participants discuss on the main character's choices but soon enough they realize that they do not have enough information on the content in order to solve the problem or even argue properly. The next step would be searching for the information needed on the internet or through other sources. A second dilemma discussion follows, where more sophisticated arguments are provided and in most cases a solution to the problem as well. Through the discussion participants realize not only that their arguments are value laden but also that some of them have a more universal and sustainable perspective, while those which are more egocentric usually tend to be rejected through the process of viability check (von Glasersfeld, 1995, 1998; Patry, 2014). In that way the dilemma discussion can be efficient to participants' moral development according to Kohlbergian theory (1984).

There are eleven steps in a prototypical V*a*KE unit as briefly presented at table 2 (Patry, Weyringer & Weinberger, 2007; Patry et al., 2013). Also a preparation and clarification step can be introduced in case students are not used in open teaching, inquiry processes or argumentation (Patry et al., 2013). After the table a more detailed description of the steps is provided.

Table 2: eleven steps in a prototypical V*a*KE unit (Patry et al., 2007)

	Step	**Action**	**Class formation**
1.	Introducing the dilemma	Understand dilemma and values	class
2.	First decision	Who is in favor, who against?	class/group
3.	1st dilemma discussion	Moral viability check	group
4.	Missing information	What do I need to know to continue?	class
5.	Looking for evidence	Getting information	group
6.	Exchange information	Inform peers; content viability check	class
7.	2nd dilemma discussion	Moral viability check	group
8.	Synthesis of results	Present conclusions	class
9.	Repeat steps 4 through 8 if needed		class/group
10.	General synthesis	Capitalizing on whole process	class
11.	Generalization	Application to other fields	class/group

Introducing the dilemma. At this first step the dilemma is presented in the target group with the appropriate form and the teacher ascertains that the values at stake are identified.

First decision. Students have to express themselves on what the main character of the dilemma story should do. At this point students just choose sides based on the little knowledge they have on the matter.

First dilemma discussion. During the first dilemma discussion students argue in favor and against the different solutions of the dilemma, as introduced in the Blatt and Kohlberg (1975) tradition.

Missing information. The group exchange experiences concerning the argumentation, although the discussion may not be finished yet. At this point, students realize that their knowledge is insufficient for solving the problem. Therefore, there is the exchange of needed knowledge. Students can set their own learning goals choosing the topic that interests them the most.

Looking for evidence. At this particular step, students are being involved in inquiry based learning as they have to obtain the missing information. The teacher can facilitate the procedure and counsel students when they need it.

Exchange information. Since students have been working in groups and on different aspects of the matter, they need to exchange the information and inform their peers. In this way all students have the same level of knowledge.

Second dilemma discussion. As it follows, students will be engaged once again at a discussion regarding the dilemma. However unlike step 3, students have now the necessary information even to answer the problem stated in the dilemma. Once again students choose sides and argue in favor or against the different solutions.

Synthesis of results. Then a general discussion presenting the current state of the negotiations takes place. This procedure can be done in anticipation of step 10 and the general synthesis of the discussion.

Repeat steps 4 through 8. If the knowledge is still not sufficient to solve the problem, then steps 4 through 8 can be repeated. This step can also be repeated as many times as necessary.

General synthesis. The final synthesis presents the solution proposed for the problem or if the dilemma cannot be solved then the current state is presented. The presentation can be done in different ways such as a role play, writing a newspaper etc.

Generalization. The generalization consists of dealing with similar issues to broaden the perspective. Very often this step happens spontaneously when, for instance, students are writing letters to ask for money concerning a specific cause and so on.

Two other forms of V*a*KE model have been introduced. The first one is V*a*KE$^+$ used mostly in classes where students differ concerning their cognitive level (Weinberger, 2006). V*a*KE$^+$ provides an opportunity to the students for more viability checks. The steps where students are looking for evidence and exchange information are repeated more times and as a result more content viability checks can take place. The V*a*KE version designed and applied for the current study is closely related to this model of V*a*KE because the steps which were repeated (steps 5-looking for evidence and 6-exhange information) provided an opportunity for more content viability checks. The main difference between V*a*KE and V*a*KE$^+$ is the systemization of the viability checks. As indicated by Weinberger (2006) the V*a*KE$^+$ model provides students with an opportunity to reflect more than in the typical V*a*KE unit. Less intelligent (IQ < 95) students' knowledge acquisition was facilitated the most from the V*a*KE$^+$ model while no statistically significant difference was found between the two V*a*KE models for the most intelligent students (IQ > 105).

The second one is V*a*KE-*dis,* where *dis* stands for *d*ifferentiated, *i*ndividualized and *s*pecified. In this V*a*KE model reflection is introduced as a step after every step described in table 2 above. In order to facilitate reflection an instrument was introduced also named WALK (Weyringer, 2008) (see unit A.3.4.).

Another aspect of the method needed to be mentioned here is that of teachers' role, which alters in comparison to traditional teaching and may also vary depending on the steps of the method. However, an important fact is that the teacher has to do little during a V*a*KE course since he mostly acts as facilitator, but there is much more in preparation. Moreover, teachers engaging in V*a*KE discard their traditional role of being the illuminati, since at the end of the unit it is possible to gain the same or even less information than their students. During V*a*KE the teacher can manage the discussion without intervening and motivate more students who are less competent than others. It is also essential to consider that V*a*KE offers an opportunity for personalized learning and therefore the teacher should not diminish this aspect of the method (Weyringer et al, 2012: Weinberger et al, 2009).

Students' role in V*a*KE also differs from their role in traditional teaching, since they need to regulate their own learning objectives as well as outcomes. Also students participating in V*a*KE have the opportunity to develop skills such as searching for the appropriate information on the matter under discussion, reasoned argumentation, cooperation, communication of findings and reflection (Weinberger et al, 2009).

A.3.4 Assessment methods and instruments in the V*a*KE approach

A wide range of methods and newly developed instruments have been used to validate the approach and assess its results. In order to examine the educational process, *the lesson interruption* method (Patry, 1997) was addressed. In this method the teacher stops the lesson at a pre-determined moment (e.g. before a new step starts) in order to administer a short questionnaire concerning students' observations during the last phase before the interruption. Once the students are accustomed to the interruption, they respond very quickly without disturbing the lesson (Patry, Unterrainer, Wageneder&Weyringer, 2003). Moreover, the studies using this method revealed high internal consistency.

The second instrument used for the evaluation of the results was the WALK ("W" assessment of latent knowledge). "The WALK is a summative assessment of knowledge based on a constructivist theoretical framework" (Patry et al., 2013, p. 572). It consists from different pictures relevant to the content of the V*a*KE course. "W" refers to the five "W" questions (who, what, where, when, why) which guide students through the first phase of WALK where students have to write down as many key worlds as possible for each picture. In the second phase students have to frame these key words to questions and at the third phase they have to answer these questions. The instrument's score is determined by the number of responses in each phase after being content analyzed (Patry & Weinberger, 2004). Experiences showed that students can perform very well at the WALK test after they have been familiarized with the instrument without showing text anxiety as well.

For the assessment of the social atmosphere in classrooms where V*a*KE was introduced, sociograms have been applied. Sociograms provide information about the level of sympathy and antipathy between the students (Coie, Dodge & Coppotelli, 1982). In addition, crossover designs were used in order to compare two groups out of which the experimental group was introduced to VaKE instruction.

In this tradition the knowledge acquisition process was evaluated and V*a*KE was proved to be in most cases more efficient. For example, V*a*KE was compared with a moderate constructivist teaching (Patry & Weinberger, 2004), proving that students in both cases gained the same level of knowledge. However, at the same intervention the results of the WALK test indicated that students participating in the V*a*KE course had constructed more applicable knowledge than with the normal way of teaching (Weinberger, 2006). Weinberger, Kriegseisen, Loch & Wingelmüller (2005) and Weyringer (2008) also reported substantial knowledge acquisition while working in summer camps for gifted students.

Although knowledge construction has been addressed, moral judgment competence has not been validated for two reasons. Firstly, it is well documented that dilemma discussions foster moral judgment (Blatt & Kohlberg, 1975; Lind, 2003) and secondly the influence on moral development is a long term process.

A.3.5 Generalizability of the theory

The V*a*KE approach has been implemented in many European countries (Austria, Spain, Norway, Germany, and Greece) and Australia, among others and its success was confirmed. It has also been applied successfully in all educational levels (starting from Grade 5) and in many other settings such as teacher training and summer camps for gifted international students, as well as in many different school disciplines.

With regard to different cultures and ethnicities one study has been conducted outside Europe, particularly in Egypt (Ali, 2006). Ali found that both teachers and students had very little experience with open teaching such as V*a*KE. However, they soon adjusted to the requirements and V*a*KE could be practiced successfully.

Concerning different groups, the impact of the native language was studied in summer camps with international students as participants. Results revealed that native language did not affect students understanding of the problem or their argumentation (Patry, Weyringer & Weinberger, 2010). Moreover, cognitively heterogeneous groups participated in a crossover design where the typical V*a*KE model and the V*a*KE$^+$ model were compared in order to examine which one facilitates knowledge acquisition the best for students. The latter proved to be more efficient for the least intelligent students (Weinberger, 2006).

With reference to different educational levels, V*a*KE has been applied from Kindergarten to Upper Secondary and even vocational education (Pnevmatikos & Patry, 2014) with some adjustments for the courses referring to Kindergarten and Grades 1 to 4 students since their lack of theory of mind does not allow them to see another person’s perspective. Overall the approach seems appropriate for all educational levels and can be applied adjusting the dilemmas according to age group and interests (see check list; Pnevmatikos & Patry, 2014).

Teacher training has been a rather important setting for V*a*KE. Experiences concerning problems about the change in teachers' role, as well as related solutions are presented by Weyringer, Patry & Weinberger (2012). Moreover, Nussbaumer (2014) focuses on specific aspects of teachers' role in order to facilitate the introduction of the method in schools. In addition, Haara & Smith (2012) trained two in-service teachers with V*a*KE in order to examine whether they would increase their use of practical activities in mathematics teaching – only one was successful. Another case study involved pre service teacher training on environmental issues with V*a*KE in such a way that teachers would understand the benefits of such an approach in future science training (Keast & Marangio, 2015). Furthermore, Greek teachers evaluated positively V*a*KE as an instructional approach which among others highly motivates students, advance their skills and facilitates not only knowledge acquisition but values education as well (Pnevmatikos & Christodoulou, 2015). Finally, V*a*KE is being implemented in adult education and lifelong learning activities (Pnevmatikos et al., in press) with encouraging results not only for teacher training but professional training as well.

Although critique has been addressed both on ethical and theoretical aspects of the approach (see Patry et al., 2013) the effectiveness of V*a*KE has been confirmed in many different settings not only on the cognitive but on the moral perspective as well.

A.4 The current study

A.4.1 The main idea, purpose and objectives of the study

Summarizing the above sections of the theoretical framework of the current study it would be important to make an integration of the three main issues of this study.

The rapid development in the field of Nanotechnology the last few decades has provided amazing applications in science and engineering that seem to be more related to fiction than reality (Stix, 2001). As commercial products are invading everyday life in a more accelerated rate than a decade ago, applications and benefits of N-ST become more and more undeniable (Jones et al., 2013; Lacaze, 2012). However risks and ethical issues can also arise from the use of N-ST not only for the human species but for other species and the environment as well (Dunphy et al., 2006; Macoubrie, 2006; Planinsic & Kovac, 2008; Shatkin, 2012; Sweeney, 2006) (for a more detailed analysis of these issues see unit A.2.1.).

Due to this rapid development of N-ST, its educational importance has advanced rapidly. “Nano” literacy emerges as an important objective of “nano” education. However, “nano” education does not come without any challenges for its implementation. In order for it to be included in education, a set of core concepts - The Big Ideas of Nanotechnology and Engineering- (see Stevens et al., 2009) (for a more detailed analysis see units A.2.2.1. & A.2.2.2.) has been developed, the understanding of which is essential (Blonder & Sakhnini, 2012). Even in this field of science education, though, students form misconceptions on main concepts of nanotechnology (Bryan et al., 2015; Castellini et al., 2007; Magana et al., 2012; Nakhleh et al., 2005, Tretter et al., 2006a, b) (for a more detailed analysis see unit A.2.2.4).

Students before exposed to instruction, form naïve concepts and ideas on specific subjects based on their previous experiences (Vosniadou, 2007). This naïve conceptualization of science is incompatible with scientific concepts. As a consequence, the learner might form a new synthetic model in order to explain the specific subject under discussion adopting this new scientific concept into his preexisting framework theory (Vosniadou, 2007). When the learner replaces these synthetic models with the scientific concepts, they have undergone conceptual change. Taking into consideration not only the importance of introducing N-ST in primary education but also the fact that students form misconceptions arising from the N-ST’s relation with materials and phenomena of the unseen world, a conceptual change approach is of great value.

Since many ethical issues arise from N-ST as already stated, “nano” education can be considered as a fundamental discipline of the 21st century science education. Moreover, “nano” education supports the development of responsible citizenship since it touches the most significant areas of every citizen’s wellbeing such as health, safety, security and environment (Lobanova-Shunina & Shunin, 2011). Nevertheless, citizenship struggles to take place in the education of a very changing society, where individualism is making strong headway (Veugelers, 2007). Taking into consideration the rapid development of science and the field of N-ST in particular, it is more essential than ever for people to make decisions based on a more social and global perspective rather than on their personal interest.

Under these circumstances combining values education along with knowledge in the field of N-ST education seems critical. Curricula usually integrate values education in every subject matter; regardless of the fact that teachers suggest a series of reasons (see Gruber 2009) not to implement values education in their teaching (for more details on the issue see unit A.3.). V*a*KE is a didactical approach aiming at addressing these issues since it fulfills teachers' double assignment (Tapola & Fritzen, 2010); ensuring not only knowledge acquisition but providing moral education as well.

Although V*a*KE is applied in specific subject matters promoting interdisciplinarity it is based on a domain general theory to explain cognitive development using the concepts of equilibrium, accommodation and assimilation (Piaget, 1950). Recent research findings concentrate on domain specific theories, such as conceptual change, in order to explain cognitive development in distinct domains of thought and attempt to describe the processes of learning and development within these domains (Vosniadou, 2007). Furthermore, the concept of viability checks employed in V*a*KE seems to be rather important with regard to conceptual change approach. Viability checks provide an opportunity for the learner to reflect on knowledge acquisition. In addition, the notion of the zone of proximal development in V*a*KE facilitates the hypothesis of cultural mediation which is also important for conceptual understanding. Particularly through the discussion, where at the same time viability checks take place, students realize that they have not acquired knowledge the same way. This procedure can render the impetus of learning within the learner, namely creating an intentional learner as well as it can facilitate students' meta-conceptual awareness.

Moreover, conceptual change in V*a*KE can be achieved though the mediation of motivational factors as well. First of all, V*a*KE has been proven to motivate students (Frewein, 2009) since it employs inquiry based activities facilitating students to fulfill their basic psychological needs as proposed by Self-Determination theory. Secondly epistemological beliefs, which are another motivation factor facilitating conceptual change, can be employed in a V*a*KE unit. The dilemma constructed for the implementation can provide opportunities for discussion regarding nature of knowing and nature of knowledge. Under these evidence and implications, it would be reasonable after all to examine whether V*a*KE can foster conceptual change in class in the field of N-ST.

The main purpose of the present study is to investigate whether V*a*KE can foster conceptual change in science education and particularly in the specific domain of Nanotechnology. Three are the main objectives of the study; firstly, to investigate whether V*a*KE can facilitate conceptual change in comparison to an inquiry based teaching; secondly, to examine if motivational aspects and epistemological beliefs can be increased in a V*a*KE process; and finally to consider which students can be more facilitated in conceptual understanding while participating in a V*a*KE process with regard to their IQ.

A.4.2 Research Questions and Hypotheses of the study

The research questions of this study are the following:

- Can V*a*KE foster the same levels of conceptual change as with an inquiry based teaching?
  - Since inquiry based teaching fosters conceptual change (see unit A.1.2.) and V*a*KE also employs inquiry activities and skills which capitalize on inquiry based teaching as implied already, we hypothesize that V*a*KE can foster at least as much conceptual change as facilitated by an inquiry based teaching.
- Can V*a*KE sophisticate epistemological beliefs and increase motivation at the same levels in comparison to an inquiry based teaching?
  - As already stated inquiry based teaching can sophisticate epistemological beliefs and increase motivation (see unit A.1.1.4.). Moreover, V*a*KE can motivate students (Frewein, 2009; Pnevmatikos et al., in press) while employing inquiry activities implies that epistemological beliefs can be also sophisticated. As a consequence, the second hypothesis would be that motivation and epistemological beliefs would be increased through V*a*KE at the same levels as the inquiry based teaching.
- Finally the last research question of the study refers to the students participating in the V*a*KE unit. In particular, the third research question asks whether there are differences in conceptual understanding over time across students of the experimental group with regard to their IQ.
  - As it has already been suggested (see unit A.3.3.) the V*a*KE model presented here is closely related to V*a*KE$^+$ and since Weinberger (2006) has indicated that the least intelligent students were benefited the most in terms of knowledge acquisition in comparison to the more and the most intelligent students, it is expected here that the least intelligent students will be benefited the most regarding conceptual understanding.

A.4.3 The research design

In order to meet the abovementioned research questions and hypotheses two groups of participants were needed, one which would participate in a V*a*KE course and the other one which would participate in an inquiry based teaching. Since the experiment took place in school environment, artificial groups could not be formed because that could disrupt the learning environment and as a result, a true experimental design was excluded (Creswell, 2012). This means that the participants in the two groups were not equated by randomization and thus a quasi-experiment was realized. Particularly the pretest-posttest nonequivalent group design was adopted (Campbell, Stanley & Gage, 1963). The pretest measure was administered one week before the interventions begin, while the posttest one week after the end of the interventions. Additionally, a follow-up measure was administered to participants approximately three months after the posttest (Table1).

Table 1: The research design of the present study

Duration of	*1stweek*	*2nd week*	*3rd week*	*4th week*	*5thweek*	*After*

Nanotechnology interventions						*three months*
class	**Pre-test**	**Treatment**			**Post - test**	**Follow-up test**
Experimental	√	V*a*KE			√	√
Control	√	Inquiry-based teaching			√	√

The interventions took place three times, one time per week for two hours during school time. The days and hours arranged for the interventions were the same every week. The whole design lasted 11 hours per group, since the follow-up test concerned only the knowledge acquisition and no other tests were administered. The interventions were based on specific teaching aims in accordance to the Big Ideas of Nanotechnology and Engineering (see unit A.2.2.2.1.) and as a consequence specific variables (Table2) regarding students' knowledge acquisition were measured through the study.

Table 2: The variables measured at the study and their correspondence to each intervention

variable	***1st intervention***	***2nd intervention***	***3rd intervention***
Size and scale	√		
Size dependent properties: hydrophobicity		√	
Size dependent properties: absorption			√

B Method

B.1 Participants

For the current study 81 schoolchildren participated from which 40 were male and 41 female. The experimental group consisted of 44 students (23=male and 21= female) while the control group of 37 (17=male and 20=female). All students were attending sixth grade and were in the same age group (M= 11.48 years, SD=.35, age range from 10.92 to 12.92).

Four schools in two different urban areas of Greece consented to their participation in the study and as a consequence they were conveniently selected to participate in the research. Participants in the experimental group were students from three different classes of two different schools in the same area, while participants in the control group were from two different classes of two different schools in the same area. In each group students came from an average socioeconomic background.

B.2 Design & Procedure

In order to test the research questions and hypotheses (see unit A.4.2.) two groups of participants were formed. The research design followed was a quasi-experiment (Cohen et al., 2007: Creswell, 2012) since the procedure took place in a school environment where artificial groups would be difficult to form. A pre-, post- and follow-up measurement took place. The duration of the interventions was 5 weeks and after a three-month interval the follow-up test was administered (unit A.4.3.). The content interventions were three, took place once per week for both the experimental and the control group and lasted six hours[3]. However, the whole experiment lasted 11 hours including the interventions concerning the measurements.

In one experimental subgroup the interventions took place during the middle of the school day (from 10:00a.m. to 11:30a.m.) without school breaks. On the contrary, the interventions for the other subgroups took place at the end of the school day (from 12:40 p.m. to 14:00 p.m.) with one intermission between the two hours. On the other side interventions for the first control subgroup occurred at the beginning of the school day (from 8:15 a.m. to 9:45 a.m.) without a break while for the other subgroup the interventions occurred the last two hours of the school day interrupted by a school break. All teachers except one from the control subgroup were present during the courses.

Interventions were designed in accordance to the basic features of each teaching approach, namely V*a*KE and inquiry based teaching. The V*a*KE procedure was adopted in order for conceptual change to be achieved. It is essential at this point to describe the design and procedure of each intervention with regard to both research groups.

[3] An hour is considered to be 45 minutes of teaching time. However, the last two hours on the timetable, namely after 13:00 pm are reduced up to 30 minutes each.

To begin with, the instructor of these interventions was in both cases the author of the present study. Researcher's diary for each intervention was kept so that the content and procedures taking place in both groups would be as similar as possible. Before the beginning of the project and since the headmasters had consented to participate in the research, all classes were observed during science courses in order to determine some aspects of teachers' current practices. In all cases teachers chose to implement the curriculum objectives by using the science book as their most common practice, something which was also recently confirmed by Dimitriadou and Spyrtou (2014). Experiments were also performed by the teachers for all participants with one exception of a teacher, who asked a few students to assist him during the experiment and make observations. In all cases teachers used closed and factual recall questions. Moreover, students did not work in groups but rather individually. As a consequence, students did not have the opportunity to express themselves or be engaged in a discussion with their classmates. In addition, since they did not also conduct experiments on their own it was assumed that students did not have advanced skills of inquiry and would not be able to act on a high degree of autonomy.

Considering these observations as well as the fact that inquiry activities can be found in a range from open inquiry activities – in which students are fully autonomous to identify a problem, generate questions, design investigations, make and record observations, interpret data, create explanations, and develop models and arguments–to more structured inquiry – in which teachers determine the questions and the specific procedures of the investigation (Crawford, 2007)– a Teaching Learning Sequence (TLS) was designed (Méheut & Psillos, 2004). Furthermore, since V*a*KE is based on social constructivism (Vygotsky) and the concept of Zone of Proximal Development (ZPD) the teacher has the opportunity to scaffold students, overcoming in that way their lack of inquiry skills.

In addition, the contents of the TLS were carefully introduced since understanding nanotechnology and its basic aspects means that first students must comprehend the idea of "nano" as size and scale before introducing any other notion to them (Magana et al., 2012). Moreover, the sequence with which the contents were introduced was also essential keeping in mind that conceptual understanding was the main objective of the interventions (Vosniadou et al., 2001). The issues discussed already relate to both the experimental and the control group.

B.2.1 Educational objectives of the TLS

The first step into preparing a lesson is for a teacher to set their educational objectives. Educational objectives are the statements expected or intended to be the outcome of instruction (Krathwohl, 2002). Researchers have classified these objectives in taxonomies such as the well-known Bloom taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956)or the further development of Bloom taxonomy by Anderson, Krathwohl, et al., 2001. In this way setting educational objectives wouldn't be one sided in favor of one domain, namely the cognitive. Moreover, educational objectives became concrete and easier to measure.

Since the present study is interested in measuring conceptual change, some variables were chosen constituting at the same time the cognitive objectives of the courses. The main concepts while introducing N-ST in K-12 education were addressed as the Big Ideas of Nanotechnology and Engineering (Stevens et al., 2009), forming simultaneously the main educational objectives of the field. From these concepts were directly introduced during the current study the Big Ideas of "size and scale" and "size dependent properties". The cognitive objectives of the designed TLS were stated as follows:

Size and scale:

- ✓ Students should be able to recognize "nano" as a size and refer to objects of the nanoscale.
- ✓ Students should be able to classify objects in different scales like the macro-, micro- and nanoscale based on specific criteria, such as with which instruments objects can be observed in the environment or which is the biggest or the smallest one.
- ✓ Students should be able to name the different tools and instruments needed to observe objects through different scales.
- ✓ Students should be able to describe the main functions of the different tools and instruments needed to observe objects through scales.

Size dependent properties:

- ✓ Students should be able to explain lotus effect and attribute its existence to the nano structures of hydrophobic surfaces.
- ✓ Students should be able to describe the properties a surface can acquire when the surface becomes hydrophobic, displaying the lotus effect.
- ✓ Students should be able to give examples of the advantages surfaces presenting the lotus effect might present, namely being hydrophobic in comparison to hydrophilic surfaces.
- ✓ Students should be able to correlate size with different properties materials can demonstrate such as absorption.
- ✓ Students should be able to explain why and how absorption of nano sized materials can cause side effects to human health.
- ✓ Students should be able to give examples of side effects caused to human beings and the environment by the absorption of nano sized materials
- ✓ Students should be able to give examples of ways through which humans could be protected from nano sized materials

Although the educational objectives of the interventions could be engaging all aspects of development and since the experimental group participated in a V*a*KE course, it would be essential to indicate that students' moral judgments are expected to be challenged during the V*a*KE course and be advanced to a higher stage of moral development. In particular, it is expected for students' individualistic moral judgments, to be decreased in comparison to the more global ones by the end of the interventions.

B.2.2 Design of the teaching learning sequence: the experimental group

B.2.2.1 The Nano-booklet

In line with the abovementioned acknowledgments and since firstly the equipment in Greek schools does not suffice the needs of educational practice and secondly literature on Nanotechnology is mostly in English, a booklet on the matter was constructed by the instructor providing all information which was likely to be needed during the interventions. Using this booklet students' options were narrowed concerning the research for new information, the use of insufficient computers was prevented and students' skills on searching for the needed information were scaffolded. The Nano-booklet was introduced to participants of the experimental group, while some units were also integrated in the control group's interventions.

The information provided in the Nano-booklet concerned the concept of size in the world generally and particularly the concept of "nano" size and scale. Then information about N-ST and their history were provided. The next units concerned properties which might be different in the nanoscale and applications in nature and technology. Attention was drawn on a specific application, the nano-coatings and further on the relation of health and nanotechnology. The case of health was also closely related to the concept of Nano-coatings. Finally, a word index was provided. At the end of each unit the literature used during the design of the booklet was provided and students were encouraged to check its validity or search for further information. Information about health protection was not provided in the booklet since the instructor chose it to be the concept where new knowledge would be applied. The Nano-booklet translated in English is included in the Appendix (see appendix 2).

B.2.2.2 Pre measurement

According to the research design pre-tests were administered to the students. Each student was assigned to a specific code during the procedure. In that way students were assured that no one could identify the person behind each test. Students had two hours at their disposal to complete two pre-tests: one with generative open questions about their former knowledge on the matter and a second one with closed questions concerning their epistemological beliefs (see unit B.3.). The procedure was the same for both the experimental and the control group.

B.2.2.3 First intervention for the experimental group

The first intervention lasted two hours and included the incorporation of the first five steps of a V*a*KE unit (see unit A.3.3.). During the first step, the dilemma was introduced to the students by the instructor who read the story although it was also provided to them in print. Then the instructor ascertained that both the dilemma story and the values at stake were understood.

"Bob and John are 12 years old and best friends. Bob is dreaming of becoming a scientist. When he does not know something he is interested in, he tries to find out as much information as possible through the internet.

Two years now though, things at home weren't that easy for John. His father has been unemployed. However, the last six months, John's father is working at the factory of Bob's father where they are producing paints and coatings. The salary at the factory is satisfying and the family is getting better financially. John's father told his family that these coatings manufactured at the factory are "magical". They are waterproof and self-cleaned while dropping off a few water drops. The coatings are being produced with nano-technology. Nano-technology will revolutionize the market and increase production. The factory's revenue will rise and the workers will be more wanted than ever.

However, John's father is experiencing, severe breathing problems along with some other co-workers for a month now. Every doctor they visited seemed unable to make a diagnosis and treat the workers. John is quite alarmed about his father's health and discusses the issue with his best friend. Bob immediately thought that although his father is working in the factory, he does not face any respiratory problems. However, Bob's father is the manager of the factory while John's father is a worker and according to John, he is not the only one facing health issues. Bob got stuck with the idea that something inside the factory caused the health issues to John's father and his co-workers.

As a matter of fact, Bob decided to do an internet research on the matter. He discovered that when the materials used in paints and coatings are crushed into nano size, other living organisms even from the environment can be easily absorbed by the human body, presenting unpredictable consequences. Bob believes that these nano-coatings are likely to be causing the health issues to John's father and his co-workers.

Bob, despite his research, hesitates to mention anything concerning this matter to John. Mostly, he is afraid that if the news spreads out at the factory and around the city (that these new nano-coatings could cause respiratory problems), a risk of the factory's closure could be poked. Then everyone could lose their jobs, his father included.

On the other hand, though, Bob thinks that if these nano-paints and nano-coatings are causing respiratory problems to John's father and his co-workers, he would be obliged to mention it to John in sake of his friendship with him.

What should Bob do?"

At the second step students raised their hands voting in favor or against the leading character's options. The instructor recorded the vote with students realizing that it was not unanimous. The results of the first argumentation are presented per class participating in the experimental group in Table 3. Although students' votes were not divided 50-50% and the dilemma was not as effective as one would expect the situation presented in the dilemma did not leave students completely indifferent (64-36%) as it would be in a case of 90-10% or more.

Table 3: The results of the first argumentation

1st Argumentation and related values	First vote			Total votes per argument
	Class 1	Class 2	Class 3	
Bob should tell what he learned to his friend (health, friendship)	13	13	2	28
Bob should not tell his friend what he found out (family, well-being/welfare)	5	4	3	12
Students who did not vote	1	1	2	4
Total votes per class	19	18	7	44

Further on, students were involved in an argumentation justifying their previous vote. However in order to avoid students' lack of confidence in expressing their personal opinion or avoid the domination of a few arguments, a card (see appendix 1) was provided to them. Each card had in advance a code inscribed referring to each student similarly to the pre measurement. The best option for the protagonist of the story according to their personal opinion was recorded and then justified with an argument. Finally, students had to identify the value suggested by their argument. After the card had been completed, it was handed in and the argumentation took place in class. The values emerged from the dilemma discussion are presented in Figure 4.

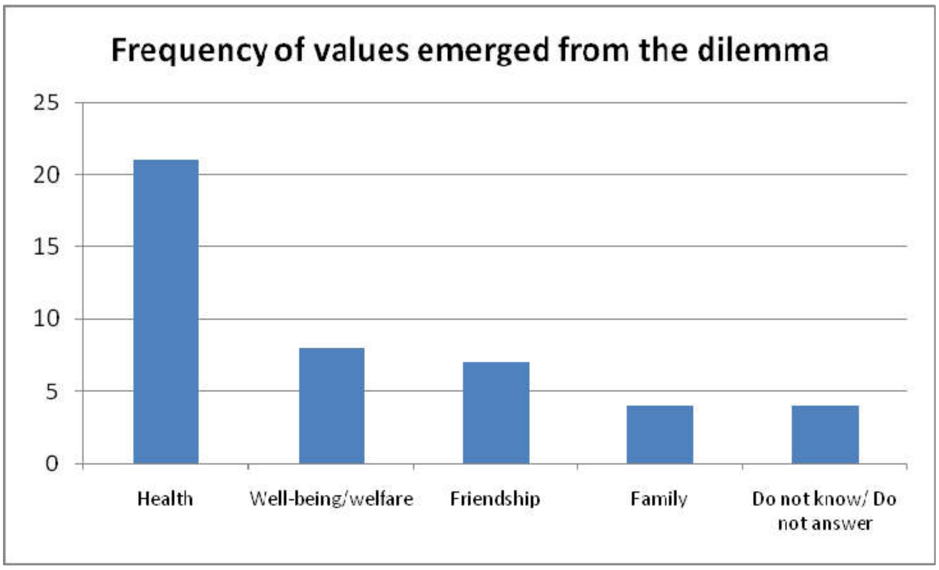

Figure 4: The values emerged from the first dilemma discussion

After the dilemma discussion the instructor facilitated the process by asking students whether they had as much information on the matter as Bob did and where they could search for this kind of information. The instructor started a discussion on the nature of knowledge, concerning its stability, its development, its source and justification as well as the nature of science, per se. The objective of this discussion was for students' epistemological beliefs to be challenged. At the end of the discussion it was also explicit that students had insufficient knowledge on the matter. The information suggested as needed concerned nano-coatings, what it would mean for a coating to be water proof and self-cleaned and which might be the side effects of nano-coatings in human health.

At the next step (step 5) of the V*a*KE approach students usually chose the subject of inquiry based on their personal interest and worked in groups to examine it. However, at the case of the current study and since other activities promoting conceptual change were also designed, all students were searching the same information simultaneously. The information suggested earlier by students was now classified starting from the concept of what nano meant in order to proceed to what nano-coatings were. Students formed groups and each group was provided with a Nano-booklet. The task was to find the relevant information concerning nano and read them. Groups were engaged in reading the first two chapters of the Nano-booklet (see appendix 2). The teacher facilitated group work when needed by asking questions with regard to the new information, like which is the size objects found in nature could exhibit.

Although at the previous step, students did not work on different aspects of the matter, a discussion along with an activity was initiated by the teacher so that students could capitalize on the new information. Peikos, Manou and Spyrtou (2014) introduced the different objects and sizes to sixth grade students according to the instrument one can use to observe these objects: Objects in the macro scale could be seen with the eyes while an optical microscope could be employed for micro sized items. Finally, nano sized materials could be perceived with the electron microscope. The activity followed was aiming at introducing these tools as a way for students to distinguish objects based on their size. Since students read in the Nano-booklet about the different sizes objects can have in the world they were asked to give examples of objects from the macro scale they could see around them which were either bigger or smaller than them. After that, they were asked to identify how man could observe these things, mentioning the eyes. Then they were asked to bring examples of objects and materials even smaller. In order to do so, it was indicated by the students that eyes did not suffice, so another instrument had to be used. Answering the question of what that tool might be students mentioned either magnifying glass or the microscope, referring at the same time to some examples of micro sized objects. As expected students mentioned examples of materials and objects categorized both in macro- and micro scale being unable, however, to distinguish between them with respect to the smallest amongst them.

At this point a set of pictures were presented to students accompanied with three questions, *(a) which were the objects depicted in the pictures*, *(b) how one could observe them*, *(c) which was their size*. In the beginning, the pictures depicted materials and items from the macro scale (see appendix 3). Students mentioned that in the Nano-booklet those objects that could be seen with the eyes were the *big* ones. The term *μεγάλο* (=big) was used by the students and was deliberately accepted instead of the word macro. However, as the pictures continued, the activity appeared to be more challenging since the objects depicted were from the unseen world. Although it was difficult to recognize at the beginning soon enough it was clear that the objects were the same with those of the macro scale (see appendix 3). However, students concluded that their appearance changed since they were unseen with the eyes and as a result no one could really know how they really seemed like. At this point students classified objects using the microscope while naming their size as *μικρό* (=small). Moreover a picture of an optical microscope (see appendix 3, image 17) was presented and the main features and functions were presented by the teacher since the emphasis was not on the instrument rather than on the ability to recognize and classify objects based on their size. Considering the fact that students lack experience with objects belonging to the spectrum of the unseen world a video was introduced in order to facilitate separation between objects of the micro scale and the nano scale (see appendix 4). During the video the teacher asked students the same questions while presenting the pictures. This video is an introduction to the nano scale allowing the viewer to identify objects not only from nano scale but macro and micro scale as well. After the end of the video the comparison between the red blood cell and the common virus was the most vibrant for the distinction between the micro and nano sized materials. A few more pictures were presented from the nano sized objects with students answering the same three questions stated earlier. Thus a picture of an electron microscope (see appendix 3, image 21) was presented and in line with the optical microscope, its main features, functions and differences with the previous type of microscope were mentioned.

A final activity generalizing the previous information was also administered. A picture (see appendix 3, image 22) depicting a scale of objects from the macro scale through the atomic scale as well as the instruments used for their observation was introduced. Also the introduction of the atomic scale pointed out that nano sized objects are not the tiniest objects existing. Students while working in groups had to prepare a poster with a similar scale and objects of their choice.

B.2.2.3.1 *Differences between subgroups and process concerning the experimental group*

Since educational praxis cannot always proceed as designed, depending on situation specific incidents teacher's operations were individualized according to the subgroups and individuals while procedure was not followed as designed. As a result differences between the groups of participants immerged and should be taken into consideration.

During the first dilemma discussion, students from the first subgroup of experimental participants had difficulties expressing their own opinion and at the second step of the V*a*KE unit, more popular and confident students affected other students' opinion with their vote and as a consequence it seemed like the students were not involved in the dilemma story. However, their argumentation cards revealed that this was not the case. Moreover, the fourth step of the V*a*KE procedure became time consuming since students thought that they already knew what nano-coatings were. However, the teacher through questions tried to reveal the contradiction that what students thought to be facts were actually only speculations. Due to time limitations the last activity where students were supposed to draw a scale with objects classified based on their size was not completed.

For the second subgroup since a preliminary discussion was not preceded students had difficulties to understand what the term "values" meant. Some clarifications and examples were provided by the instructor and then the procedure continued. At this group missing information was easily identified; however only girls participated in the procedure vividly. In addition, once again due to time limitations students did not have a chance to complete their posters with the scale of different sized objects.

The last subgroup of the experimental group the participants had also difficulties understanding what values meant but the instructor tried to provide them with the same clarifications and examples as in the previous group. In this case the whole procedure was completed as designed. It is also important to report that although students do not work in groups regularly they cooperated well enough and were provided with the least assistance from the instructor.

B.2.2.4 Second Intervention for the experimental group

The second intervention took place one week after the first one and as a result the dilemma story, the values at stake and the information needed had to be refreshed. In the beginning, some students reminded the class about the abovementioned information. Furthermore, an activity was introduced to recapitulate the scientific knowledge introduced so far: The teacher printed the pictures used in the previous lesson. In this case students were familiar with the objects depicted on the pictures and were asked to classify them according to their sizes. On the board the teacher had drawn a conceptual hierarchy representing three groups of sizes. Also a picture of the instrument used for their observation was placed near the suitable group (see appendix 5). Students placed all pictures under the correct group of sizes.

Since all the required new information was not acquired by the students during the last session, steps five and six of the prototypical V*a*KE unit were repeated. At this point students were interested in examining why the nano-coatings are waterproof and self-cleaning. In order to investigate that, students worked in groups and searched the Nano-booklet to find out the information (see appendix 2). They discovered that nano-coatings are mimicking the lotus leaf and as a consequence they read the information about the leaf of the lotus flower and its properties, well-known as the lotus effect. Besides the text, pictures were also provided. The teacher assisted students per group in order to help them comprehend the pictures. As soon as all groups had finished reading, a worksheet (see appendix 6) on the matter was provided to each student. During this procedure and after a group of activities was completed, the students exchanged their information and ideas. The first group of activities in the worksheet concerned the lotus leaf and its properties. In order to enhance understanding of the lotus effect besides the information provided from the Nano-booklet, a simulation (see appendix 7) of the lotus leaf and lotus effect was presented to students as well. Then they were asked to design an experiment using a few materials provided by the teacher, to make predictions and observations and then to reach a conclusion on the lotus effect. The next section of the worksheet concerned the nano-coatings. Students worked on the activities and in the end a video (see appendix 8) of such a nano-coating was presented.

B.2.2.4.1 Differences between subgroups and process concerning the experimental group

The first subgroup experienced difficulties in understanding how to design the lotus flower in the first activity of the worksheet. However, while they were reading the Nano-booklet, the fact that they could not comprehend the pictures and figures provided was of great importance. When this difficulty was made explicit the teacher asked questions to the working groups in order to guide them on the information that should be apprehended from the pictures. Furthermore, students had difficulties designing and planning the procedures involved in an experiment and referring to an example proved to be critical. Students did not manage to finish the whole worksheet and the part concerning the nano-coatings was left to be completed during the last intervention.

The second subgroup experienced difficulties in many levels during the intervention. Students were not familiar with working on worksheets and seemed unable to answer the questions. Furthermore, the instructor guided students as much as possible and consequently the inquiry resulted in being quite structured. Moreover, for this subgroup it was quite challenging to design and plan the experiment since they were incompetent to distinguish between the procedures involved in an experimental process. An example on designing and planning an experiment was provided, as did with the previous subgroup. Since students were also trying to self-regulate in a situation proven to be demanding, working in groups also seemed impossible. As a result, the rest of the worksheet was completed without the class working in groups. The teacher was asking questions out of the activities on the worksheet and students were answering and completing the activities on the worksheet. However, at some point and since the students were not participating actively, the regular teacher of the class interrupted the process and started teaching students traditionally. Finally, there was not enough time for students to see the video regarding nano-coatings.

On the contrary, the last subgroup encountered less difficulty, although once again designing and planning an experiment proved to be the most challenging activity. However, by the moment the example was provided, students were able to continue their work without any further difficulties. The procedure was completed according to the design.

B.2.2.5 Third intervention for the experimental group

After another week had passed between the lessons, the dilemma story, the values at stake and the required information had to be reminded once again; this was also the starting point of the final session. Students also indicated how the information they had already found was connected to the dilemma story. Once again step five of the V*a*KE method was repeated.

As an introductory activity students had to read a different advertisement of nano-coatings in groups and to write down on a “post-it” note arguments in favor of using nano-coating. During this time the teacher drew a conceptual map on the board (see appendix 9). The main idea (concept) of the map was the nano-coating and it was placed in the center. On the left students posted their arguments in favor of using nano-coatings. Each group posted its arguments while announcing them to the rest of the class.

Afterwards, students were asked which would be the last piece of information they would need to provide a solution to the dilemma. Side effects on human health were defined as the last piece of information needed. Students cooperated in groups for searching the information in the Nano-booklet. They read an article about a similar incident with the one described in the dilemma story as well as some summaries on side effects nano-particles can cause to the environment and the human health. The teacher pointed out at each group the picture (see appendix 2) depicting a nano-material inside human cells and eventually inside their nucleus. A conversation started in order for the students to exchange their opinions and reflect on the information. The teacher asked students whether they could recognize differences among the nano-materials in the cells. It was pointed out that the size of the nano-material was different indicating that the smaller the material was, the easier it seemed to penetrate the nucleus of the cell. Furthermore, it was argued that since it could penetrate the nucleus of the cell it could also cause different kinds of side effects. Therefore, students were asked to write arguments per group on “post-it” notes mentioning the side effects of using nano-coatings. By the end, each group posted their papers on the concept map announcing to their classmates what they had written about. At this point, step six of the method V*a*KE was completed.

A second dilemma discussion was initiated. Students voted once again in favor or against the options Bob had according to the story. Students' second vote is presented in Table 4. The values emerged from the dilemma and the difference between the first and the second dilemma discussion are presented in figure 5. Before the argumentation could take place the cards (see appendix 1) introduced at step 3 (see second intervention, this unit) were completed by the students for the second time.

Table 4: The second argumentation of students

2nd Argumentation and related values	**Second vote**			**Total votes per argument**
	Class 1	Class 2	Class 3	
Bob should tell what he learned to his friend (health, friendship)	14	13	4	31
Bob should not tell his friend what he found out (family, well-being/welfare)	5	4	1	10
Students who did not vote	0	1	2	3
Total votes per class	19	18	7	44

The second vote revealed slight difference in students' perspective taking since only four students changed their initial choice. A statistically significant association was found between students' first and second argumentation during the first and the second discussion (x^2=10,911, df=4, p<0.05)[4]. In particular, the majority of the students (70,5%) were in favor of a more global perspective, which was related to the values of health and friendship, in comparison to the minority of students (22,7%) who held on to a more individualistic perspective related to values of family and well-being/welfare. Only a few students (6,8%) did not answer during both discussions. Finally, the argumentation took place providing a solution to the problem. Although information regarding means of precaution was not acquired from the students, it was suggested as a solution that special masks and uniforms would be important for people working with nano-materials. Thus it was suggested that these means of precautions should be manufactured in a way that nano-materials would not be big enough to penetrate them. With this discussion step eight was fulfilled. According to the steps proposed for a V*a*KE unit step 9 was not fulfilled and step ten was succeeded with the general synthesis and presentation of the dilemma solution.

[4] Reporting results regarding the values dimension of V*a*KE at this point is deliberate since they are not directly related to the questions stated by the research. Consequently, they are being presented at the current part of the paper, namely the *Method* and will be discussed at section D, namely the *Discussion* section.

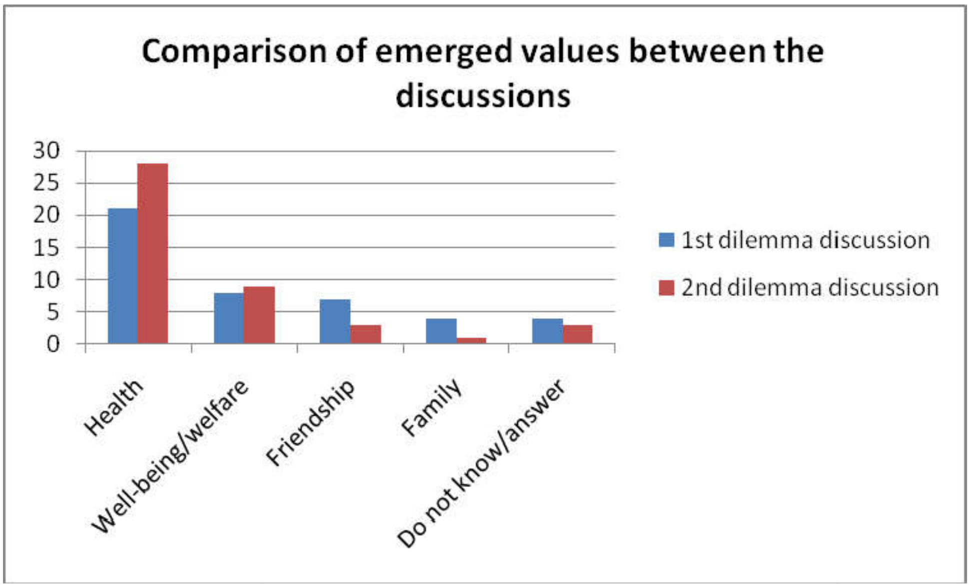

Figure 5: The emerged values from the second dilemma discussion are presented along with students' change in values choice

Students created posters in order to inform viewers about nano-coatings (see appendix 10). The posters presented many concepts either recommending and advertising for nano-coatings or warning against nano-coatings. Generalization is considered as the final step of the method. In this step the teacher introduced another similar case scenario. How would they react if they knew that a factory producing nano-coatings in the area provided working positions to a lot of people but was also disposing industrial waste in the city's river? Students suggested that they would inform the authorities of the side effects nano-materials could cause. Furthermore, they would demand for the factory to use special filters which would clear the disposals from harmful nano-materials before disposing their waste in the river as well as special uniforms and means of precautions for the workers. This precaution could protect the ecosystem from a potential environmental disaster along with the health of the staff working in the factory. It was obvious that students' moral judgments were more advanced in terms of knowledge and values as well.

B.2.2.5.1 Differences between subgroups and process concerning the experimental group

Concerning the first two subgroups of participants in the experimental group, the activities which were not completed during the second intervention were the starting points for the final intervention. During this last intervention for the experimental group, students worked on the activities of the worksheet concerning nano-coatings before proceeding to the design of the last content intervention as described already. Only issues regarding class management aroused this time but due to the fact that many activities were to be completed, time limitations resulted in the poster completion in another hour provided by the regular teacher.

This was also a solution provided by the teacher in the case of the third subgroup where due to the interesting second dilemma discussion there was not much time left to complete both steps 10 and 11 of the V*a*KE unit and subsequently step 11 was chosen to be completed instead.

Regarding the second experimental subgroup the final content intervention did not seem to motivate students and the teacher during the intermission pointed out that she did not approve this teaching approach and she had shared her opinion with the students. During the second dilemma discussion only a few students participated and even throughout the construction of posters (step 10: general synthesis) only particular students in each group, who seemed to be motivated the most, worked.

B.2.2.6 Post measurement

The posttests provided were inscribed with the personal students' codes. Two hours were provided since students had to complete three tests. The first test was the one with the knowledge generative questions; the second one concerned their personal epistemological beliefs while the final one accounted for students' motivation (see unit B.3.). The procedure was the same for both the experimental and the control group.

B.2.2.7 Follow-up measurement

The follow-up test was administered to students after an interval of three months. The questionnaire concerned students' knowledge acquisition on the matter of nanotechnology. Students had one hour at their disposal to complete it since it was the same test with the generative questions provided in both the pre and post measurement. The procedure followed was the same for both the experimental and the control group.

B.2.2.8 Group work and teachers' role in the procedure

During the interventions the students cooperated in smaller groups in many cases and activities. These working groups formed each time were not specific since in all cases teachers were changing students' seats weekly. Since it was not intended to disturb their learning environment, students in most cases cooperated with their classmates who were seated nearby in groups of four. Overall, the instructor facilitated the procedure and integration of V*a*KE by assigning the designed activities to the students. With regard to the available time, the teacher was strictly trying to ensure that both conceptual change activities (addressing the knowledge part) and moral discussions would be carried out. This created the perception that time was not enough while the designed activities were too many for each intervention.

B.2.3 Design of the teaching learning sequence: the control group

B.2.3.1 First intervention for the control group

Since the impact of V*a*KE as a teaching approach facilitating conceptual change is under discussion in the current study, the control group classes were taught with another equally challenging method which has many theoretical principles in common with V*a*KE but with a main difference as well. Inquiry based teaching does not address directly or explicitly values education unlike V*a*KE. As a result, a dilemma story was not introduced to the students; however, a starting question (Krajcik, 2001) was under discussion in almost every intervention. All interventions in both the experimental and control groups had a common pool of educational objectives particularly the cognitive ones (see unit B.2.1) and as a result the interventions concerning the control group are going to be in line with those already presented but with slight differences in the activities and the procedure.

The first intervention took place one week after the pretests' administration. Students were aware of the interventions' concepts since their teachers had already informed them despite their being suggested not to do so. The intervention began with a brainstorming aiming at concluding to the starting question. Students expressed their ideas about the word "nanotechnology". As it was expected, the word "nano" could not be defined or explained with more words than "small". Consequently, the starting question was written on the board and students referred to what nano could mean. Students were asked to work in pairs and find objects of any size around them. They presented these objects to the class and referred to them with regard to their size always keeping themselves as a constant to compare them with. Then they were asked to think what these items shared in common since they could either be bigger or smaller than themselves and whether other even smaller objects existed in the world. It was indicated that smaller materials exist but they could not be seen with the naked eye.

At this point according to Peikos, Manou and Spyrtou (2014) introductory activity of size, students were asked to work in pairs and find items which could not be seen with the naked eye. To do so the teacher provided them with magnifying glasses as well as mobile devices (mobile phones and tablets) enhanced with microscope applications. Only a few items were found by the end of the activity and a discussion was initiated aiming at classifying all objects found in two main groups. Firstly, a group of objects which could be seen with the naked eye and another one which could be seen with a microscope were identified. Secondly, these groups were named according to their sizes as μεγάλα (= big) items or μικρά (= small) items.

Afterwards the set of pictures with the different sized items which were displayed to the experimental group was introduced here as well (see appendix 3). Students had to answer the same questions for each picture, *(a) which were the objects depicted in the pictures*, *(b) how one could observe them*, *(c) which was their size*. After macro- and micro- scale items were presented, the picture of the optical microscope (see appendix 3, image 17) was also presented by the teacher along with its basic features and functions.

After that, students suggested that as an instrument, optical microscope has limitations. As a consequence, a better microscope would be needed in order to see even smaller items or even atoms. The video "what nano means" (see appendix 4) was also introduced in order for students to understand the different sizes micro and nano objects could have. During the video students were asked to answer the previous set of questions with regard to the size of the objects and how they could be seen. In this way it was identified that students could categorize objects using their means of observation as a criterion. Next the pictures of the nano sized objects were presented as well as a picture of the electron microscope. In line with the optical microscope, its main features, functions and differences with the previous type of microscope were mentioned.

Finally, an activity generalizing the previous information was administered. A picture (see appendix 3, image 22) depicting a scale of objects from the macro scale through the atomic scale as well as the instruments used for their observation was presented. Students while working in groups this time had to prepare a poster with a similar scale and objects of their choice.

B.2.3.1.1 Differences between subgroups and process concerning the control group

In both control subgroups, participants were asking far more questions which in a few cases were not closely related to the content of the intervention. However, it seemed like their interest was sparkled due to the fact that they would search information concerning nanotechnology. The final activity where students were supposed to draw a scale with objects classified according to their size was not completed.

B.2.3.2 Second Intervention for the control group

A week later the second intervention took place. The starting point was the activity where students had to classify objects according to their size and instruments used for their observation. The activity occurred in exactly the same way as in the experimental group. The teacher had drawn a conceptual hierarchy on the board and each student had to classify at least one object (see appendix 5).

Next, students formed groups and a worksheet (see appendix 11) was handed out to each one in order to investigate a technological application of nanotechnology. This time the worksheet was slightly changed from the one employed in the experimental group, since the Nano-booklet was not provided to the students in order to search for information. At the beginning students had to observe two pictures and then explain the differences between them. The pictures depicted two wet leaves where in the first case the droplets were like spheres but in the other case they were not. Then some materials were provided to the students who had to make them wet and observe how the water droplets would look like. Afterwards these materials were classified in two groups according to the shape of the water droplets. The next activity required from students was to design an experiment in order to investigate which of the objects used during the previous experiment could be cleaned more easily. The steps of the experiment had to be described and observations were made. Then a few pictures provided also in the Nano-booklet, were included in the worksheet so that students could visualize how the structure some leaves display in the nanoscale, is responsible for the round water droplets observed in their experiment. The lotus effect was also presented in the pictures. As in the experimental group, the teacher was facilitating the group work when needed. Also attention was brought to the pictures presenting the lotus effect which were assisted by the presentation of the simulation of the lotus leaf (see appendix 7). Then students described the structure of the lotus leaf along with the lotus effect according to the activities in the worksheet. Finally, they were asked to write a conclusion on why some of the materials used during the experiment displayed the same properties as the lotus leaf.

A set of activities concerning a technological application mimicking the lotus effect, namely the nano-coatings, were next in line. At the beginning of these activities students predicted with a draw, how a surface on which nano-coating had been applied would look like. Then a picture was provided comparing a surface with a regular coating and a surface with a nano-coating. Students had to explain the differences and then draw a picture in order to explain what would happen if a dirty nano-coated surface became wet. Finally a video introducing the benefits of a nano-coating was presented to the students (see appendix 8).

B.2.3.2.1 Differences between subgroups and process concerning the control group

Students in the control classes, while working on the provided worksheet, had different pace since some groups were more efficient with the least provided guidance while others needed more time and assistance. That resulted in different levels of completed activities on the worksheet between the groups. The teacher decided it would be better if all students were engaged in the same activities and eventually the worksheet was not completed. Only the first part regarding the lotus effect was carried out successfully.

B.2.3.3 Third intervention for the control group

The final content related intervention occurred after the interval of three days. The content of the last intervention was reminded to the students through a conversation initiated by the teacher. The discussion concluded to the question, whether nano-coatings should be used or not. In order to examine the first part of the question advertisements of some nano-coatings were handed out to the students. Students formed groups and each group had to think of an argument in favor of using nano-coating and then write it down on a “post-it” note. Later the arguments were presented in class and posted on the board. A conceptual map was constructed by the teacher as presented in appendix 9. The advertisements provided to the students were the same included in the Nano-booklet.

After working with the advertisements it was clarified that nano-coatings can be useful. The second part of the question was examined through a newspaper article about health related issues speculated to be caused during the manufacture of nano-coatings to some workers (see appendix 2).The same article had also been provided to the experimental group. Students collaborated in order to read and comprehend the article. Furthermore at each group a picture (see appendix 2) and a list of other side effects of nano-coatings were also provided. The image depicted a nano-particle of a nano-sized material (carbon nano tube) inside human cells and eventually inside the nucleus of the cells. A conversation started in class in order for students to exchange their opinions and reflect on the information. The teacher asked students to reflect and think how the article and all side effects presented could be related to the picture. It was pointed out that the size of the nano-material was different indicating that the smaller the material was, the easier it appeared to penetrate the nucleus of the cell. Furthermore, it was argued that since it can penetrate the nucleus of the cell it could also generate different kind of side effects. Students suggested a few side effects nano-coatings could induce and wrote them on “post-it” notes. Each group announced arguments and posted them on the board so that the concept map could be completed. Then, according to the conceptual map, students could decide if one could use or not nano-coatings. Finally, the teacher asked students if they could indicate ways humans could be protected from nano-materials. Suggestions concerned special uniforms, masks and gloves which would prevent nano-particles from invading the human body and penetrating cells inducing a series of negative side effects.

B.2.3.3.1 Differences between subgroups and process concerning the control group

Finally, in both control subgroups the final content intervention was carried out although there were time constraints. However, in the first class on account of limited time there was no chance for students to be involved in the discussion concerning protection measurements from the nano-particles.

B.2.3.4 Group work and teachers’ role in the procedure

Students in the control classes also worked in groups of four. These groups where not specific and their synthesis depended on the way the teacher had chosen for the students to be seated during regular classes. During the last intervention participants in one of the two classes chose to work in pairs rather than groups of four students, which however is still accounted as a form of group work (Slavin, 2010). Regarding the teachers’ role in the procedure, she was less time concerned since in comparison to the experimental group, fewer activities were designed because values were not addressed and students had the chance to work more with each designed activity.

It is crucial for the reader to make a clear distinction about the content of the interventions between the experimental and the control group, since the differences are constitutive for the independent variable. Table 5 presents the communalities and differences between the interventions.

Table 5: Communalities and differences between the interventions designed for both the experimental and the control group.

	Communalities	Differences	
		Experimental	Control
First intervention	• knowledge addressed: size and scale • activities: observation of the world around, images, movie about nano	• activities: oral description of microscope and electron microscope from the instructor based on the provided images • explicit epistemological discussion	• activities: video about microscope and electron microscope • no explicit epistemological discussion
Second intervention	• knowledge addressed: hydrophobicity • activities: conceptual hierarchy, working sheet, simulation on lotus effect, nano-coating video		
Third intervention	• knowledge ad-dressed: absorp-tion • activities: argu-mentation with advantages and disadvantages from nano-coatings usage, provision of solution to the problem	• Provision of a solution to the problem emerged from the dilemma story • Students made a poster by the end of the intervention	• Provision of a solution to the problem emerged from the question stated at the beginning of the intervention • No poster

Overall		• Use of the Nano-booklet • Teacher' s role: strict with regard to the available time and designed activities (since in the time provided both values and knowledge had to be addressed)	• Material from the Nano-booklet was provided separately and individually when needed • Teacher's role: more moderate with respect to the available time for the fulfillment of the designed activities (since only knowledge had to be ad-dressed)

B.3 Measures

B.3.1 Generative questionnaire

To examine conceptual understanding in the concept of Nanotechnology a questionnaire was constructed and two kinds of questions were used: factual and generative open ended questions.

As described already (see unit A.2.2.4.)generative questions provide information on children's underlying conceptual structures while factual questions provide information with regard to children's exposure to scientific facts rather than on their ability to use these facts in a generative way. Consider the question "What is the shape of the earth?" Students instructed on the matter are most likely to answer this question by repeating the scientific fact they have received in comparison to the answer they would provide in a generative question such as "If you were to walk for many days in a straight line, where would you end up?" (Vosniadou & Brewer, 1992).

In the first part of the questionnaire participants were denoting their sex along with their birth date and the current date the questionnaire was completed. The questionnaire consisted of totally 18 open ended questions, addressing students' misconceptions with respect to the Big Ideas of Nanoscience and Engineering, size and scale, size related properties(hydrophobicity and absorption). The questionnaire was administered in Greek language (see appendix 12 for a version translated in English).

- The first three questions referred to size related properties of nano-materials and in particular to gold's property to change color as it becomes smaller.

- The next set of five questions concern the lotus effect and especially the shape a liquid droplet might present while touching different kind of surfaces as well as the property of self-cleanliness.
- The next three questions are related to size and instruments used to observe objects according to their size.
- Another set of three questions concerning the lotus effect are included adjusted this time in the concept of coatings.
- Finally, the last five questions concern size and size related properties like absorption. However, the matter of absorption is not straightly suggested through the questions which rather stimulate students' generative thinking.

The questionnaire was administered three times as pre, post and follow-up measures in a period of four months. Each student was assigned to a code during the research which was inscribed on the tests in advance.

Students' answers were classified as correct/scientific (3) if they were in accordance with the scientific view, as initial/intuitive (1) if they were in accordance to a naïve theory of physics and as alternative (2) if they were in accordance with synthetic models, namely the incorporation of the scientific information to their incompatible prior knowledge (Skopeliti, 2011). The questions, which were not answered either because students did not know the answer or because they did not want to provide an answer were classified as irrelevant (0). In this category irrelevant answers were also included. Criteria were established and two coders coded the data. The established criteria are described in detail in Table6 (see appendix 13). The criteria were defined taking into account not only the physics behind N-ST but the theory of conceptual change as well. The first coder had knowledge in both fields of nanotechnology and conceptual change while the second coder was a cognitive psychologist classifying the answers in accordance to the established criteria. For the interrater agreement Krippendorff's alpha coefficient, namely Kalpha (Krippendorff, 1970; 2004) was applied. The Kalpha coefficient can be used regardless the number of observers, levels of measurement, sample sizes and presence of missing data (Hayes & Krippendorff, 2007). The interrater agreement for all items and measurements was between .82 and 1. As a result the interrater agreement was considered extremely high and the data coding was reliable. After discussion, coders reached full agreement for all items and measurements of the questionnaire. In the following table (Table 6) the coefficients per item are provided.

Table 6: The Kalpha coefficient provided per item and measurement

#	Item	Pre measurement	Post measurement	Follow-up measurement
1	If we cut bulk gold in smaller pieces which we can still be able to see with our eyes, what is their colour going to be? Why is that?	1	.98	.90

2	If we cut the previous pieces in even smaller pieces will they keep the same color? Why?	1	.96	.88
3	Do Materials keep the same color no matter how small we cut them? Why is that?	.85	.83	.82
4	We are in the country side and we want to make a salad. But we must choose between cabbage and lettuce since we do not have much water in our disposal. Which one will be better cleaned? The cabbage, the lettuce or will both be cleaned better? Why?	1	.88	.98
5	If I spill a drop of water on a smooth piece of glass and on an absorbent piece of cloth, will the shape of the water droplet be in both cases the same? Why is that?	.82	.94	.88
6	If I spill a drop of water on a cabbage leaf and on a lettuce leaf, will the shape of the water droplet be the same? Why?	1	.97	.96
7	If I spill a drop of water on a cabbage leaf and on a broccoli leaf, will the shape of the water droplet still be the same? Why is that?	.92	.92	.96
8	John went to visit his father at work. His father showed him a microscope and John felt excited. He wanted to see how the smallest object on earth would look like under the microscope. However, his father showed him an onion cell telling him that this is the smallest object he could see with this microscope. Which is the size of an onion cell so that his father could take it and place it under the microscope? How was it was possible for him to see it?	.90	.95	.96
9	Is the onion cell the smallest object on earth? Are there even smaller items on earth? How would they be like? How are they called?	.97	.95	.85
10	If the smallest object John could see under his father’s microscope was an onion cell, then how those objects which are even smaller could be seen?	.95	1	.89
11	I apply a coating on a wall and on the iron railings of the porch. However, the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall or the iron railings? Why?	.82	.89	.87
12	I apply a coating on a wall and a special coating on the iron railings of the porch. However, the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall or the iron railings? Why?	.98	.95	.82

13	I apply the special coating on both the wall and the iron railings of the porch. However, the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall, the iron railings or maybe both surfaces will clean the same? Why?	1	.93	.95
14	Imagine you have gone fishing to a lake. You have forgotten to take water with you and there is no drinking water around you. You can find water only in the lake. Would you drink water from the lake, yes or no? Why would you or would not you do so?	.94	.88	.98
15	Could you drink the water if you clean it first?	.90	.86	.86
16	How could you clean the water?	1	1	.83
17	When are you going to be sure that the water is completely clean and you can drink it without getting sick?	.95	.95	.89
18	John says that there is a special filter which can clean water even from bacteria. Is this possible? What kind of filter is that? How is this happening?	.96	.97	.90

B.3.2 Intrinsic motivation inventory (IMI)

The Intrinsic Motivation Inventory (IMI) is a multidimensional measurement device intended to assess participants' subjective experience related to a target activity (Ryan, 1982; Ryan, Mims & Koestner, 1983; Plant & Ryan, 1985). In the present study the instruction provided to students in both groups with regard to the "target activity" was to take into consideration the experimental activities which took place during the nanotechnology courses.

The instrument assesses participants' intrinsic motivational aspects such as interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure and tension, and perceived choice while engaging in a given activity. Recently another subscale was added concerning the feeling of relatedness to the activities but the validity of this subscale needs to be established. Although the instrument is called intrinsic motivation inventory only the sub scale of interest/enjoyment (7 items) assesses intrinsic motivation, per se. Subscales concerning perceived competence (6 items) and perceived choice (7 items) are suggested to be positive predictors of self-report and behavioural measures of intrinsic motivation. On the other hand, pressure/tension (5) is theorized to be a negative predictor of intrinsic motivation. Moreover, effort/importance (5) is a separate variable relevant to some motivation questions while value/usefulness (7) has been used in internalization studies (e.g. Deci et al., 1994). Finally, the subscale of relatedness (6) is used in studies having to do with interpersonal interactions, friendship formation, and so on. A seven-point Likert scale is used by the questionnaire (from 1 = not at all true to7 = very true).

The items within subscales were randomly ordered in the questionnaire while some questions were reversed. The instrument was provided in Greek language, adopted from Loukomies et al (2013) who first implemented the Greek version of the questionnaire. All questionnaires were inscribed with the students' code in advance and they were completed once by the participants in a two-hour intervention where all post measurement instruments were completed.

Originally all subscales of the IMI were included in the questionnaire; however, the subscales of relatedness and effort/importance were excluded by the analysis since they are not directly related to motivation which was one of the objectives to be investigated in this study. Moreover, the inclusion or exclusion of specific subscales appears to have no impact on the others. Cronbach's alpha coefficient was used for the reliability of the instrument and found to be acceptable (Table 7).

Table 7: Cronbach's alpha per subscale of the Intrinsic Motivation Inventory (IMI)

Subscale	Cronbach's alpha
Interest/enjoyment (1)	.77
Perceived competence (2)	.79
Pressure/tension (3)	.60
Perceived choice (4)	.76
Value/usefulness (5)	.80

Item example in each subscale: (1) I enjoy the activity very much, (2) I think I am very good at the activity, (3) I was anxious while working on the activity, (4) I felt like it was not my own choice to do the activity (R), (5) I believe the activity has some value for me.

B.3.3 Epistemological beliefs questionnaire

Epistemological beliefs were measured regarding science along four dimensions proposed by Hofer and Pintrich (1997) with a 20-item scale of Conley et al. (2004) questionnaire. The questionnaire was introduced in Greek version adopted by Pnevmatikos and Papakanakis (2009). The questionnaire can be applied to different subject domains because all the items contain a general form (e.g. 'this field', 'this subject'). The frame of reference was given by asking the students to bear the particular discipline of physics in mind when responding.

The dimensions of epistemological beliefs measured in the questionnaire were source (4 items) and justification (5 items) constructing the dimension of nature of knowing, while stability (5 items) and development (6 items) constructing the dimension of nature of knowledge. Particularly, nature of knowing refers to the procedure of knowing while the nature of knowledge refers to the nature of knowledge per se. Items were rated on a 5-point Likert scale (1= strongly disagree; 5 strongly agree); items regarding source and stability were reversed in order to denote more sophisticated, epistemological beliefs. Less sophisticated answers regarding the epistemological dimension of source view knowledge as external to the self, originating and residing in outside authorities while less sophisticated answers concerning the epistemological dimension of stability reflect beliefs in one right answer (Conley et al., 2004). In addition, items within subscales were randomly ordered in the questionnaire.

Cronbach's alpha revealed poor reliability (Table 8) which, however, is still acceptable taking under into previous findings (Conley et al., 2004).

Table 8: Cronbach's alpha on the personal epistemological beliefs in science

Epistemologicalbeliefs	Pre measurement	Post measurement
Source (1)	.51	.69
Justification (2)	.52	.55
Stability (3)	.44	.61
Development (4)	.64	.64

Items examples per subscale: (1)Everybody has to believe what scientists say; (2) In science, there can be more than one way for scientists to test their ideas; (3) Scientists pretty much know everything about science; there is not much more to know; (4) Ideas in science sometimes change.

B.3.4 Raven test

In order to test our last hypothesis concerning those students who would benefit the most participating in the V*a*KE process, Raven's test (1936) of non-verbal intelligence was administered to participants. Raven progressive matrices are 60 multiple choice questions where a piece is missing from the given diagram or design. Raven's test has been standardized across different ages and nationalities (Raven, 2000).

Each participant was examined individually in a separate room; a laptop was used for this measurement while the researcher remained in the room with the participant and assisted him or her if necessary. Instructions appeared on the laptop screen and then the task was presented. The current computerized version of Raven's test consisted of 36 items and the examination lasted approximately four to five minutes depending on the participant.

C Results

C.1 Conceptual change findings

At this part of the study results concerning conceptual change will be presented. These results address the first research question, namely whether V*a*KE can foster the same levels of conceptual change compared to an inquiry based teaching. To address the first research question multiple repeated measures ANOVAs were conducted using time (pre-post-follow-up measurement) as the within-subjects factor and group (experimental and control) as the between-subjects factor for each question of the questionnaire. The means and standard deviations of students' conceptual change in each question of the generative questionnaire per group are presented aggregated in Table 12 (see Appendix 14).

With regard to the first question about gold's properties to change color depending on its size, repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean conceptual change differed significantly for time ($F_{(1.692,\ 133.699)}$ = 14.411, p< 0.1, η_p^2= .154). Pairwise comparisons using the Bonferroni correction (Figure 6) revealed that conceptual understanding from pre measurement to post measurement (mean difference .312, std error .065) as well as from the pre to the follow-up measurement (mean difference .305, std error .053)were significantly (p<0.1) increased. However, no statistical significance (p= 1.000) was found between post and follow-up measurement (mean difference .007 & std error .078). Group as a between-subjects factor did not reveal statistical significance ($F_{(1.692,\ 133.699)}$ = 1.163, p> 0.1, η_p^2= .015) indicating that students, regardless the intervention they attended, were benefited the same in terms of conceptual change.

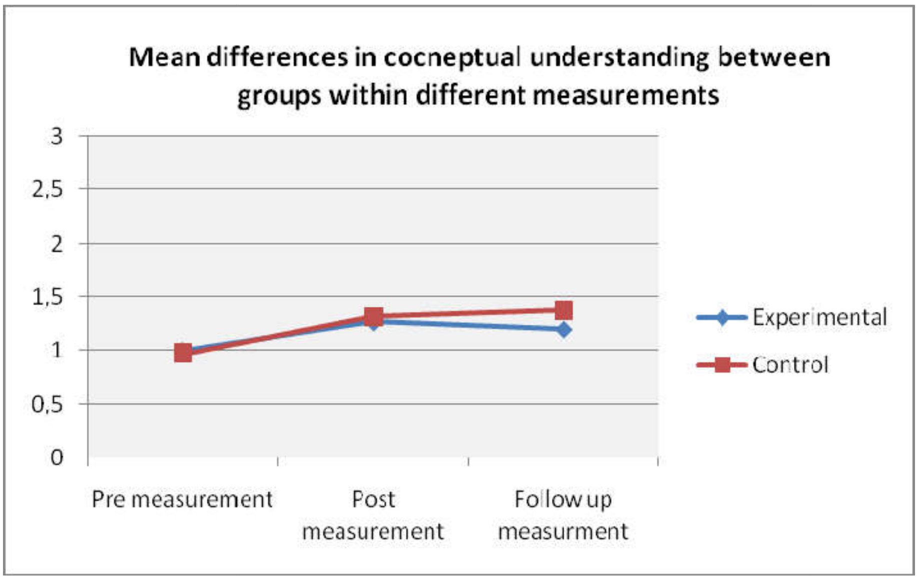

Figure 6: Conceptual understanding for Question 1 and the color of the small pieces of gold.

The second question examined once again gold properties to change color depending size however the size implied was different. Once again repeated measures ANOVA with a Greenhouse-Greisser correction indicated statistical significance among different measurements ($F_{(1.803,\ 142.451)}$ =14.917, p< 0.1, η_p^2= .159). Pairwise comparisons with Bonferroni adjustment (Figure 7) revealed statistical significance (p<0.1) between pre and post measurement (mean difference .249, std error .074) as well as pre and follow-up (mean difference .389, std error .060). No statistical significance (p> 0.1) was revealed for the between subjects factor of group ($F_{(1.803,\ 142.451)}$ =.504, p> 0.1, η_p^2= .006).

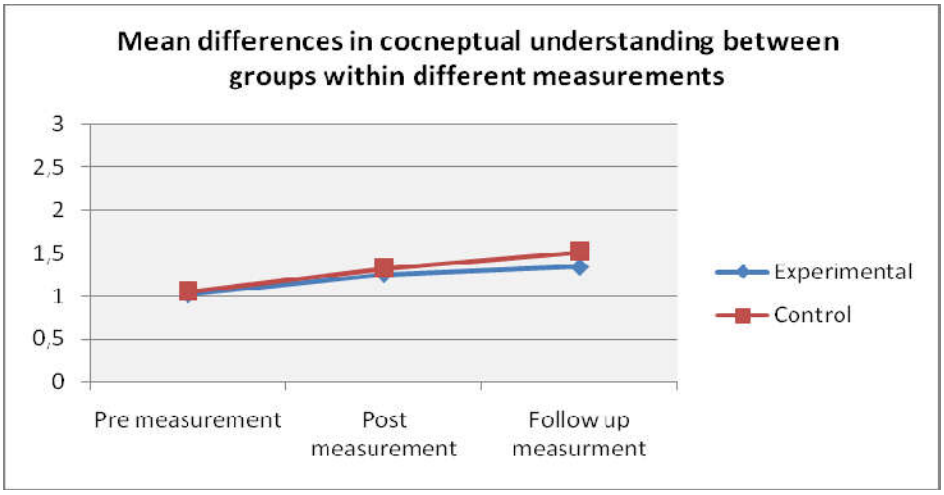

Figure 7: Mean differences in conceptual understanding for Question 2 regarding the size depended property of gold to change color.

The next question examined whether students applied gold's properties to change color regarding to its size, on every material. Repeated measures ANOVA revealed statistical significance ($F_{(2,158)}$ = 11.481, p<0.1, η_p^2 = .127) of different time of measurement with regard to the current question. Moreover, pairwise comparisons with Bonferroni correction (Figure 8) revealed statistical significance (p< 0.1) between pre and follow-up measurement (mean difference .423, std error .85), as well as between post and follow-up measurement (mean difference .213, std error .086) where a statistical significance (p< 0.1) was revealed. Statistical significance was not revealed (p> 0.1) between pre and post measurement (mean difference .210, std error .093). Both approaches benefited students at the same level($F_{(2,158)}$ = .099, p> 0.1, η_p^2 = .001) with respect to the within subject factor of group.

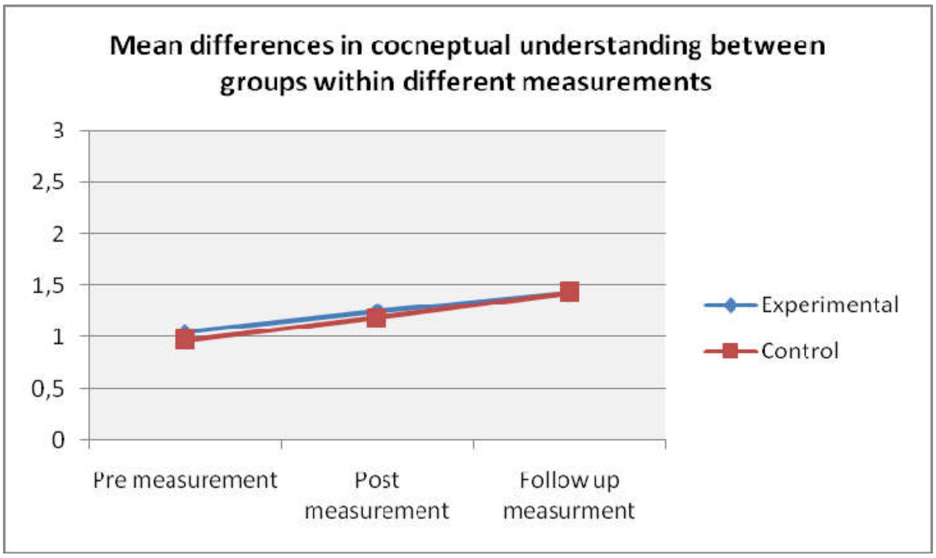

Figure 8: Mean differences in conceptual understanding regarding Question 3 and the property of materials in general to change their color with respect to their size

Later on, the lotus effect is investigated with multiple questions. With respect to the first question where the cabbage and the lettuce are being examined for their ability to be easily cleaned a significant effect of time on conceptual change was found ($F_{(2,\ 158)}$ = 46,327, p<0.1, η_p^2= .370). Pairwise comparisons with Bonferroni correction (Figure 9) revealed a statistically significant increase (p<0.1) between pre and post measurements (mean difference .758, std error .089) as well as (p<0.1) between pre and follow-up measurements (mean difference .602, std error .079). Nevertheless the between-subjects factor of group was not found as statistically significant ($F_{(2,\ 158)}$ = .563, p>0.1, η_p^2= .007).

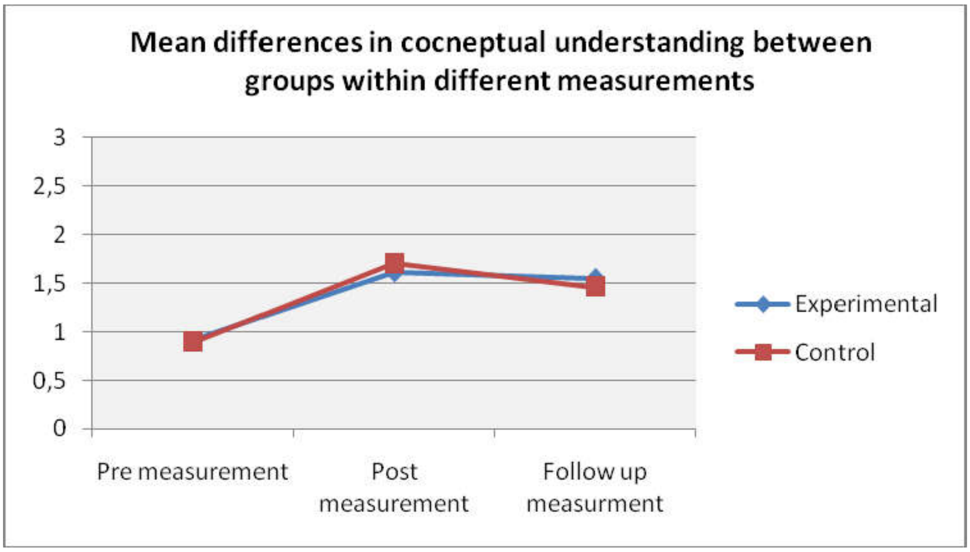

Figure 9: Mean differences in conceptual understanding for Question 4, examining the ability of two vegetables, namely the cabbage and the lettuce to clean easily with water

Concerning the second question on the lotus effect examining the shape of a water droplet in two different hydrophilic materials, repeated measures ANOVA revealed the within-subjects factor of time statistically significant ($F_{(2, 158)}$ = 38,085, p<0.1, η_p^2= .325). Pairwise comparisons with Bonferroni correction (Figure 10) revealed statistical significance between all different measurements. In particular, statistical significance was found (p<0.1) between pre and post measurement with conceptual change being increased (mean difference .428, std error .074). Moreover, significance (p<0.1) was indicated from pre to follow-up measurement (p<0.1) where once again students' naïve theories appeared to be reduced (mean difference .593, std error .071). Finally, statistical significance was found between post and follow-up measurement (p<0.1) indicating that conceptual understanding was more sophisticated with time. Regarding this question the between-subjects factor of group was not found significant ($F_{(1,79)}$ = 1.276, p>0.1, η_p^2= .016) indicating that the method was not important for students' conceptual understanding.

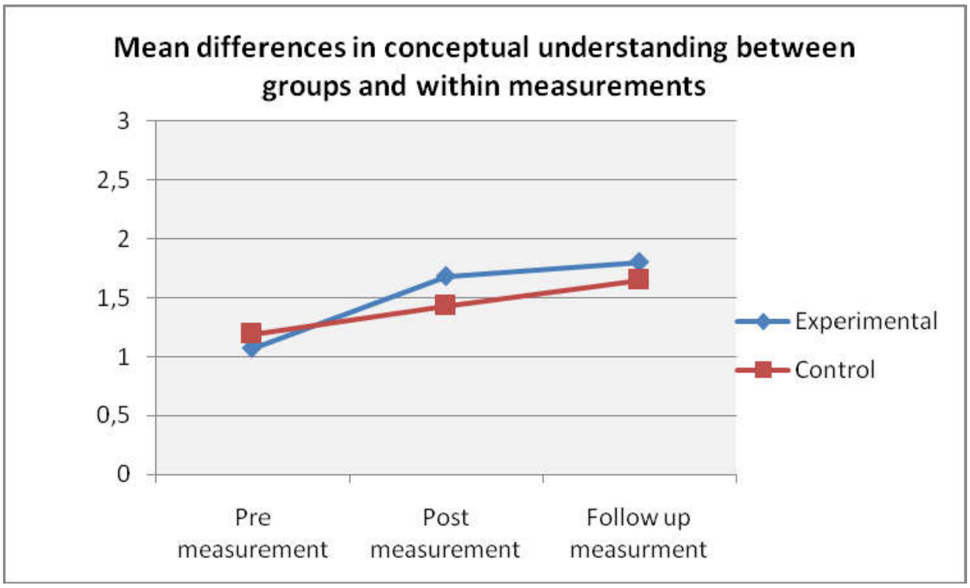

Figure 10: Conceptual understanding regarding Question 5 and the shape of a water droplet in two different hydrophilic materials

Next on the generative questionnaire were two questions comparing the surface of some vegetables on whether they demonstrate the lotus effect or not. Concerning the first question where one hydrophobic and one hydrophilic surface were examined time proved statistically significant ($F_{(2,158)}$ =25.479, p<0.1, η_p^2= .244) and particularly pairwise comparisons with Bonferroni corrections revealed significance between pre and post measurement (p<0.1, mean difference .608, std error .088) as well as between pre and follow-up measurement (p<0.1, mean difference .419, std error .081). No statistical significance (p>0.1) was found between post and follow-up measurement although conceptual understanding was reduced (mean difference .190, std error .092). Furthermore, no statistical significance was indicated for the group factor on different times of measurements ($F_{(2,158)}$ = .204, p> 0.1, η_p^2= .003) (Figure 11).

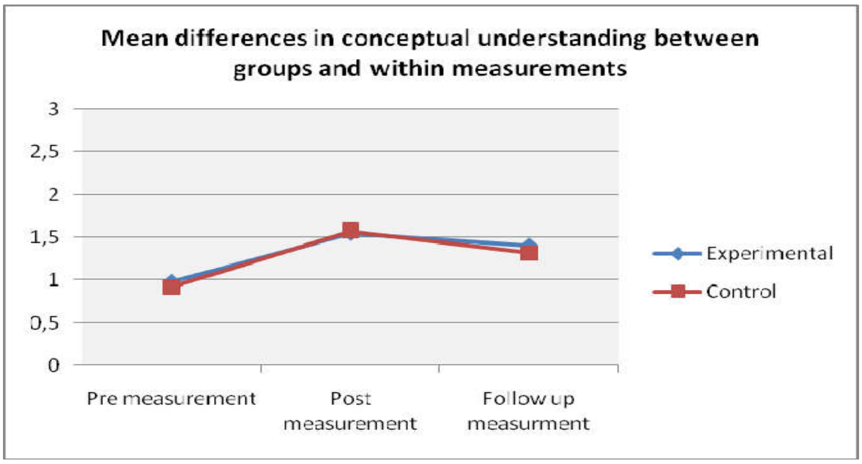

Figure 11: Mean differences in conceptual understanding regarding Question 6 and the property of hydrophobicity

The second question examined the property of hydrophobicity on two hydrophobic surfaces revealed once again a time significant effect ($F_{(2,158)}$ = 32.025, p<0.1, η_p^2= .288) with post hoc tests of Bonferroni adjustments yielding significance between pre and post (p<0.1, mean difference .683, std error .095) measurement as well as pre and follow-up measurement (p<0.1, mean difference .543, std error .092). No statistical significance was found between post and follow-up measurement (p> 0.1, mean difference .140, std error .083) (Figure 12). The between subjects factor of group ($F_{(1,79)}$=.180, p>0.1, η_p^2=.002) was not significant.

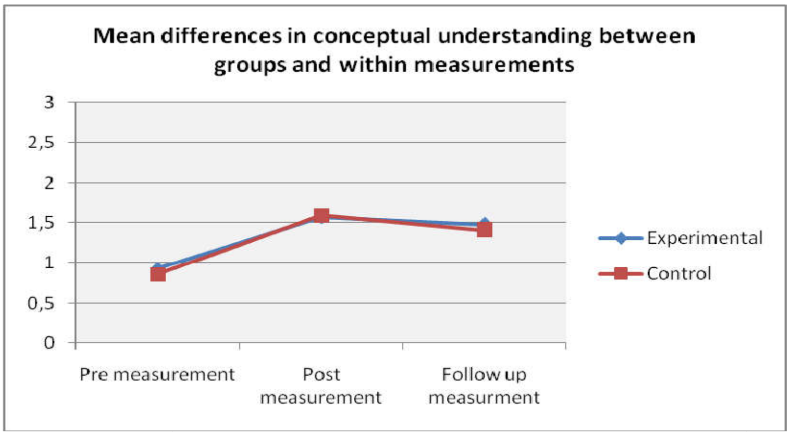

Figure 12: Conceptual understanding regarding Question 7 and the lotus effect on two hydrophobic surfaces

The next set of questions concern the different sizes of matter. According to the repeated measures ANOVA performed for the first question namely the size of an onion cell and the instrument used for its examination, statistical significance was found for time on students' conceptual change ($F_{(2,158)}$ =8.292, p<0.1, η_p^2= .095). In particular, pairwise comparisons with Bonferroni corrections revealed statistical significance between pre and post (p<0.005, mean difference .404, std error .107) measurement as well as between pre and follow-up measurement (p<0.1, mean difference .299, std error .101) (Figure 13). However, no statistical significance was found between post and follow-up measurement (*p*>0.1, mean difference .105, std error .101). Group as a between-subjects factor did not make any difference and as a consequence participants were benefited the same ($F_{(2,158)}$ = 3.418, *p*<0.1, η_p^2= .041).

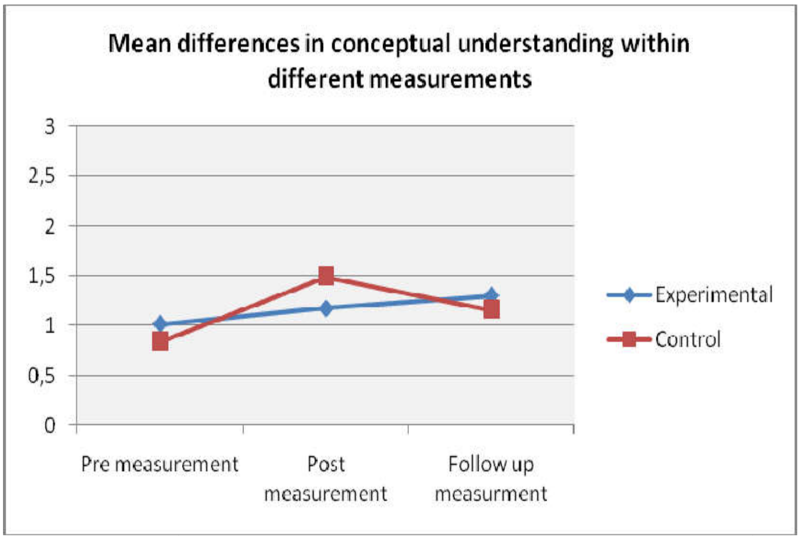

Figure 13: Conceptual understanding within different measurements with respect to Question 8 which examined the size of an onion cell and the instrument used for its examination

The next question concerned the concept of size and different scales. Repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean conceptual change differed statistically significantly among different measurements ($F_{(1.842, 145.505)}$ = 20.661, *p*< 0.1, η_p^2= .257). Pairwise comparisons with Bonferroni corrections revealed statistical significance not only between pre and post measurement (*p*<0.1, mean difference .861, std error .150) but between pre and follow-up measurement with considerable increase in conceptual understanding (*p*<0.1, mean difference .823, std error .123). However, the difference between post and follow-up measurement (*p*>0.1, mean difference .038, std error .120) was found not to be significant. Group as the between-subjects factor revealed statistical significance ($F_{(1, 79)}$ =9.015, *p*<0.1, η_p^2=.102) indicating that the intervention students attended did not benefit the same in terms of conceptual change (Figure 14). In particular, pairwise comparisons with Bonferroni corrections revealed statistical significance (*p*<0.1) with the experimental group being benefited the most (mean difference .417, std error .139).

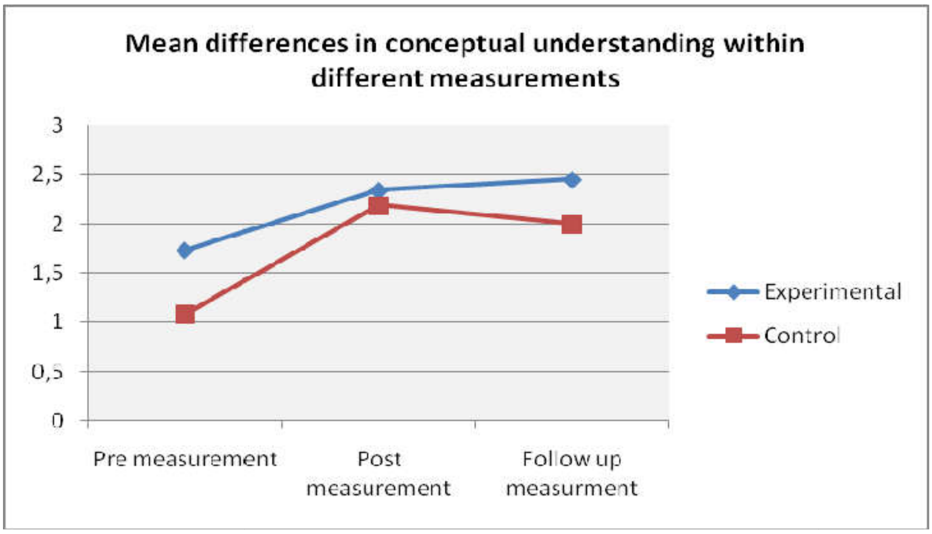

Figure 14: Conceptual understanding on Question 9 and students' ability to discriminate between scales and sizes of different objects

Repeated measures ANOVA corrected with Greenhouse-Geisser on the final question concerning the instrumentation used to examine objects of the smallest scale revealed statistical significance once again in time factor over students' conceptual change ($F_{(1,795,\ 141,789)}$ = 87,130, p<0.1, η_p^2= .524). Pairwise comparisons with Bonferroni corrections proved pre and post difference in measurements to be statistically significant (p<0.1, mean difference 1.327, std error .142). Moreover, significance was found between pre and follow-up measurements as well (p<0.1, mean difference 1.633, std error .107). Once again the difference in mean conceptual understanding of post and follow-up measurement was insignificant (p>0.1, mean difference .306, std error .143). Group as a between-subjects factor consistently was found statistically insignificant ($F_{(1,795,\ 141,789)}$ = 1.476, p>0.1, η_p^2=.018) (Figure15).

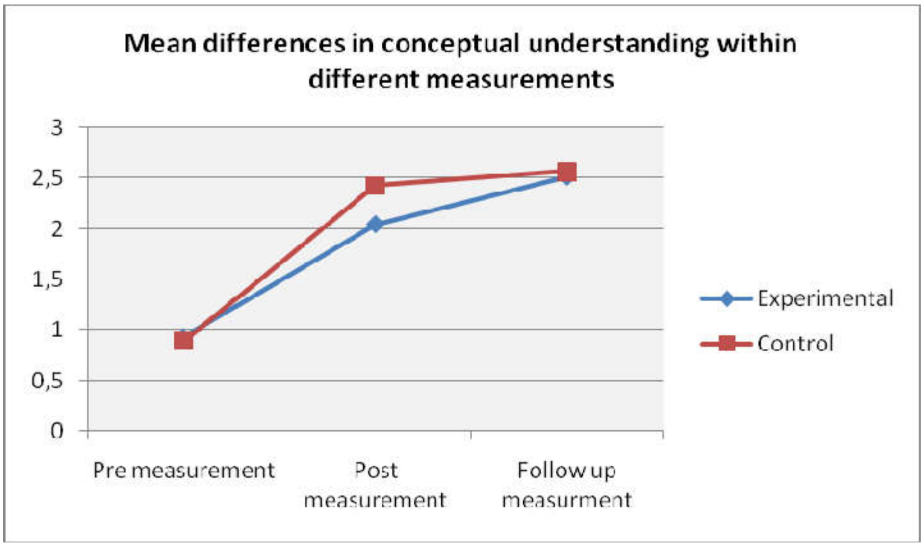

Figure 15: Conceptual understanding on Question 10 concerning the instrumentation employed to examine the smallest objects on earth

The next three questions of the generative questionnaire concern the generalizability of the lotus effect on other surfaces like those applied with simple coatings and nano-coatings. In the case of the first question two simple coated surfaces are being examined for their property of hydrophobicity, both time of different measurement ($F_{(1.405,\ 110.960)} = 1.029$, $p>0.1$, $\eta_p^2=.013$) as well as group, did not prove to be significant factors ($F_{(1.405,\ 110.960)} = .342$, $p>0.1$, $\eta_p^2= .004$) (Figure 16).

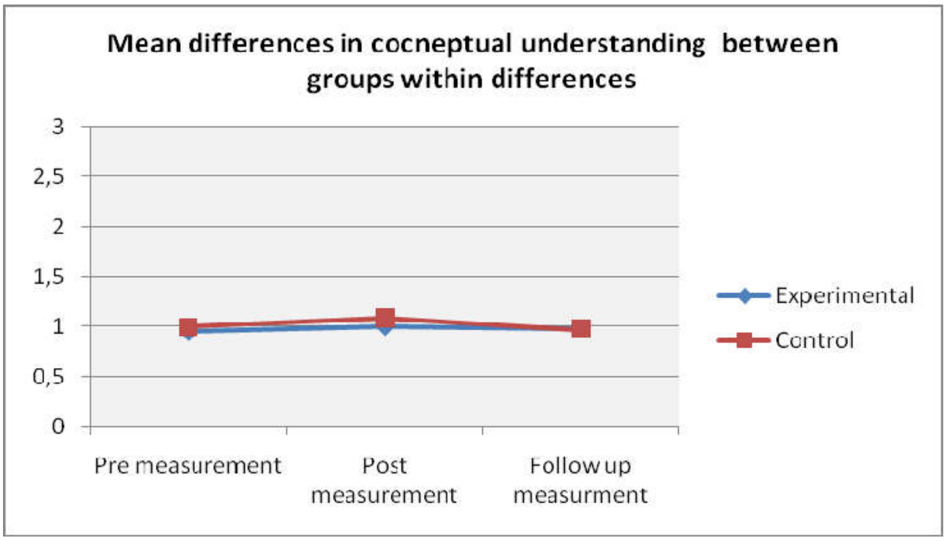

Figure 16: Conceptual understanding on Question11 where two simple coated surfaces are being examined on whether they display the lotus effect

The same was the case for the second question where a simple coated surface was compared to a nano-coated surface revealing no statistical significance for both time ($F_{(2,158)} = .153$, $p>0.1$, $\eta_p^2= .002$) and group ($F_{(2,158)} = .670$, $p>0.1$, $\eta_p^2= .008$) indicating that students did not change their naïve theories and misconceptions and that both approaches benefited them the same (Figure 17).

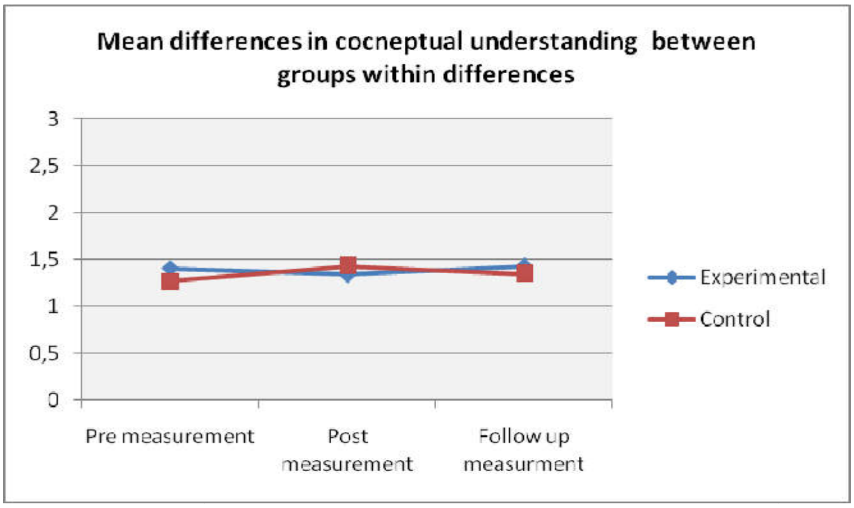

Figure 17: Mean differences on conceptual understanding on Question 12 concerning a simple coated surface and a nano-coated surface displayed the lotus effect

However, the last question (Figure 18) comparing two nano-coated surfaces revealed that the within-subjects factor of time was statistically significant ($F_{(2, 158)} = 6.322$, $p<0.1$, $\eta_p^2 = .074$). The mean difference of students' conceptual change suggested by the post hoc tests with Bonferroni adjustments was found statistically significant ($p<0.1$ and $p< 0.1$ respectively) not only between pre and post test (mean difference .299,std error .095) but between pre and follow-up test (mean difference .283, std error .089) as well. Nevertheless, the mean difference of students' conceptual understanding was not found significant between post and follow-up measurement ($p>0.1$, mean difference .016, std error .099). Furthermore, no statistical significance was found concerning the between-subjects factor of group on conceptual change ($F_{(2, 158)} = 0.86$, $p>0.1$, $\eta_p^2 = .001$). These findings indicate that students did not change their previous misconceptions and that although they have changed their naïve theories regarding the lotus effect as stated earlier they are unable to apply these new synthetic models in most cases to another concept such as the nano-coatings.

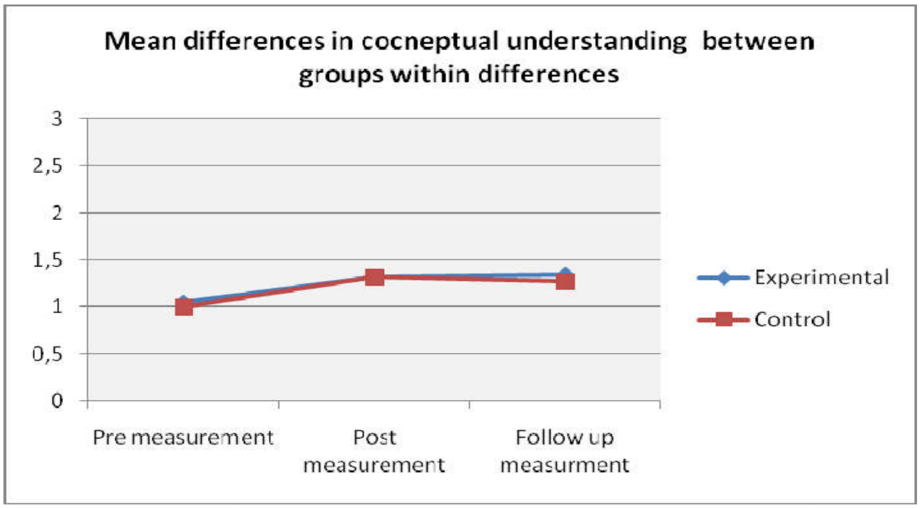

Figure 18: Mean differences on conceptual understanding with regard to the application of the lotus effect on two nano-coated surfaces, Question 13

The final five questions regarding the generalizability of the concept of size as well as the previous three questions concerning nano-coatings have in common the fact that they were not explicitly taught through the interventions. Nonetheless the result could be an important indicator of whether students can apply their knowledge in other settings suggesting also their level of conceptual understanding. Concerning the first question where students were asked to examine whether they could drink water from a lake in case there was not another option provided, repeated measures ANOVA revealed a statistical effect of time as the within-subjects factor ($F_{(2,158)} = 10.288$, $p<0.1$, $\eta_p^2 = .115$). More specifically pairwise comparisons with Bonferroni correction revealed statistical significance ($p<0.1$) between pre and follow-up measurement where the mean difference of students' conceptual change was increased (mean difference .437, std error .103). Another significance ($p<0.1$) was found between post and follow-up measurement where the mean difference of conceptual understanding was increased (mean difference .259, std error .036). On the other hand, although pre and post measurement revealed an increase (mean difference .178, std error .086) in conceptual understanding this increase was not considered significant (p> 0.1) (Figure 19). The between subjects factor of group was not revealed to be significant ($F_{(1,79)}$=.569, p>0.1, η_p^2=.007).

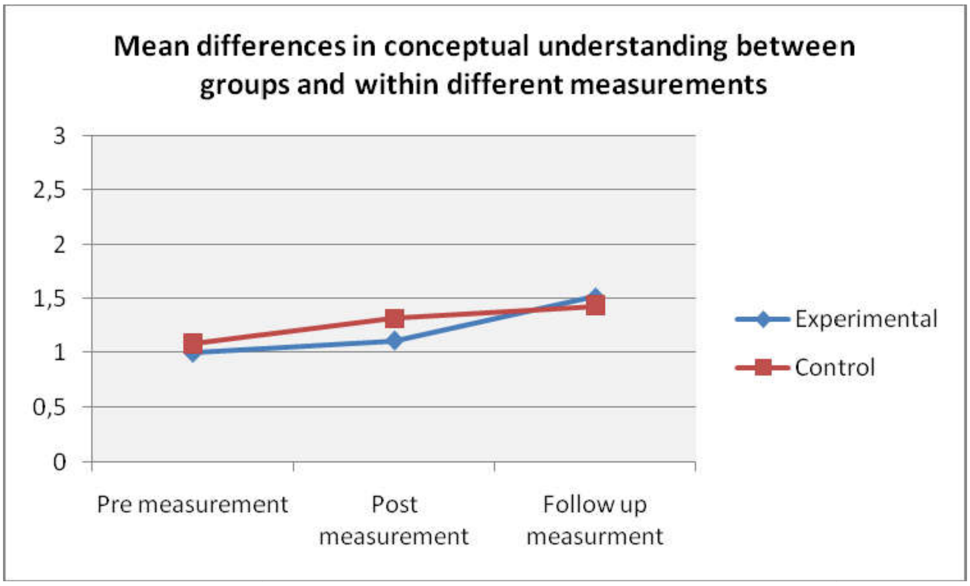

Figure 19: Conceptual understanding concerning Question 14 where students are asked to examine whether they could drink water from a lake in case there was not another option provided

The next question examined whether cleaning the lake's water could be sufficient enough in order to be drinkable (Figure 20). Repeated measures ANOVA corrected with Greenhouse-Geisser revealed that neither time ($F_{(1.552,\ 122.600)}$ = .178, p>0.1, η_p^2= .002) nor group ($F_{(1.552,\ 122.600)}$ = .178, p>0.1, η_p^2= .002) was a statistically significant factor for conceptual change.

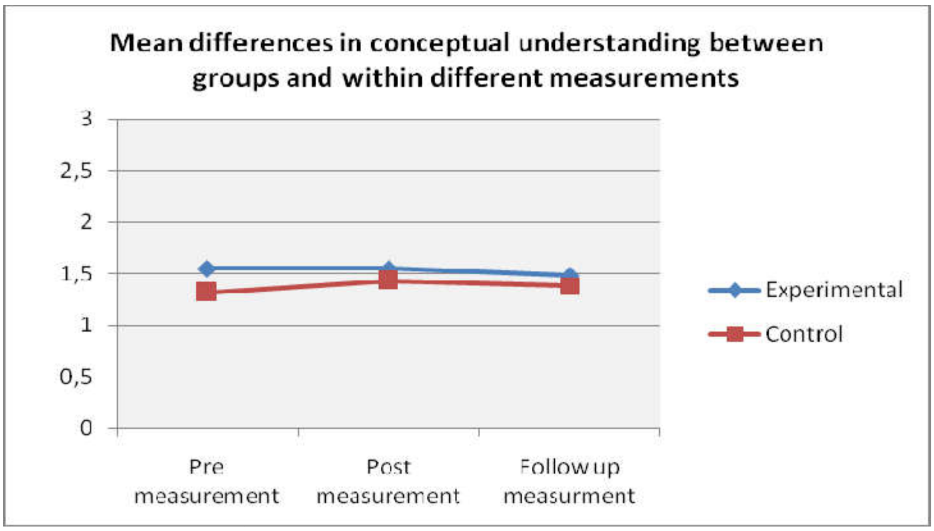

Figure 20: Mean conceptual change differences on Question 15 regarding the possibility to drink the water from a lake when cleaned

Repeated measures ANOVA, for the succeeding question concerning the way one could clean the lake's water(Figure 21) revealed the within-subjects factor of time as a statistically significant factor ($F_{(2, 158)}$ = 28.350, p< 0.1, η_p^2= .264). Pairwise comparisons with Bonferroni corrections revealed all measurements as statistically significant when compared to each other. In particular, conceptual understanding between pre and post measurements was increased (p<0.1, mean difference .308, std error=.094), as well as in both pre and follow-up measurements (p<0.1, mean difference .777, std error .100) and post and follow-up measurements (p<0.1, mean difference .468, std error .166). This time the between subjects factor of group revealed to be significant ($F_{(1, 79)}$ = 9.072, p<0.1, η_p^2= .103). Pairwise comparisons with Bonferroni adjustments revealed statistical significance (p=0.003) in favor of the control group which was benefited the most (mean difference=.391, std error=.130).

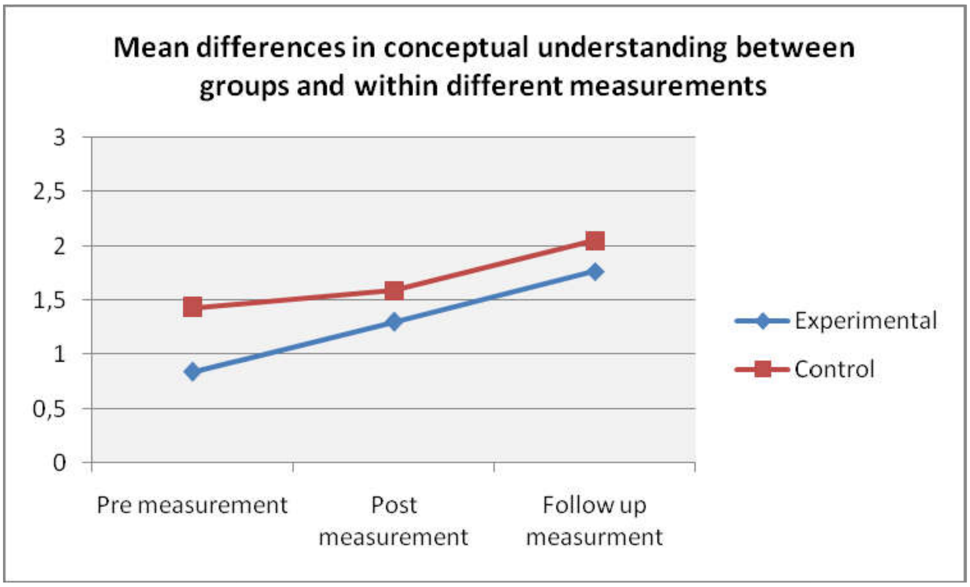

Figure 21: Conceptual understanding on Question 16 examining ways of cleaning the lake's water

Repeated measures ANOVA corrected with Greenhouse-Geisser revealed only time as significant factor on students' conceptual understanding for the question examining when and how one can be certain that the lake's water will be sufficiently cleaned (Figure 22) (F $_{(1.851, 146.233)}$ = 7.644, p<0.1, η_p^2= .088). Specifically post hoc test with Bonferroni correction revealed significant differences between pre and follow-up (p<0.1) measurement as well as between post and follow-up (p<0.1) measurements where in both cases an increase was observed (mean difference .400, std error .117 and mean difference .395, std error .131 respectively). Regarding the between-subjects factor of group, there was not a statistical significance revealed ($F_{(1.851, 146.233)}$ = .773, p>0.1, η_p^2= .010).

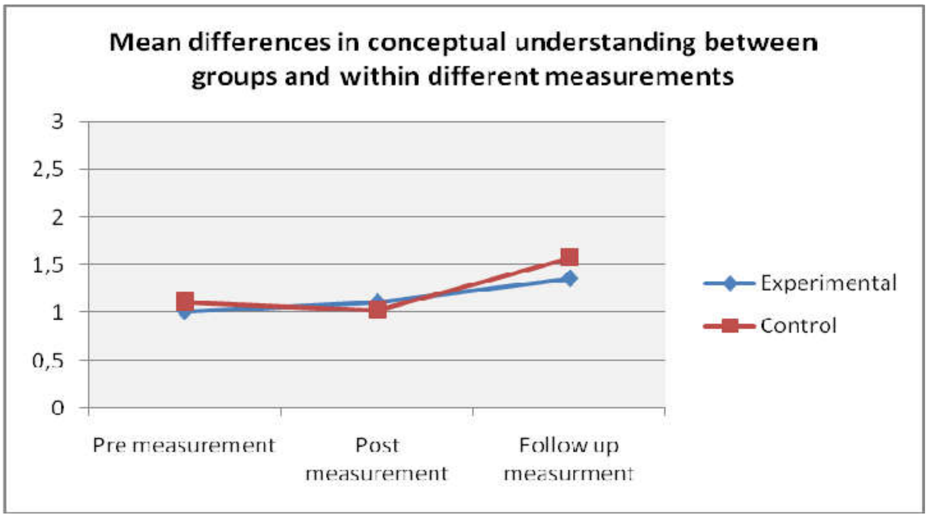

Figure 22: Mean differences on conceptual change about Question 17, examining when one can be certain that the lake's water is sufficiently clean in order to drink it

Finally, repeated measures ANOVA to the last question (Figure 23) referring to water nano- filters revealed different time of measurements to be statistically significant for conceptual change ($F_{(2, 158)} = 10.462$, $p<0.1$, $\eta_p^2 = .117$). Post hoc tests with Bonferroni measurements revealed statistical significance only between pre and follow-up measurement ($p<0.1$) where mean difference of conceptual change was increased (mean difference .452, std error .097). Insignificant was the increase in mean differences between pre and post measurements ($p>0.1$, mean difference .220, std error .094) as well as between post and follow-up measurements ($p>0.1$, mean difference .232, std error .106). Furthermore, group was found significant as a between-subjects factor on conceptual change ($F_{(1,79)} = 4.227$, $p<0.1$, $\eta_p^2 = .051$) indicating that the teaching method affects conceptual change. In particular, pairwise comparisons with Bonferroni adjustments revealed a statistical difference ($p=.043$) in favor of the control group (mean difference=225, std error=.109).

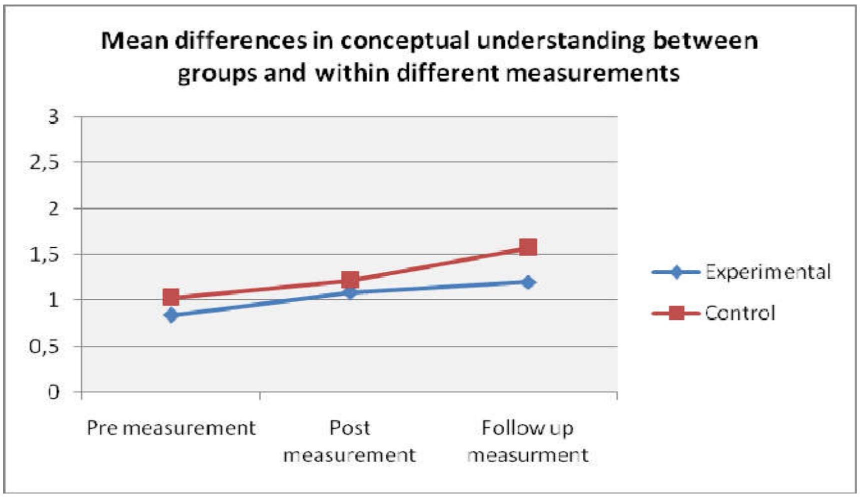

Figure 23: Conceptual change with regard to Question 18 and the use of nano filters

Table 9 presents in summary the results of the ANOVAs with respect to the significance of the within-subjects factor of time and the between subjects factor of group.

Question	Repeated measures ANOVAs	
	time	group
1	*.000	**.281
2	*.000	**.170
3	*.000	**.618
4	*.000	**.960
5	*.000	**.262
6	*.000	**.662
7	*.000	**.672
8	*.000	**.970
9	*.000	*.004
10	*.000	**.303
11	**.360	**.411
12	**.858	**.679
13	*.002	**.697
14	*.000	**.453
15	**.781	**.115
16	*.000	*.003
17	*.001	**.510
18	*.000	*.043

Table 9: Presenting in summary the significance of the within subjects factor of time and the between subjects factor of group (*sig<0.1, **n.sig>0.1)

Overall the within-subjects factor of time according to the repeated measures ANOVAs revealed to be significant at all but three questions, indicating that students acquired new knowledge which as suggested by the mean scores and standard deviations was classified as naïve theories in the pre measurement while altering to synthetic models between post- and follow-up- measurement. The interactions in most cases between the three time measurements revealed a significant change between pre and post measurement as well as between pre and follow-up measurement but significance was not found in many questions between post and follow-up measurements. In the following figures the significant interaction between the factors of group and time are presented in three out of 18 questions.

Repeated measures ANOVA revealed only three times where the between factor of group was found significant. Moreover, the significant interactions between group and time as suggested by the following figures indicate that in two cases the control group was more facilitated to achieve conceptual understanding while the experimental group was more benefited by the method in one out of the three cases. Nevertheless, it cannot be assumed that one of the two methods can benefit conceptual understanding more than the other. Consequently, with respect to the first research question it is indicated that V*a*KE can achieve conceptual understanding at least at the same levels to an inquiry based teaching.

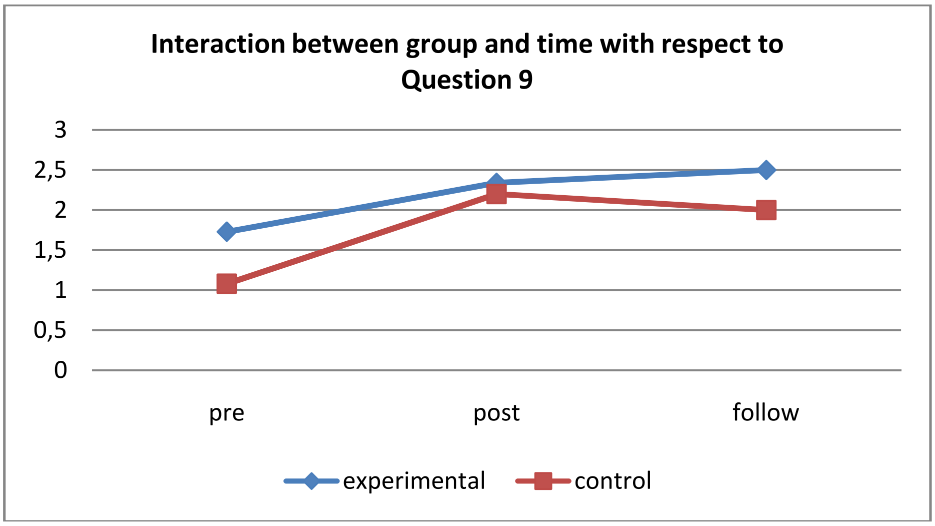

Figure 24: The interaction between group and time for Question 9 and students' ability to discriminate between size and scales

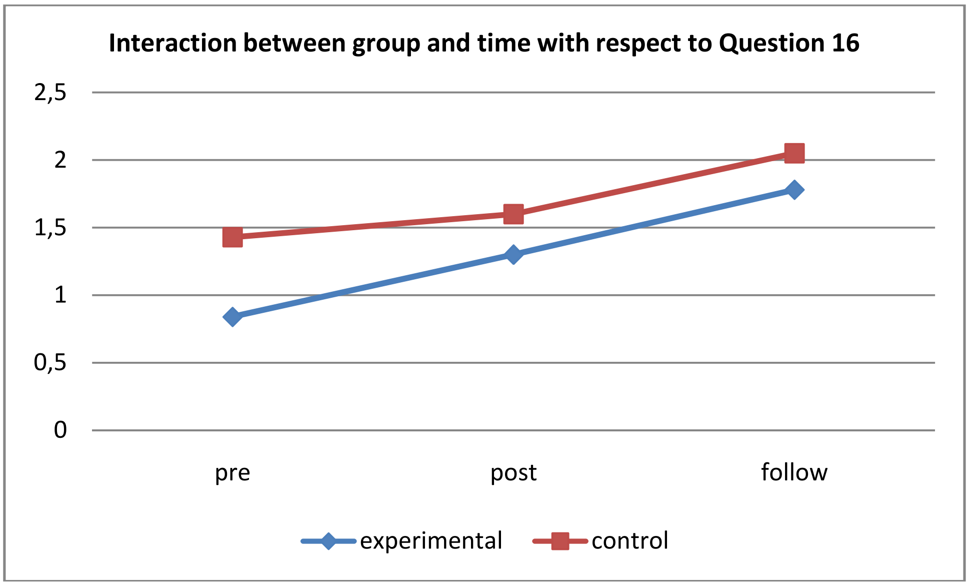

Figure 25: Interaction between group and time with respect to Question 16 and how lake's water could be cleaned

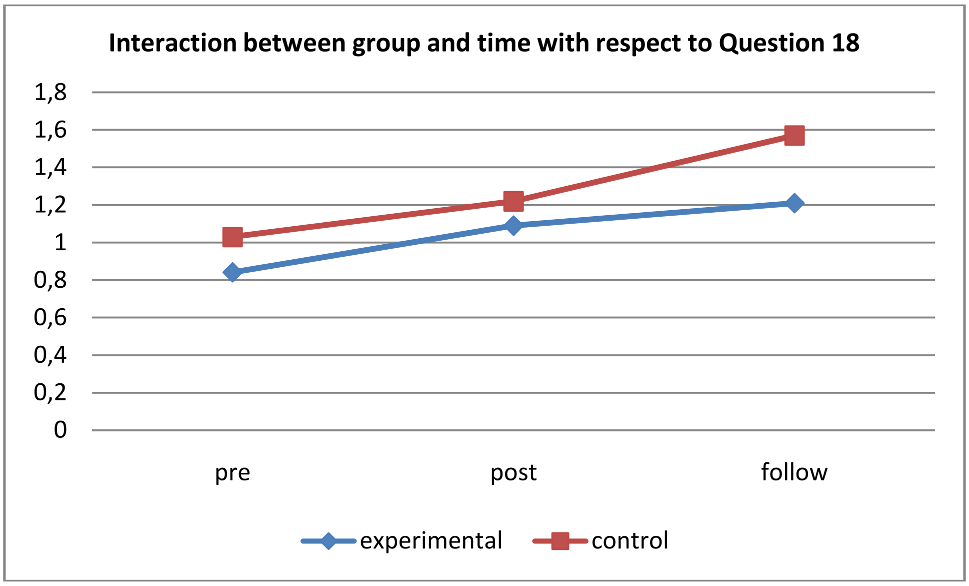

Figure 26: The interaction of group and time with respect to Question 18 and the use of nanofilters

C.2 Findings on students' epistemological beliefs and motivation

The second question of the present study was investigating whether V*a*KE could sophisticate and increase motivation at the same levels compared to an inquiry based teaching. For starters findings on epistemological beliefs will be presented.

Sum variables for epistemological beliefs were constructed based on the dimensions suggested by Hofer and Pintrich (1997) for both the experimental and the control groups. Answers greater than 3 were considered as mature epistemological beliefs (Conley et al., 2004). In Table 10 means and standard deviations of the dimensions of epistemological beliefs are presented for both groups (Mexperimental=Mex & Mcontrol=Mc).

Table 10: Means and standard deviations of students' epistemological beliefs

Group	**Dimensions of epistemological beliefs**	**Pre measurement**		**Post measurement**	
		Mex	SDex	Mc	SDc
Experimental (N=44)	source	3.07	.577	3.14	.706
	justification	4.04	.516	4.06	.533
	stability	2.93	.641	2.88	.539
	development	4.03	.602	4.05	.644
Control (N=37)	source	3.01	.946	3.13	1.042
	justification	4.00	.616	3.96	.650
	stability	3.03	.797	2.94	1.051
	development	3.88	.564	3.74	.803

Four repeated measures ANOVAs were conducted to meet the research question and hypothesis with time (pre and post measurement) as the within-subjects factor and group (experimental and control) as the between-subjects factor. Time did not reveal to be significant factor for all dimensions of epistemological beliefs. In particular, the dimension of source proved to be insignificant since $F_{(1, 79)}$ =.953, p>0.05, η_p^2=.012, the dimension of justification for $F_{(1, 79)}$ =.013, p>0.05, η_p^2= .000, the dimension of stability for $F_{(1, 79)}$ =.540, p>0.05, η_p^2= .007 and finally the dimension of development since $F_{(1, 79)}$ = .575, p>0.05, η_p^2= .007. These results indicate that although students' epistemological beliefs could be identified as mature almost in all cases, they did not become significantly more sophisticated (Figure 27) across measurements.

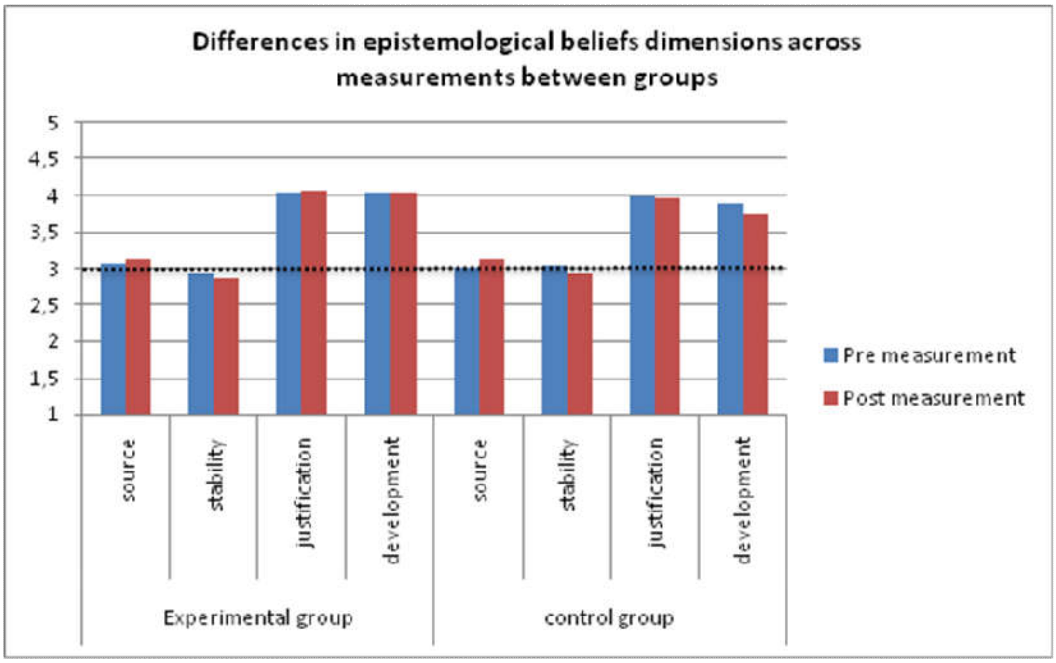

Figure 27: Differences between the dimensions of epistemological beliefs between groups with respect to the different time measurements

Moreover, the between-subjects factor of group also was not revealed as significant for all but the dimension of development, particularly for source $F_{(1, 79)} = .098$, $p>0.05$, $\eta_p^2=.001$, for justification $F_{(1, 79)} =.246$, $p>0.05$, $\eta_p^2= .003$, for stability $F_{(1, 79)} = .039$, $p>0.05$, $\eta_p^2= .000$, for development $F_{(1, 79)} = .364$, $p<0.1$, $\eta_p^2= .010$. The interaction between group and time for the development dimension is presented in Figure 28, indicating that there was a difference between the two groups.

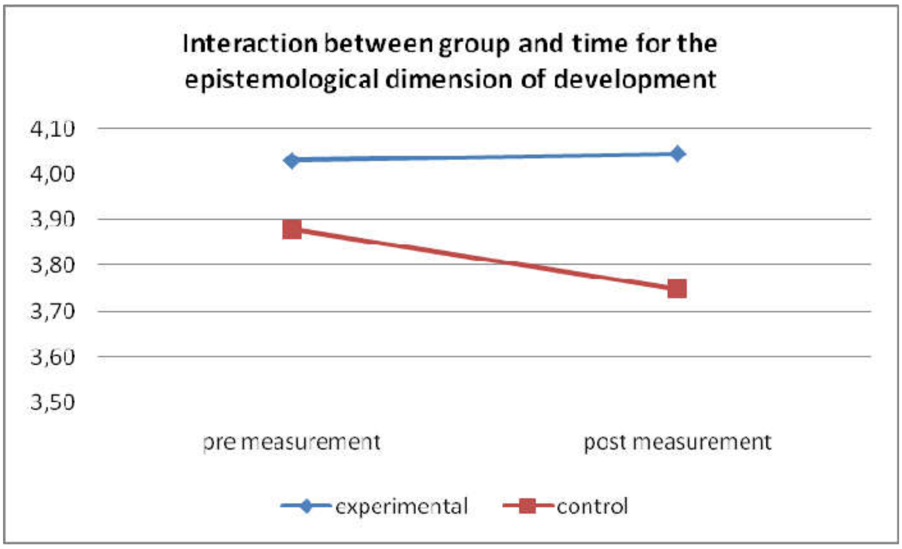

Figure 28: The interaction between group and time for the epistemological dimension of development

With respect to students' motivation sum variables were constructed based on the items of the subscales of the IMI questionnaire for the experimental group and the control group. The means and standard deviations for each subscale of each group (Mex & Mc) are presented in Table 11. To test whether motivation facilitated conceptual change in both groups multiple independent sample t tests were conducted.

Table 11: Means and Standard deviations from the five motivational subscales of the IMI questionnaire per group of participants and a comparison of mean differences in both groups (^{ns} p>0.1; **p<0.1)

Subscales of the IMI question naire	**Experimental (N=44)**		**Control (N=37)**		**Mean Difference**	
	Mex	SDex	Mc	SDc	Mex-Mc	*t*
Interest/ enjoyment	5,95	1,223	5,79	1,364	,158	,56 ^{ns}
Perceived competence	5,77	1,008	5,08	1,594	,684	2,26**
Pressure/ tension	2,30	1,264	2,35	1,318	-,686	-1,9 ^{ns}
Perceived choice	4,73	1,716	5,42	1,433	,079	,31 ^{ns}
Value/ usefulness	5,89	1,074	5,81	1,208	,062	,21 ^{ns}

Multiple independent sample t tests revealed the subscale of perceived competence as statistically significant ($t_{(58.730)}$ =2.259, p<0.1) for the experimental group and the subscale of perceived choice $t_{(79)}$=-1.931, p<0.1 for the control group. In particular with respect to the subscale of interest/enjoyment $t_{(79)}$= .551 and p>0.1, for the subscale of pressure/tension $t_{(79)}$=.214, p>0.1 and finally concerning the subscale of value/usefulness $t_{(79)}$=.313 and p>0.1. Moreover, the power of the difference with respect to perceived competence and perceived choice were tested using Cohen's *d* (*d=Mex-Mc/SD pooled,* where SD pooled=square root [(SDc^2 + $SDex^2$/2] (Cohen, 1988)) which was 0.51 (moderate effect) for the subscale of perceived competence and 0.43 (small effect) for the subscale of perceived choice. Cohen's *d* measures the effect size for the difference: no effect at d<0.2, small effect at 0.2≤ d≤0.5, moderate effect at 0.5 ≤ d≤0.8 and large effect at d≥0.8.In Figure 29 the differences between groups in each subscale are presented.

The hypothesis of the second research question was partially confirmed since epistemological beliefs were more sophisticated in the experimental group compared to the control group regarding the development dimension. Motivational factors affected both groups however mean scores in the subscales of the IMI questionnaire revealed that students from the experimental group were more motivated (means> 5.6) than students from the control group.

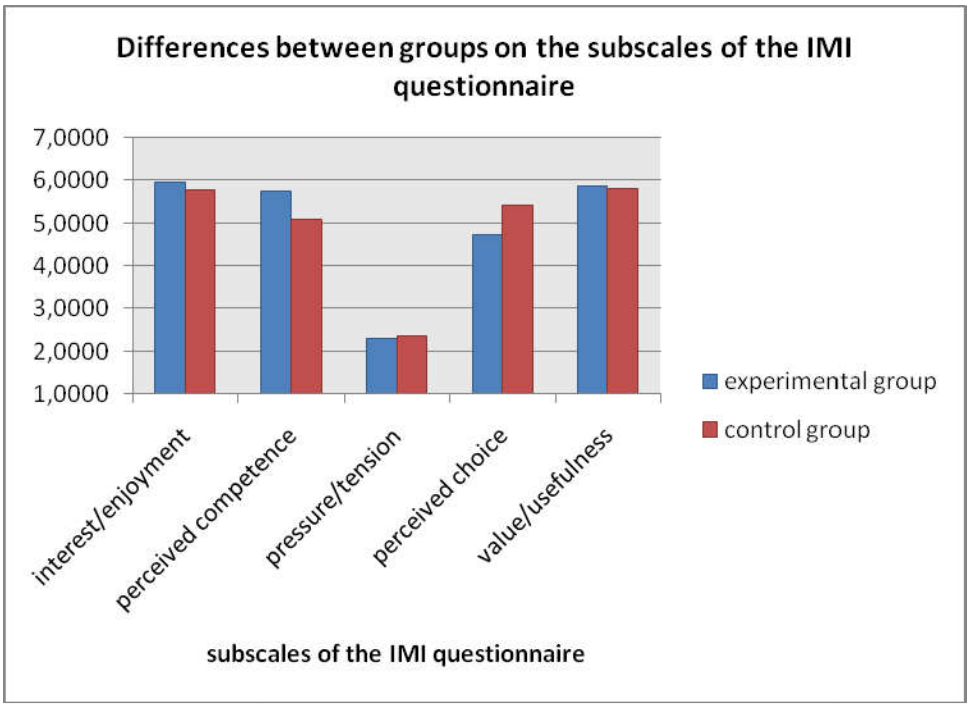

Figure 29: Mean scores on the subscales of the IMI questionnaire between groups

C.3 IQ and conceptual change findings

At this point the results which will be presented concern the last question of the current study, namely which students of the experimental group were more benefited in conceptual understanding with respect to their non-verbal IQ.

Descriptive statistics revealed that students in the experimental group (N=44) had a mean IQ of 95 with standard deviation 13 following normal distribution (Figure 30). The maximum IQ was 121 while the minimum was 73. Moreover, 25% of the students had an IQ below 73; half of the students had an IQ below 93 while 75% of the students had an IQ of 106. Although emphasis will not be laid on the control group's IQ (N=37), descriptive statistics will be presented as well. The mean IQ of this group is 93 with standard deviation 13 following as well normal distribution (Figure 31). The maximum IQ was 113 while the minimum was 70. Moreover 25% of the students had an IQ of 82, 50% of the students' IQ was 91 and finally 75% of the students' IQ was 107.

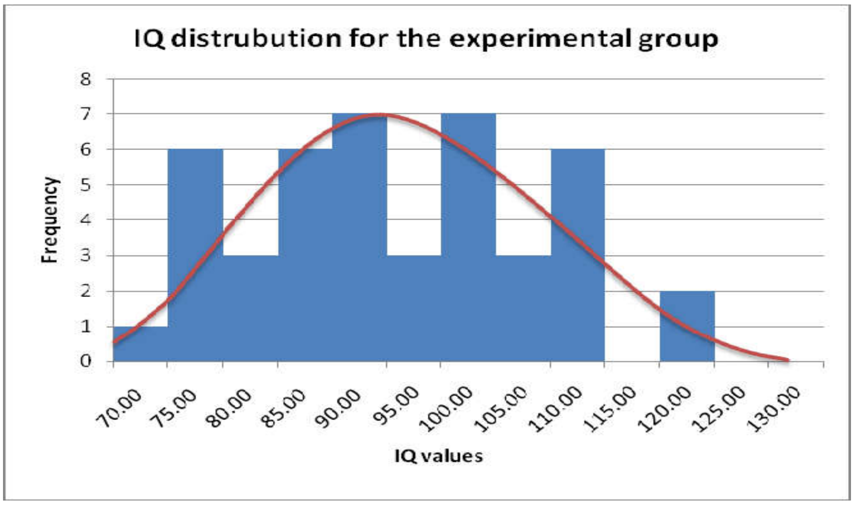

Figure 30: The IQ distribution for the experimental group

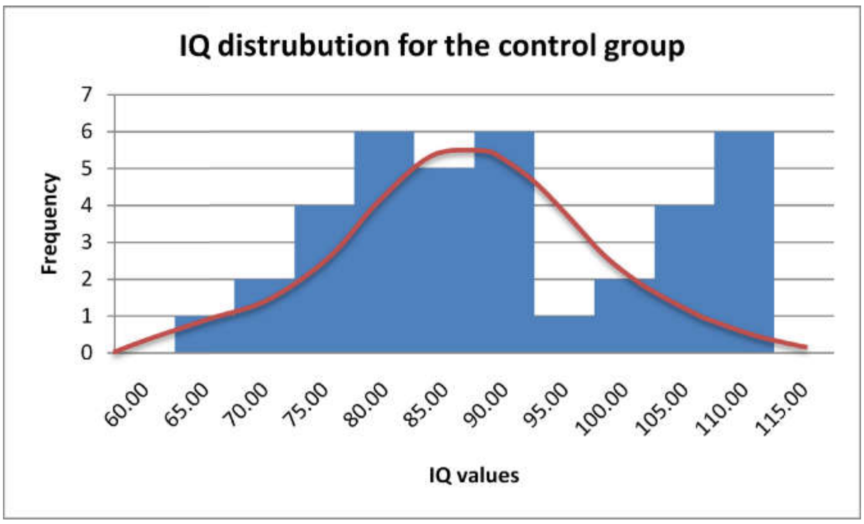

Figure 31: The IQ distribution of the control group

To address the third question of the research multiple repeated measures ANCOVAs were conducted with time (pre-post-follow-up measurement) as the within-subjects factor, group (experimental and control) as the between-subjects factor and IQ as the covariate. The results will be presented separately for each question of the generative questionnaire. The covariate appearing in the model of ANCOVA had a value of 94.

With regard to the first question about gold's properties to change color depending on its size, repeated measures ANCOVA with a Greenhouse-Geisser correction determined that mean conceptual change did not differ when controlling for students' IQ within the three time measurements $F_{(1.673,130,480)}=1.808$, $p>0.05$, $\eta_p^2=.023$ or between groups ($F_{(1,78)}=2.089$, $p>0.05$, $\eta_p^2=.026$).

The second question examined once again gold properties to change color depending size however the size implied was different. Once again repeated measures ANCOVA with a Greenhouse-Greisser correction did not indicate statistical significance for the within subjects factor of time ($F_{(1.787,\ 139,402)}=.895$, $p>0.1$, $\eta_p^2=.011$) but revealed significance for the between subjects factor of group ($F_{(1,78)}=2.876$, $p<0.1$, $\eta_p^2=.036$). The interaction (Figure 32) between group and time reveals that the control group was benefited the most in terms of conceptual understanding.

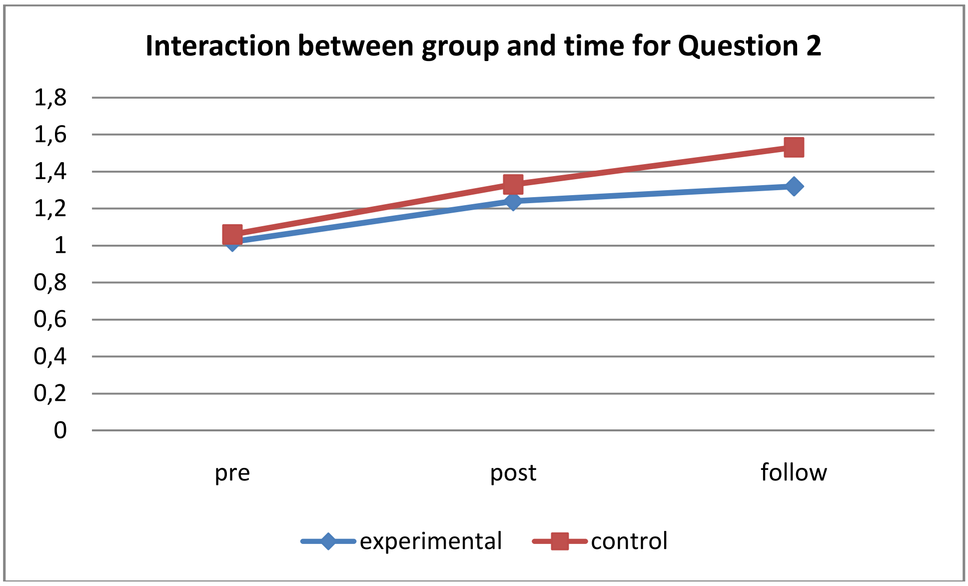

Figure 32: The interaction between group and time for Question 2 and the property of gold to change colour depending its size

The next question examined whether students applied gold's properties to change color regarding to its size, on every material. While examining IQ as the covariate, repeated measures ANCOVA did not reveal a statistical significance neither for the within subjects factor of time ($F_{(2,156)}=2.286$, $p>0.1$, $\eta_p^2=.028$) nor for the between subjects factor of group ($F_{(1,78)}=.123$,$p>0.1$, $\eta_p^2=.002$).

Later on, the lotus effect is investigated with multiple questions. With respect to the first question where the cabbage and the lettuce are being examined for their ability to be easily cleaned repeated measures ANCOVA revealed significant effect of the within subject factor of time ($F_{(2,156)}=8.863$, $p<0.1$, $\eta_p^2=.102$). Pairwise comparisons with Bonferroni correction revealed statistically significant increase (*p*=0.000) with regard to the mean difference between pre and post measurement (mean difference .761, std error .082). Similarly, statistically significant increase (*p*=0.000) in the mean difference was revealed between the pre and follow-up measurements (mean difference .604, std error .077) but not between the post and follow-up measurement (mean difference .157, std error .079, p>0.1). Once more the between factor of group was not found significant ($F_{(1,78)}$=.065, p>0.1,η_p^2=.001).

Concerning the second question on the lotus effect examining the shape of a water droplet in two different hydrophilic materials, repeated measures ANCOVA indicated, the within subjects factor of time significant ($F_{(2,156)}$=2.950, p<0.1, η_p^2=.036). Pairwise comparisons with Bonferroni corrections revealed statistically significant increase between all three time measurements. The mean score in the post test was increased (mean difference .429, std error .075, p<0.1) compared to the pre test, while also a slight significant increase was indicated between follow-up and post measurement (mean difference .164, std error .064, p<0.1). Finally the difference between the pre and follow up measurement was significant since the mean difference was increased (mean difference .593, std error .071, p<0.1) The between subjects factor of group was not revealed to be significant ($F_{(1,78)}$=.735, p>0.1, η_p^2=.009).

Next on the generative questionnaire there were two questions comparing the surface of some vegetables on whether they demonstrated the lotus effect or not. Concerning the first question where one hydrophobic and one hydrophilic surface were examined, repeated measures ANCOVA did not reveal time ($F_{(2,156)}$ = 2.130, p>0.1, η_p^2= .027) or group ($F_{(1,78)}$=.021, p>0.1, η_p^2=.000) as significant factors.

The second question examined the property of hydrophobicity on two hydrophobic surfaces. Similar results were indicated from the repeated measures ANCOVA with IQ as the covariate. Time ($F_{(2,156)}$ = 1.206, p>0.1, η_p^2= .015) as well as group ($F_{(1,78)}$=.088, p>0.1, η_p^2=.001) were not found to be significant factors.

The next set of questions concern the different sizes of matter. When controlling for non-verbal intelligence with repeated measures ANCOVA, the within subjects factor of time reveals to be significant ($F_{(2,\ 156)}$ = 4.864, p<0.1, η_p^2= .059). Especially pairwise comparisons with Bonferroni correction were revealed to be statistically significant (*p*=0.000 and *p*=0.000 respectively) while mean difference between both pre and post measurement (mean difference .407, std error .103) as well as between pre and follow-up measurement (mean difference .301, std error .097) was increased. The factor of group was not found to be significant (F(1,78)=.031, p>0.1,η_p^2= .000).

The next question concerned the concept of size and different scales. Repeated measures ANCOVA with a Greenhouse-Geisser correction determined that time does not appear to be significant ($F_{(1.839,143,436)}$=.198, p>0.1, η_p^2=.003) whilst the between factor of time is significant ($F_{(1,78)}$=7.786, p<0.1,η_p^2=.091). In particular, pairwise comparisons with Bonferroni adjustments revealed that the experimental group was benefited the most (*p*=0.007, mean difference=361, std error=.129) as it is obvious from figure 33 where the interaction between group and time is presented.

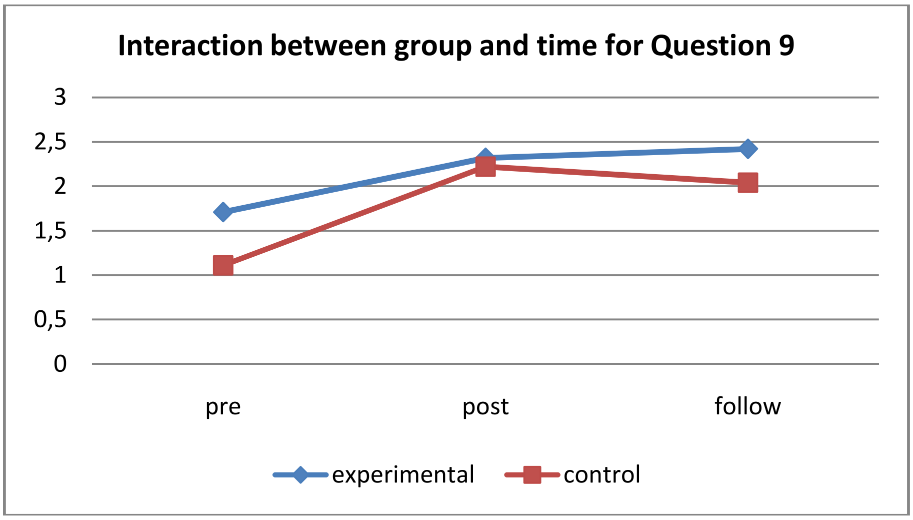

Figure 33: The interaction between group and time for Question 9 and students' ability to discriminate between size and scales

Repeated measures ANCOVA corrected with Greenhouse-Geisser on the final question concerning the instrumentation used to examine objects of the smallest scale revealed statistical significance for the between factor of time ($F_{(1.796,140,051)}$=3.031,p<0.1, η_p^2=.037). Pairwise comparisons with Bonferroni adjustments revealed significant increase (p<0.1) between pre and post measurements (mean difference 1.328, std error .142) as well as between pre and follow up (mean difference 1.632, std error .107), no significance was found between post and follow up measurement (mean difference .304, std error .142). The between subjects factor of group was not found significant $F_{(1,78)}$=1.727, p>0.1, η_p^2=.022.

The next three questions of the generative questionnaire concern the generalizability of the lotus effect on other surfaces like those applied with simple coatings and nano-coatings. In the case of the first question two simple coated surfaces are being examined for their property of hydrophobicity, neither the within subjects factor of time ($F_{(1.397,\ 108,930)}$=1.222, p>0.1,η_p^2= .015) nor the between factor of group ($F_{(1,78)}$=.851,p>0.1, η_p^2=.011) were significant and as a result we cannot assume either that conceptual change was achieved or that one of the methods employed in the research design facilitated students conceptual understanding.

Similar was the case for the second question where a simple coated surface was compared to a nano-coated surface revealing no statistical significance for both time ($F_{(2,156)}$=.074, p>0.1, η_p^2= .001) and group ($F_{(1,78)}$=.151, p>0.1, η_p^2= .002).

However the last question comparing two nano-coated surfaces revealed no significant differences among the three different measurements and the within subjects factor of time ($F_{(2,156)}$=.159, p>0.1, η_p^2= .002) or between the two different approaches and the between subjects factor of group ($F_{(1,78)}$=.177, p>0.1, η_p^2=.002).

The final five questions regarding the generalizability of the concept of size as well as the previous three questions concerning nano-coatings have in common the fact that they were not explicitly taught through the interventions. Nonetheless the result could be an important indicator of whether students can apply their knowledge in other settings suggesting also their level of conceptual understanding.

Concerning the first question where students were asked to examine whether they could drink water from a lake in case there was not another option provided, repeated measures ANCOVA suggested that neither time ($F_{(2,156)}$=.136, p>0.1, η_p^2= .002) nor group ($F_{(1,78)}$=.554, p>0.1, η_p^2= .007)are significant factors in students conceptual understanding.

The next question examined whether cleaning the lake's water could be sufficient enough in order to be drinkable. Repeated measures ANCOVA with IQ as the covariate did not reveal either time ($F_{(1.557,\ 121,446)}$ = .829, p>0.1, η_p^2= .011) or group ($F_{(1,\ 78)}$ = 2.321, p>0.1, η_p^2= .029) as significant factors for conceptual change.

Repeated measures ANCOVA, for the succeeding question concerning the way one could clean the lake's water the effect of the within subjects factor of time ($F_{(1.850,144,266)}$=.247, p<0.1, η_p^2=.018) was not revealed to be significant in comparison to the between subjects factor of group ($F_{(1,78)}$=9.903, p<0.1, η_p^2=.113) which was once again significant (p=0.002) in favor of the control group (mean difference=.409, std error=.130), as indicated also by the interaction between the factors of group and time (Figure 34)

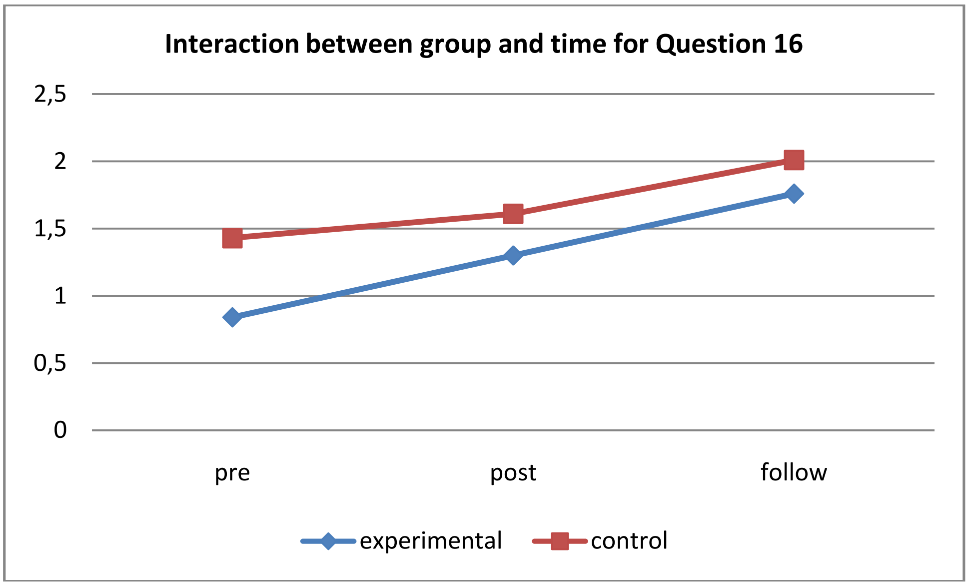

Figure 34: Interaction between group and time with respect to Question 16 and how lake's water could be cleaned

Repeated measures ANCOVA corrected with Greenhouse-Geisser revealed neither time ($F_{(1.831,\ 142,839)}$=.202, p>0.1, η_p^2=.020) nor group ($F_{(1,\ 78)}$=.581, p>0.1, η_p^2=.007) as significant factors.

Finally, repeated measures ANCOVA for the last question referring to water nano- filters the within-subjects factor of time was found statistically significant when controlling for IQ ($F_{(2,\ 156)}$ = 4.383, p<0.1, η_p^2= .053). Once again pairwise comparisons with Bonferroni correction indicated that the mean difference of conceptual understanding between pre and post measurement (p<0.1, mean difference .222, std error .089) and between pre and follow-up measurement (p<0.1, mean difference .454, std error .095) was statistically significantly increased. At last the between subjects factor of group was found significant ($F_{(1,78)}$=5.705, p<0.1, η_p^2=

.068). Specifically, pairwise comparisons with Bonferrroni adjustments revealed that the control group was significantly (p=.019) more benefited than the experimental (mean difference=.255, std error=.107) group as further supported by the interaction between factors of group and time (Figure 35).

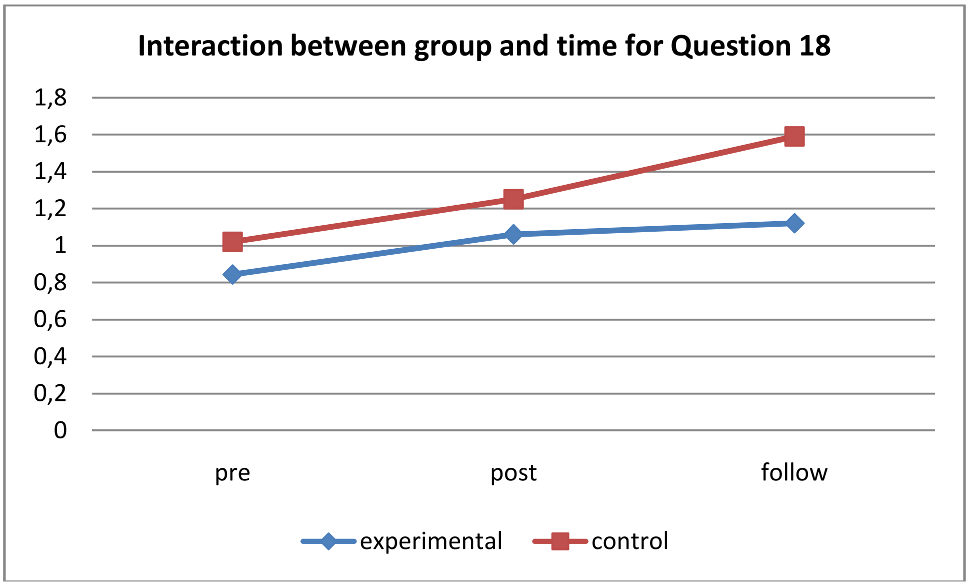

Figure 35: The interaction of group and time with respect to Question 18 and the use of nanofilters

Table 12 presents in summary the results of the ANCOVAs with respect to the significance of the within-subjects factor of time and the between subjects factor of group.

Question	**Repeated measures ANCOVAs**	
	time	group
1	**.436	**.152
2	**.806	*.094
3	**.224	**.727
4	*.016	**.799
5	*.055	**.394
6	**.122	**.886
7	**.302	**.768
8	*.041	**.860
9	**.741	*.007
10	*.057	**.193
11	**.350	**.359
12	**.931	**.699
13	**.632	**.675
14	**.922	**.459
15	**.440	**.132
16	**.347	*.002

17	**.326	**.448
18	*.034	*.019

Table 12: The significance of the within subjects factor of time and the between subjects factor of group (*sig<0.1, **n. sig>0.1)

Overall when controlling for IQ the number of questions where conceptual understanding was found important decreased at only five out of the 18 questions. This finding does not indicate that conceptual change was not achieved at all, rather it highlights the difficulty for an individual to undergo fundamental ontological re-categorizations in order to achieve full conceptual change. With respect to the between subjects factor of group, it was found to be significant in four cases, where the interaction between the factors of group and time revealed three cases where students of the control group were benefited the most and one case where students of the experimental group were benefited the most in terms of conceptual change. With regard to the last research question it is suggested that since the covariate in the ANCOVA model has the value 94, the students who were benefited the most were those with an IQ of 94 and below. Therefore, this finding is in line with the hypothesis stated, since it was expected that students with the lowest IQ would be benefited the most in terms of conceptual change that those with a higher or the highest IQ.

D Discussion

The purpose of the present study was to investigate whether V*a*KE, a didactical approach combining values and knowledge education, could foster conceptual change in science education and in particular in the domain of Nanotechnology. There were three main objectives of the study reflecting the research questions defined; (a) whether V*a*KE could foster conceptual change comparing with an inquiry based teaching, (b) whether epistemological beliefs and motivation could be mediators of conceptual understanding in V*a*KE in comparison to an inquiry based teaching and finally (c) which students according to their IQ level would be more facilitated to achieve conceptual understanding while participating in a V*a*KE unit.

A quasi experimental design was followed with pre, post, and follow-up measurements for both the experimental and the control group. Three interventions mediated between pre and post measurements addressed two of the Big Ideas of Nanoscience and Engineering, namely scale and size and size related properties. Moreover, epistemological beliefs were measured with pre and post tests while motivation and IQ were measured after the interventions.

D.1 Discussion: Findings on conceptual change comparing VaKE and inquiry based teaching

The first research question referred to whether V*a*KE could promote the same levels of conceptual understanding in comparison to an inquiry based teaching. The hypothesis stated was that V*a*KE could foster conceptual change for students at least at the same levels with an inquiry based teaching. The repeated measures ANOVA revealed time as a significant within-subjects factor for almost all questions of the generative questionnaire indicating that students acquired new knowledge in both cases. In terms of the framework theory approach of conceptual change, students through the interventions gradually changed their naïve theories and underwent conceptual change.

In particular, questions from the generative questionnaire referring to the lotus effect (e.g. questions 4,5,6,7,11,12,13) and size (questions 8,9,10) which as concepts were addressed through the interventions reveal that most students altered their framework theories and created synthetic models or even in less cases acquired the scientific view. The fact that students created synthetic models which have limited explanatory power and cannot justify satisfactory scientific issues is obvious from the questions (e.g. questions 1, 2,14, 15, 16, 17, 18) that were not explicitly addressed through the interventions or the questions which demanded from students to apply their newly acquired knowledge in different settings (e.g. questions 12, 13, 14, 15, 16, 17, 18). In these cases, students' conceptual understanding was lower compared to other questions of the questionnaire. Nevertheless, since conceptual change is a gradual approach and cannot happen overnight, fragmentation or misconceptions can be created leading to synthetic model constructions (Vosniadou, 2013). One could claim that since students did not acquire the scientific view they did not achieve conceptual change; however, this is not the case since synthetic models are one step before full conceptual change according to the framework theory and as a consequence they should not be considered as unimportant. Furthermore, synthetic models are dynamic and constantly changing as children's knowledge systems develop. Consequently, if the interventions had lasted more than six hours and had longer duration addressing the same concepts then students' synthetic models would have altered even further achieving eventually full conceptual change. As Vosniadou (2007) states some concepts such as the concept of photosynthesis, force, heat and energy require systematic instruction and years of instruction in order to be fully understood. This could be implied for the concept of size and scales since N-ST concentrates on phenomena of the unseen world. A systematic design of curriculum introducing carefully the issues of N-ST would be in order. However, if the interventions were to last longer a question could arise for the experimental group. Would the dilemma story still be powerful enough to motivate students' search for information? In such a case new dilemma stories could result by students' former inquiry with N-ST issues or could be introduced by the teacher so that a new set of information could be under investigation.

The pairwise comparisons between the post and follow-up measurements indicated that students did not preserve the newly acquired knowledge at the follow-up measurements at the same level as the post measurement revealed. Many students activated their naïve theories and intuitive concepts rather than their newly acquired scientific concepts (Vosniadou, 2014).Along this finding it is highlighted that learning science requires fundamental ontological reorganizations (Vosniadou & Skopeliti, 2014) which were not achieved fully by the participants of the current study. Hence recent findings in science and mathematics suggest that initial conceptions continue to coexist and influence problem solving even when conceptual change has been achieved (DeWolf & Vosniadou, 2011; Shtulman & Valcarcel, 2012; Vamvakoussi van Dooren and Verschaffel, 2012). These results imply that access to a scientific concept requires inhibition of a developmentally prior initial concept and shifting between these initial and the scientific responses. Inhibition and shifting are domain general cognitive abilities, known as executive functions (e.g., Miyake et al., 2000). Overall it is assumed that although conceptual change is a domain specific approach, domain-general abilities might constrain conceptual understanding or be responsible for the creation of new conceptual structures and forms of reasoning (Vosniadou, 2014). In this case educational implications would be major since teachers who want to remove or modify students' framework theories are not likely to teach the same way as those who want to help their students acquire a new scientific conception by teaching them strategies of how to inhibit their naïve theories (Foisy, Potvin, Riopel & Masson, 2015).

Hence the analysis revealed that the between-subjects factor of group but in particular the interactions between the factors of group and time were not statistically significant in all cases implying that both the experimental and the control group underwent at least the same levels of conceptual understanding, confirming the hypothesis originally stated. Inquiry based teaching was chosen as the control group treatment for two main reasons; firstly, because it can foster conceptual change and secondly because it does not address values and is more challenging than a traditional frontal teaching. However, this renders the results more conservative with regard to knowledge acquisition than comparing V*a*KE to a more traditional frontal teaching. Nevertheless, students acquired at least the same levels of knowledge since no statistical differences were found between the groups but in three cases. Finally, the main difference between V*a*KE and inquiry based teaching, the values dimension, proved to be effective for students whose initial individualistic perspectives were reduced by the end of the interventions, as presented in unit B.2.2.5 of the current study.

The above mentioned finding, namely that V*a*KE promotes conceptual understanding, yields some interesting implications for the method and its theoretical underpinnings.

As it has already been pointed out conceptual change approaches assume domain specificity. There are three main conceptualizations of domain specificity in the sphere of conceptual change approaches (see unit A.1.). First of all, V*a*KE can be applied in specific subject matters such as physics, biology, religion or language. Although it is a multidisciplinary teaching approach specific subject matters can be employed (for multiple implemented examples in Greek curriculum see Pnevmatikos & Patry, 2014) and in that way is in line with one conceptualization of domain specificity in conceptual change theory approach. Another conceptualization of domain specificity in conceptual change theory approach regards domain-specific constraints on learning, which for Hatano and Inagaki (2000) can be “sociocultural factors” guiding the learner to select the most appropriate behavior among a range of alternatives. Sociocultural factors are in line with what Vosniadou has suggested as cultural mediation hypothesis (see unit A.1.1.3.). Within the framework of V*a*KE the notion of zone of proximal development is in line with the sociocultural factors mediating conceptual change. The learner cooperates with other individuals who could scaffold the process of knowledge acquisition and values education.

Moreover, in V*a*KE through the notions of viability checks and the zone of proximal development meta-conceptual awareness can be achieved and consequently intentional learners can be created. Through viability checks individuals have an opportunity to reflect further on their acquired knowledge. As a result, learners who have constructed synthetic models are most likely to become meta-conceptually aware, realize the limited explanatory power of their synthetic models and undergo full conceptual change. Furthermore, through learners’ discussion and the zone of proximal development meta-conceptual awareness can be scaffolded. The moment the learner realizes that his newly acquired knowledge is not in accordance with the scientific view, the process of knowing has become intentional and in that way conceptual understanding can be achieved. In this way also V*a*KE employs top-down, conscious and deliberate mechanisms for intentional learning which are applied in domain specific approaches, unlike bottom-up, conservative, additive and unconscious mechanisms applied in domain general theories, such as the notions of assimilation and accommodation which could lead to the formation of misconceptions (Vosniadou, 2007).In addition, in order to achieve conceptual understanding through V*a*KE specific activities were designed. Particularly the inquiry employed in a typical V*a*KE unit would require neither using models and multiple representations nor designing and completing experiments. However, in order to achieve conceptual change in the field of physics and specifically in the field of N-ST, such activities proved to be mandatory according to the literature review. Therefore, implementing V*a*KE in order to promote conceptual understanding in specific subjects matter, yields specific consequences for practice, such as the implementation of further activities in inquiry.

D.2 Discussion: Findings on epistemological beliefs and motivation

Regarding the second research question it was examined whether V*a*KE could affect sophisticate epistemological beliefs and increase motivation compared to an inquiry based teaching. The hypothesis stated that both epistemological beliefs and motivation could be facilitated though V*a*KEat least at the same levels with inquiry based teaching was partially confirmed as revealed by the statistical analysis.

Repeated measures ANOVA were conducted to examine whether epistemological beliefs were sophisticated, with time as the within-subjects factor and group as the between subjects factor, did not reveal time as a significant factor but the factor of group was found as a significant one. Although epistemological beliefs and particular the dimensions of source, justification and development for both groups had a mean score above 3 indicating that they were mature, they did not get more sophisticated overtime. Even though such a finding is in contrast to other findings suggesting that hands on activities facilitate the sophistication of epistemic beliefs (Conley et al., 2004; Solomon, Scott & Duveen, 1996), it is reasonable due to the short duration of the interventions. Moreover, as Sandoval (2005) argues simply engaging in inquiry based activities is insufficient to change students' epistemological beliefs. In addition, Kienhues et al. (2008) indicated that due to the instructional approach employed in the interventions, epistemological beliefs can be both sophisticated but they can even turn to a more naïve standpoint.

Nevertheless, beliefs regarding the dimension of development revealed to be significantly more sophisticated in the experimental group than in the control group. As already indicated the development dimension concerns beliefs that recognize science as an evolving subject where ideas and theories can change on the basis of new data and evidence (Conley et al., 2004). This finding could explain levels of conceptual understanding in the current study, since students who believe that knowledge does change may have fewer difficulties in achieving conceptual change (Stathopoulou & Vosniadou, 2007). In addition, it has already been stated that epistemological beliefs can mediate for conceptual understanding however the nature of the current study did not provide an opportunity for such an analysis. Moreover, this difference between the groups could be attributed to the dilemma story where the development of science in the field of N-ST was implicit but nevertheless apparent. Therefore, an opportunity was given to the students for discussion on the topic. As opposed to the control group where neither such discussion took place nor the epistemological framework of inquiry based teaching was introduced explicitly in order to facilitate students' sophistication of their epistemological beliefs (Sandoval, 2005; Zoupidis et al., submitted).

With regard to motivation multiple independent sample t tests revealed the subscale of perceived competence as statistically significant with a moderate effect in favor of the experimental group. V*a*KE as a process facilitates autonomous student work (Weyringer, Patry & Weinberger, 2012), since the introduction of the topic, students have to decide what knowledge they need to search for, or how the discussion will proceed. The teacher is only the "orchestrator of learning" (Salomon, 1992). In addition, the leading idea of Self Determination Theory is fulfilled through the employment of certain activities during the interventions such as designing an experiment. In particular, as it was indicated by the literature activities which fulfill basic psychological needs such as autonomy, competence and social relatedness could lead to more motivated students (Loukomies et al., 2013). Although during the process students seemed to face difficulties while reflecting on the courses, they expressed their ability to manage through difficult activities as self-efficacy, which is in line with the definition of self-efficacy according to Bandura (1977, 1986, 1997). On the other hand, although students in the control group had the same activities to complete they evaluated them as more difficult so they could feel less competent to handle. Moreover, according to the Self-Determination Theory (Deci & Ryan, 1985; Deci et al., 1991) interest rises when students feel in control of an activity or believe in the importance of the activity per se. Nevertheless, what is interesting and in a way contradictory to the previous finding is that the motivational subscale of perceived choice was found to be more important for students in the control group. Although both teaching approaches facilitate autonomy, students in the experimental group felt that their ability to choose was more restricted. However, such a result could be justified by the means and process followed in the experimental group. In particular, the implementation of the Nano-booklet guided students and limited their search of information only to that which was included in the booklet. On the contrary, the students of the control group did not use the Nano-booklet in order to search for their information although some of the material included was provided also to them. In addition, as it has already been indicated motivational factors can predict conceptual understanding. In the current case motivation could explain conceptual understanding in both groups. However, a different kind of statistical analysis would be in order.

D.3 Discussion: Findings on differences of conceptual change across VaKE participants according to their IQ

The last research question of the study concerned the students who participated in the experimental group and in particular whether depending on their non-verbal IQ some students were more facilitated to achieve conceptual change while participating in the V*a*KE unit. The hypothesis was that for less intelligent students the method would be more effective unlike more intelligent students for whom no difference would be revealed.

Only five out of the 18 questions of the generative questionnaire revealed time as a statistically significant factor when controlled for the covariate of IQ. Conceptual understanding was increased for an IQ around 94. This finding indicates that students with an IQ lower than 94, were more facilitated than those with a higher or the highest IQ while participating in the V*a*KE unit. The hypothesis was confirmed and it is in accordance with the findings from Weinberger, Patry & Weyringer (2008). According to them V*a*KE^{+} which is more structured and allows for more viability checks proved to be more effective for the least intelligent students (<95). As shown the current V*a*KE unit benefited the most the least intelligent students in terms of conceptual understanding. The questions which revealed a highest mean of conceptual understanding when controlling for IQ, concerned the lotus effect and nano as size. This can be interpreted by the fact that more viability checks were initiated after each search for new information. Viability checks provide an opportunity for participants to embed the newly acquired information in their preexisting schemata (Patry, 2014)-their framework theories, suggesting that this information is viable. However, this new information could be embedded by the students either with the construction of misconceptions which would lead to synthetic models for students or by the reconstruction of their framework theories according to the scientific view, which would lead to full conceptual change. Furthermore, these viability checks are being facilitated through the discussion within the class where the zone of proximal development is triggered between cognitive heterogeneous students, in favor of those who are cognitively in lower levels.

Overall it is suggested that V*a*KE is an important tool for instructors since it provides an opportunity for achieving the double assignment, namely not only promoting knowledge acquisition but values education as well. Moreover, as it is already proven it is an ideal tool for implementing socioscientific issues in science education, while it addresses students' widespread failure to understand counterintuitive concepts, which are usually attributed to the inadequate attention given to the problem of conceptual change.

D.4 Limitations and future research

The current study had particular limitations which were taken into account. Regarding the study design not all predicting factors included in the "warming" trend of conceptual change were examined since that would lead to a great amount of data which would not after all be easy to be presented here. Secondly although students were examined according to their non-verbal IQ for plausible differences in conceptual change measurements, other factors such as reading comprehension which could inhibit comprehension of texts used in both cases was not taken into account.

Another limitation of the current study was that the researcher served as the instructor for both groups to control for applying the teaching methods according to their basic premises as well as the content knowledge. This means that the instructor was not blind to condition. However limited this approach may be, the benefits must be considered for controlling the knowledge provided and the application of the approaches as it would have been quite challenging to find or train other instructors on both aspects. Someone might consider that the results are due to instructor effects but this is not the case regarding conceptual understanding, since it occurred in both groups at the same levels.

In addition, the participants' number was not sufficient to perform some statistical analysis like mediation analysis which would have revealed more precisely direct and indirect effects of epistemological and motivational aspects on conceptual change.

Finally, one should consider the limited duration of the interventions. If the interventions were to last longer, better results in terms of conceptual change would have yielded.

It would be interesting to examine the approach of V*a*KE^{+} with respect to conceptual change since it provides more opportunities for students to reflect on the subject matter. This could presumably result in more meta-conceptual awareness from students leading them eventually to full conceptual change. Additionally, it would be intriguing since moral motivation (e.g. empathy) can be related to the V*a*KE approach (e.g. Gastager & Weinberger, 2012) to examine particularly the effect of moral motivation on conceptual understanding. This could yield further implications on whether conceptual change approach on knowledge acquisition could support the theoretical part of cognitive development within V*a*KE. In addition, such a research could add on the existing research concerning the hot aspects of conceptual change. Furthermore, since at the current study only assessment instruments used in conceptual change approaches were employed, it would be also engaging to investigate how assessments tools, such as WALK and LIM, constructed within the framework of V*a*KE could apply on the conceptual change framework. Moreover, based on the experiment of Nussbaum, Mason & Poliquin (2008) it would be interesting to examine whether providing explicit instruction of scientific argumentation in a V*a*KE unit aiming at conceptual change would lead to greater results concerning knowledge acquisition. In that case a variation of VaKE implementing Miller’s tree would be indicative.

In addition to recent results indicating that naïve physics continue to coexist with the scientific view suggesting that domain general abilities, such as executive functions interfere to domain specific conceptual changes, further research could take place investigating how executive functions interfere with the acquisition of values. V*a*KE could be an appropriate approach to examine moral development however a longitudinal approach would be important since values are not concepts acquired within a V*a*KE approach but demand more and systematic effort.

Regarding now the field on N-ST in primary education plenty of topics are indicative for future research. However, what is more important for someone who is interested in implementing this scientific field in primary education in terms of conceptual change is that the topics should be implemented following a specific order. In that way it would be more appropriate for students in order to make the required ontological changes in their cognitive schemata and achieve conceptual understanding.

Overall V*a*KE is a multidisciplinary approach with many choices of topics’ implementation not only in primary education but in every educational level. In addition, the current study indicated that it can foster conceptual change, motivate students and sophisticate their epistemological beliefs. Nevertheless as it is pointed out specific activities should be implemented in a prototypical V*a*KE unit while teaching for conceptual change.

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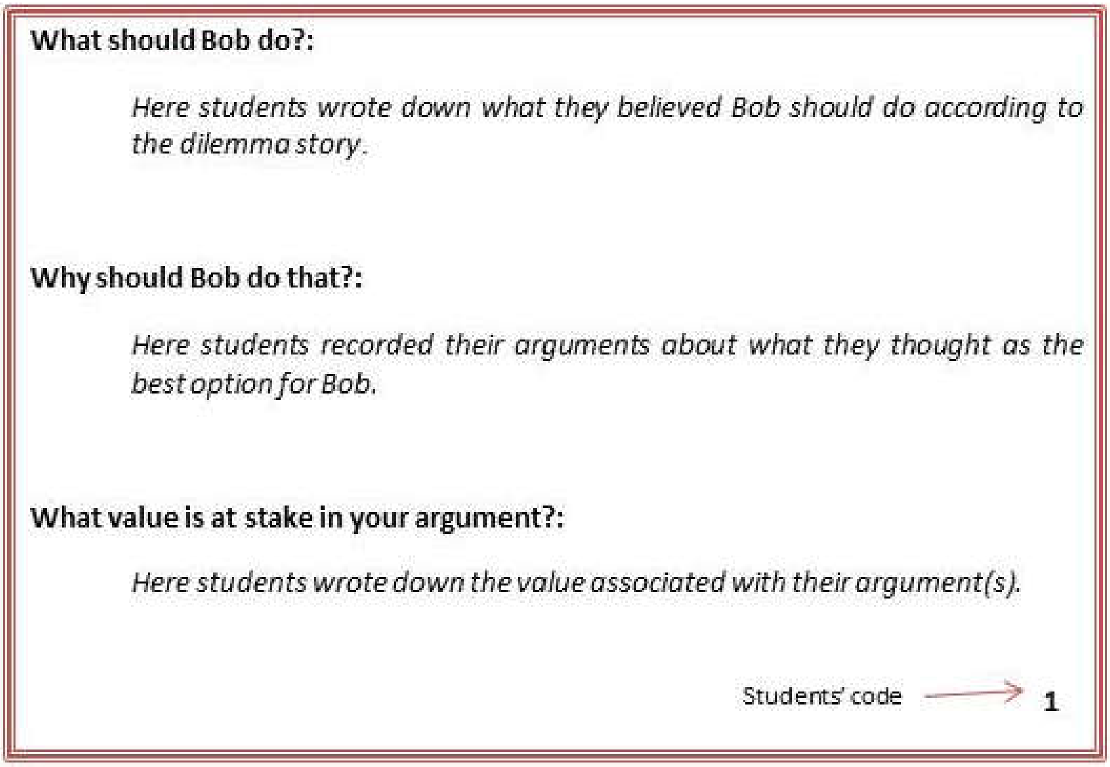
F Appendixes

F.1 Appendix 1



What should Bob do?:

Here students wrote down what they believed Bob should do according to the dilemma story.

Why should Bob do that?:

Here students recorded their arguments about what they thought as the best option for Bob.

What value is at stake in your argument?:

Here students wrote down the value associated with their argument(s).

Students' code → **1**

Image 1: The cards provided to participants in the experimental group during the first and second dilemma discussion

F.2 Appendix 2

The Nano-booklet provided here is a version of the original booklet, translated in English. All rights of the pictures included in the Nano-booklet belong to their rightful owners. The texts included were rewritten and simplified to match students' level of reading comprehension. The term nano-particle (νανο-σωματίδιο) was not adopted during the interventions. Instead the term nano-piece (νανο-κομμάτι) was used (Geddis, 1993; Shulman, 1986). However, in this translated version of the Nano-booklet the reader will find the term nano particle.

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3rd Educational district, Florina
3rd Elementary school, Florina
5th Elementary School, Florina

Florina, 2014

....investigating**nan o sized** objects

How small can objects be?

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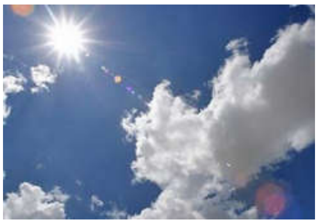
The meaning of "size" around of us…

Look for a moment outside your window. What do you see? How many objects have the same size as yours? How many objects are smaller

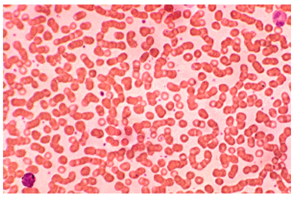
than you? How many objects are bigger than you? The trees, the mountains, the buildings, the sun, the moon are only a few examples of bigger objects than you. Can you think of more examples?



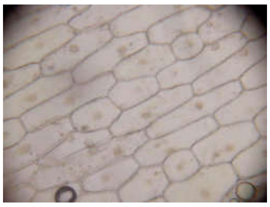
Now try to think of how many those objects and organisms are that are smaller than you or even completely invisible to your own eyes.

At this point where your eyes cannot see any further objects of the "invisible" world is where the world of big objects comes to an end.

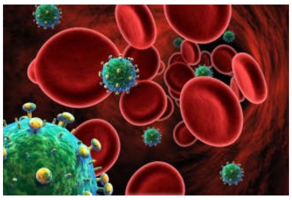
Have you ever wondered "which is the smallest thing you can see with your eyes?" What happens when our eyes can't see other objects? Does that mean that they do



not exist? If we use a magnifying glass or even better a microscope and we look closely at our blood, we will see that tiny cells exist which we couldn't see with our eyes. How does an onion look like if we observe it with a microscope? These are only a few examples of objects that we can't see with a naked eye so we would need some assistance from the microscope. And this is the world of small things.



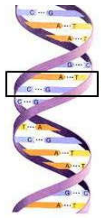
One might think: are there any smaller objects than the small ones? How could these be seen? If they exist, can humans use these tiny items for their own benefit?



What does nano mean anyway?

The world "nano" comes from the ancient-Greek word denoting dwarf. How small is the nano-size? In the International System of Units (SI), the word "nano" means one billionth of a meter! It is difficult to imagine how small that size can be, isn't it? We can measure these nano-objects in a specific scale, called nanoscale, using nanometers as a unit of measurement. In nanoscale we can measure sizes from 1 to 100nm.

We can say that an object is nano sized only when one of its dimensions (height, length, width) can be measured in the nanoscale. Here are only a few examples of objects belonging to the nano scale.



Your nails grow one nanometer per second!

DNAhasa diameter 2,5 nanometers.

The width of a wool of hair ranges from 80.000 to 100.000 nanometers!

The following picture (image 4) compares the size of several objects.

The biggest ones from the tennis ball till the dot belong to the world of **big** objects. Then from the cancer cell till the bacterium is the world of **small** objects, while from the virus till the glucose one can find the world of **nano** objects! At the end of this scale the smallest part of water can be found, namely a water **atom**.

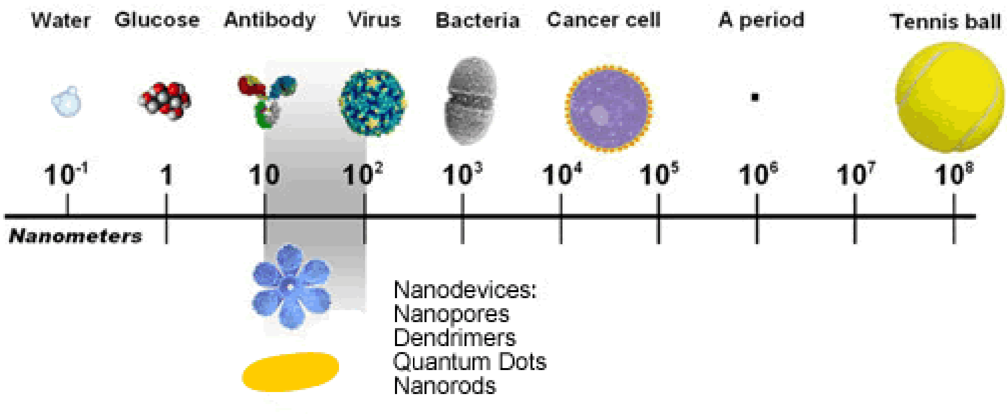


Image 1: The comparison of objects according to their dimensions

Reference:

http://www.nano.gov/nanotech-101/what/nano-size(retrieved 13/11/2014)
Filipponi, L & Sutherland, D, (September 2010). *NANOYOU Teachers Training Kit in Nanoscience and Nanotechnologies, Chapter 1*. Aarhus University, Denmark.

What exactly Nanoscience and Nanotechnology are?

Nanoscience deals with the investigation and process of nano sized objects and materials.

Nanotechnology deals with the manufacture of technological nano sized applications. In Nanotechnology and Nanoscience many other fields of expertise are evolved like physics, chemistry, material science and engineering science.

Nanotechnology provides the opportunity to scientists to manipulate these objects always employing the appropriate equipment. The first tools however for the observation of nano sized objects, were developed only over the last 30-40 years and that was the time when nanotechnology "was born" for the first time. (image 1)

Image2: Electron microscope

A few words about the "short" story of Nanotechnology…

The first scientific reference to Nanotechnology was in Richard Feynman's famous speech in 1959, "There is Plenty of Room at the Bottom". The word Nanotechnology though, has been first introduced by Professor Norio Taniguchi in 1974. During the decade of 80s, Eric Drexler used this word, mostly at his book "Engines of Creation: The Coming Era of Nanotechnology" which was published in 1986. However, research in the field of Nanotechnology was initiated after the invention of the appropriate instruments like the electron microscopes.

"Has anyone noticed the changes?"

In these dimensions, unusual physical, chemical and biological phenomena might be observed. There are many differences between small and big objects as far as their properties are concerned.

Gold is a common example since from the ancient years it has been used for its color properties which are in relation to its size. Golden jewelry display the usual gold color (image 2). But if we start to "cut" gold in pieces which are nano sized its color will be other than gold. Finally, if we observe the smallest part of gold, we can see that its color is white!!

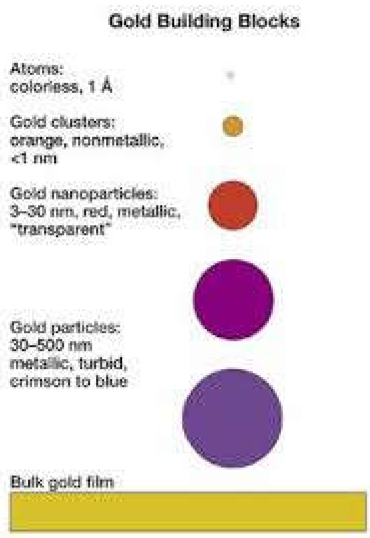


Image 2: Gold and its colour changes

In the Middle Age, gold was used to provide the red color in the stained glasses used in catholic churches (image 3).

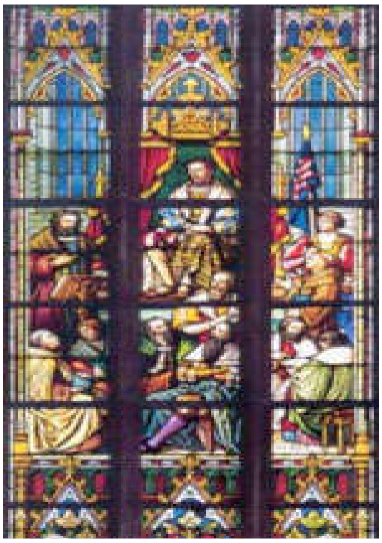


Image 3: The nano-parts of gold that appears in stained glass give them the red colour

References:

EuropeanCommittee. (2007). Nanotechnology: Innovation for tomorrow's word. Educational Leaflet (in Greek).

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http://www.nanotec.org.uk/report/chapter2.pdf (Retrieved 22/11/2014)

Applications of Nanotechnology: The case of nature

Examining nature...
Various species of living organisms in nature are of interest to nanotechnology scientists. Animals such as geckos (species of lizard) and mussels are considered to be very good "welders" in nature. Sharks have "nano-scales" which allow them to swim very quickly, while Morpho butterflies have intense blue feathers, because they have "nano-wings" that cause strong reflection of this highly intense blue. Next in line of interest is an Asian plant which is of interest in terms of nanotechnology and scientists try to imitate it in many new applications.

The lotus effect

Have you ever noticed that when water droplets fall on leaves of a cabbage, they turn into small spheres of water? But does this happen with other plants or vegetables as well? The leaves of the Asian lotus plant (image 5), were the first studied displaying an interesting surface. This surface helps the plant to remain waterproof, when water falls on them.

The lotus flower is "hydrophobic, and this means that it is afraid of water. If water also falls on the lotus leaf, they easily clean all the dirt from their surfaces keeping them clean. This phenomenon is called self-cleaning. If you look at a lotus leaf with a microscope you will notice many micro-projections. If you later observe it with an electron microscope you will see that each micro-projection has some other very fine nano-protrusions, which essentially allow dirt only to stand on its surface. In that way whenever water passes over the leaf dirt is being cleaned (image 6).

Image 4: The water drop becomes round in the surface of a lotus leaf

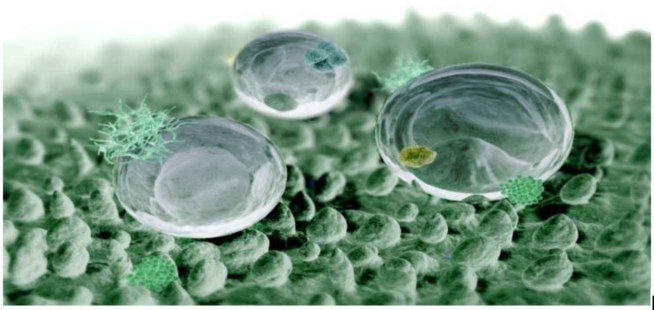

Image 6: Water drops drag along all the dirt from the surface of a lotus leaf

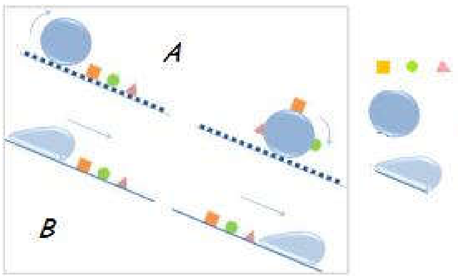

Image 5: The self-cleaning of a leaf that has nano-protrusions and of a leaf that does not have any

In picture 7 we can notice:

A: A surface exhibiting the lotus effect, with the round water drop and self cleaning effect (ex. cabbage)

B: A surface which does not react like the lotus effect (ex. lettuce)

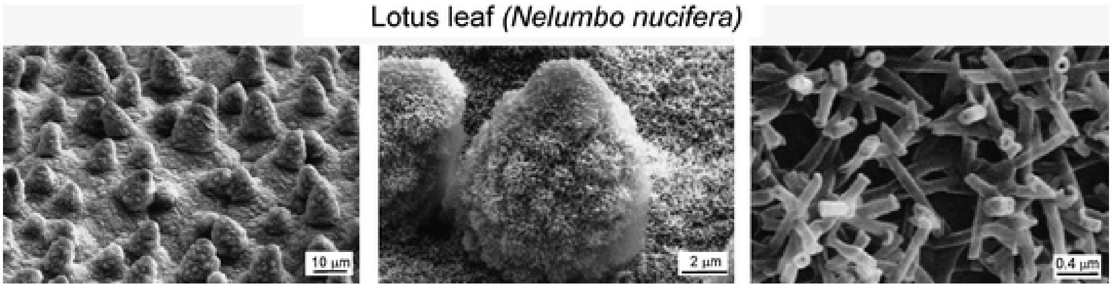

Image 7: From left to right. The structure of the lotus leaf under the microscope is presented. Next the lotus leaf appears in progressive magnification. Finally, the nano structure of the lotus leaf can be observed.

In the first part of image 8 from the left, we can see the micro-projections in the lotus leaf. In the second part there are the nano-protrusions up on a micro-projection. The third image shows the nano-projections.

References:

EuropeanCommittee. (2007). Nanotechnology: Innovation for tomorrow's word. Educational Leaflet (in Greek).

Filipponi, L & Sutherland, D, (September 2010). *NANOYOU Teachers Training Kit in Nanoscience and Nanotechnologies, Chapter 1*. AarhusUniversity, Denmark

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http://goo.gl/jlCvw7(Retrieved 14/11/2014)

http://www.lotusflowermeaning.net/(Retrieved 14/11/2014)

Applications of Nanotechnology: The case of Technology

As we said before, Nanotechnology employs many disciplines together. In many cases technology imitates nature. Below are some indicative applications of nanotechnology in everyday life:

Medicine
Scientists try to develop new techniques to treat cancer with nano particles which can delivery drugs to the cancer infected cells.

Computers
Scientists create nano sized computer components aiming at increasing their performance.

Food
Scientists consider using nano-materials for better taste in food, to ensure their safety or even to enhance their packaging process.

Space
Using nano-fuel the amount of fuel that a spacecraft may need will be significantly reduced, the cost of a mission will be reduced and the journey to space will become much easier.

Clean water
Nanotechnology can facilitate water filtration providing better water quality for countries in need. Even mud can be turned into drinking water.

Sports products
Far more resistant tennis rackets, golf clubs etc. are being manufactured.

Fabrics
Waterproof and Self cleaned fabrics are being produced.

Reference:

http://www.understandingnano.com/nanotech-applications.html (Retrieved 14/11/2014)

Nano-coatings

Many applications in fabrics and coatings have imitated the lotus effect. For example, if we “add” some “nano-materials” in paints and coatings regular surfaces can be turned into water proof and self-cleaning surfaces. Nano-coatings and nano paints can protect surfaces from rain and dirt, postponing also the process of fading for a long time.

Image8: The ForthBridge, Scotland

A well-known example of the application of nano-colours is the Forth Bridge in Scotland (image 9), where due to the size of the bridge, the painting process lasted from 2002 and it was completed in 2011! However, it is expected that because of nano-coatings use, the bridge won’t need to be painted again for at least 25 years. In addition, nano-coatings have been used on ships, thus many algae and barnacles cannot be hooked on their surface under the water. In this way people can save significant amounts of money spent on processes of cleaning and conservation.

References:

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http://wherefivevalleysmeet.blogspot.gr/2012/04/forth-bridge-and-nanotechnology-paint.html(retrieved 14/11/2014)

http://www.nanowerk.com/spotlight/spotid=19644.php(retrieved 14/11/2014)

www.nanoandme.org/nano-products/paintsand-coatings(retrieved 14/11/2014)

http://www.nanoandme.org/nano-products/paints-and-coatings/(retrieved 14/11/2014)

http://www.nanophos.com/gr/SurfaPoreTD_el.html(retrieved 14/11/2014)

http://goo.gl/RLhmhy(retrieved 14/11/2014)

http://www.polykem.gr/storage/pdf/TIMOKATALOGOI%202012/3.18%20NANOPHOS.pdf(retrieved 14/11/2014)

http://www.monosi-group.gr/index.php?option=com_content&view=article&id=65&Itemid=60(retrieved 14/11/2014)

Let's see some examples for "nano-coatings"…

Ultra-Ever Dry is a coating applied on various surfaces in order to repel every kind of fluids. This product is applied as a layer that adds to the surface a rough texture of edges and corners. These edges and corners (image 10) can responsible for repelling water, oils, liquid concrete and many other liquids.

Image 9: Ultra Ever Dry nano-coating has been applied on the surface.

Ultra-Ever Dry protects the surfaces from:

- **Corrosion.** It keeps objects dry. Water and many other liquids are repelled easily.
- -**Corrosion.** It offers improved protection by repelling water, seawater, acids and bases.
- **Freezing.** It repels water and thus the formation of ice, which can be easily removed from the surfaces.

- **Infection.** Liquids containing various bacteria, such as water are being repelled thereby bacteria cannot stand on the surface.

Ultra-Ever Dry allows the surfaces to:

- **Be self cleaned** since dirt, dust and bacteria can be cleaned only using some water droplets. Water drags along the dirt and the surface remains clean.

Reference:

http://www.spillcontainment.com/everdry (Retrieved 14/11/2014).

"NANO PROOF MARMO DS-275" is a product of the Duro Stick Company and it is suitable for marble and granite surfaces. This product repels liquids and makes surfaces waterproof and easy to clean, by means of nanotechnology.

USE

1. Substrate preparation

Surfaces must be clean, dry and free of dust, salts, grease and any loose material. The biodegradable cleaner BIOCLEAN by DUROSTICK is recommended for joints, tiles, granite and marble.

2. Application

We apply it with brush, roller or spray over the whole surface. 10-15 minutes later remove the excess material that has not been absorbed with a damp, soft cloth. For longer-lasting protection, use a second coat 30 minutes after the first use, especially in most absorbent surfaces. Stir well before use. The product is ready for use. It does not need to be diluted.

3. Storage

It must be stored in a cool place, protected from frost, for at least 24 months after production date.

4. Precaution Instructions

The product does not require a hazard labeling under current European and national legislation. However, it is recommended to keep away from children. If swallowed, you must immediately seek for medical advice and show the bottle or the label.

5. Packaging

Carton 15 pcs. 750 ml / Carton 6 pcs. 3,5 lt / 18 lt tank.

Reference:

http://www.durostick.gr/index.php?option=com_virtuemart&Itemid=477&lang=el (Retrieved 14/11/2014)

SurfaPore ThermoDry is a Nanotechnology product, which can be mixed with any other aqueous and acrylic paint for interior or exterior use.

It makes the surfaces waterproof while providing thermal insulation. It does not allow water vapor to pass the applied surface while holding off fungi, bacteria and dirt. The triple action of SurfaPore ThermoDry, namely keeping the heat off, preventing the transfer of heat from the interior of a surface to the exterior and waterproofing surfaces can help the energy performance of the buildings.

Available Packages:

Buckets for mixing in 3L and 10L aqueous acrylic paint

<u>Reference:</u>

http://www.nanophos.com/gr/ThermoDry_el.html (Retrieved 14/11/2014)

TROPICAL® Nano

A Nanotechnology Company

Nanotechnology Laboratory of Nano-materials

TROPICAL produces ecological nano-coatings which can be used for buildings, shops, offices, houses, for indoor and outdoor applications with various nano-materials (eg nano-carbon) giving paints and coatings amazing properties such as:

- Protection from UV radiation
- Repelling heat and cold from the building
- Saving energy
- Less energy for cooling or heating of buildings
- Self-cleaned walls using water or rainwater
- Waterproof walls
- Repel insect and microorganisms from walls
- Antimicrobial protection of the walls
- Antibacterial protection of the walls
- Protecting the walls against moisture and mold

APPLICATIONS

Tropical Nano-coatings are ideal for buildings, shops, offices, homes, schools, hotels, hospitals, theaters, cinemas, conference rooms.

Welcome to the world of nano-technology......

Tropical-Nano is a Greek high-tech company with significant innovations in nanotechnology, which has won awards for its innovative products from Bill Gates, (chairman of Microsoft).

Our company cooperates with the University of Crete and the German GKSS Research Center with which these new nano-materials and products were developed.

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Fax: +30 210 5151065

Reference:

http://www.tropical.gr/site/images/nano/nanocolors.pdf (Retrieved 14/11/2015)

Nanotechnology: Two women were killed by Nano-parts of matter

After the death of two women working in a factory producing paints and coatings in China from severe lung disease, researches warn that tiny pieces of matter, used in thousands of household products can kill.

Researchers from China said that seven women workers in a coating and paint producing factory where nano-materials have been used, became seriously ill and two of them died. Experts say that these are the first strong evidence that nano-particles can be dangerous to our health. The nano-pieces, measuring billionths of a meter, encountered in coatings, sunscreen, medicine and elsewhere. Researchers publishing in the European Respiratory Journal reported that nano-particles were found deep in the lungs of the workers who were ill.

Beijing Clinic who treated the workers mentions that the workers' rural origin and the fact that they have been working without safety and hygiene measures and also without knowing the potential toxicity of the materials were handled. However, people from the clinic cannot be completely sure that the nano-particles caused the illness so they have decided to cooperate with researchers in order to answer this upcoming challenge.

Dr. Andrew Maynard, chief science adviser of the Woodrow Wilson International Center in Washington says that the researchers have not yet identified what kind of nano-particle was used or what the inhaled quantity was. However, he states that "it is the first clear case denoting a correlation between someone who inhales nano-particles in the workplace and gets seriously ill. The world will have to take this very seriously. The international research community should be alarmed."

September 2009

From: BiotechWatch.gr

Reference: DailyTelegraph

Reference:

http://www.biotechwatch.gr/nanoChinaVictims (Retrieved 14/11/2014)

Nano-coatings & life

Nano-materials have entered our lives progressively and they can often be found in products such as creams and sunscreens without even knowing. So a debate has launched between scientists and committees controlling various products' safety.

Different kind of nano materials have been used for each application and that is also the case for nano-coatings.

However, the most essential aspect of nano-materials is their dimensions, which are identified in the nanoscale. A nano-particle can be so small (image 11) that can penetrate the cells of our skin or it can be inhaled and transferred through blood in the lungs of humans and other organs or even can be swallowed without knowing.

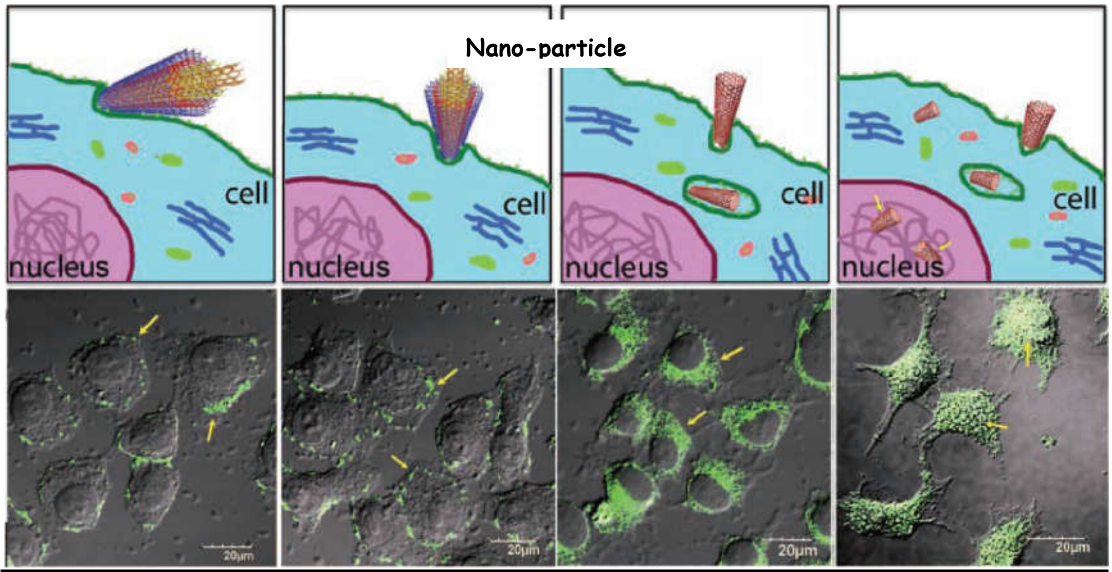

Image 10: From left to right. We see nano-particles of the same material trying to get into the cell but only the smallest ones on the right part of the picture manage to penetrate the nucleus of the cell. Adapted from Kang et al: Cell response to carbon nanotubes: Size-dependent intracellular uptake mechanism and subcellular fate. Small. 2010. Vol. 6. p. 2362–2366.
Copyright Wiley-VCH Verlag GmbH & Co KGaA.

Scientists while experimenting with living organisms found that some nano-particles may cause side effects on human health and other living organisms, when they invade them.

It was found that they can cause:

- Damage to fish brain
- They can kill a zooplankton species, thus they can disrupt the marine food chain
- They can infect the blood of an opaque fish species, called medaka leading to giving birth to infected eggs and ultimately eliminating the species
- Difficulties in breathing and respiratory problems in rats

- Respiratory problems in mice, especially when they are exposed to nano-particles for a long time.
- Respiratory problems to people who are being exposed long term to nano-particles in their workplace.

If nano particles can cause side effects on kinds of living organism, how can mankind be **protected** in order to continue their use in applications?

<u>References:</u>

Hoet, Peter HM; et al. (2004). "Nanoparticles – known and unknown health risks". *Journal of Nanobiotechnology 2* (1): 12. DOI:10.1186/1477-3155-2-12.

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http://www.nanotechproject.org/cpi/browse/categories/health-and-fitness/cosmetics/ (Retrieved 16/11/14)

Kashiwada S (Nov 2006). "Distribution of nanoparticles in the see-through medaka (Oryzias latipes)". *Environ Health Perspect. 114* (11): 1697–702. DOI:10.1289/ehp.9209

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Lam, C. W., James, J. T., McCluskey, R., & Hunter, R. L. (2004). Pulmonary toxicity of single-wall carbon nanotubes in mice 7 and 90 days after intratracheal instillation. *Toxicological Sciences, 77*(1), 126-134.

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Oberdörster, Günter; et al. (2005). "Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy". *Particle and Fibre Toxicology 2:* 8. DOI:10.1186/1743-8977-2-8.

Oberdörster, Günter; et al. (July 2005). "Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles". *Environmental Health Perspectives 113* (7): 823–39. DOI:10.1289/ehp.7339

Ryman-Rasmussen, Jessica P.; et al. (2006). "Penetration of Intact Skin by Quantum Dots with Diverse Physicochemical Properties". *Toxicological Sciences 91* (1): 159–65. DOI:10.1093/toxsci/kfj122.

Word-index

<u>Nanotechnology</u>: is the combination of scientific fields like science, engineering and technology which manipulate objects in sizes impossible to observe with naked eyes. The word “nano” derives from the ancient Greek word meaning dwarf.

<u>Nanoscale</u>: Objects smaller than the microscale and employed in nanotechnology are being measured on a scale called “nanoscale” using nanometers as its unit. In nanoscale the sizes are between 1 to 100nm.

<u>Nano-material:</u> a material which has one of its dimensions (height, length, width) small enough to belong to the nanoscale (1 to 100 nm).

<u>Nano-particle:</u> A part of a nano-material.

<u>Nano-coatings:</u> Coatings where nano-materials have been used in order to create surfaces mimicking the lotus effect.

<u>Hydrophobicity:</u> When some surfaces are “afraid” of water and other fluids so they eventually repel them. When liquids are repelled, droplets are converted into small spheres.

<u>Self-Cleaning:</u> When some surfaces have the property to repel dirt and clean themselves while water is spilled on them. Lotus leaves, cabbage leaves and nano-coatings are only a few examples.

F.3 Appendix 3

Pictures used during the main activity of the second intervention in both the experimental and the control group. All rights of the picture used belong to their rightful owners.

Image 2: Pollen as can be seen with naked eyes

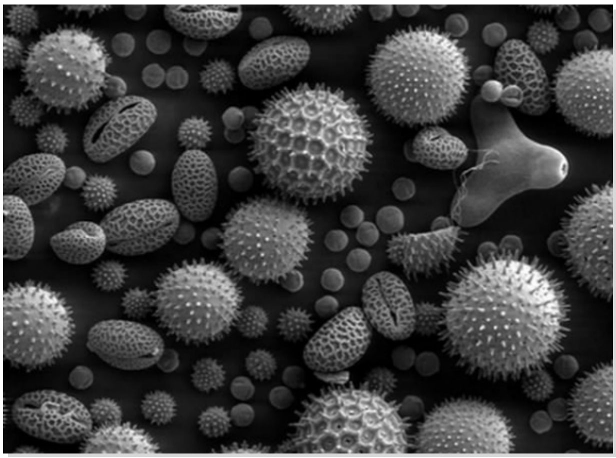


Image 3: Black and white picture of pollen grains in micro scale

Image 4: Sand in the macro scale

Image 5: Sand in the microscope

Image 6: Salt and pepper

Image 7: Salt and pepper under the microscope

Image 8: An onion

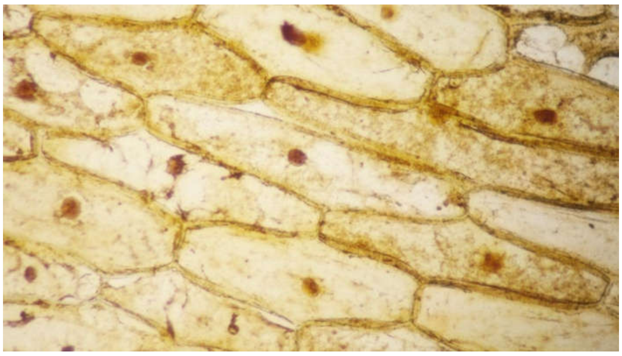


Image 9: Onion cells under the optical microscope


Image 10: Dust specks in the macro scale


Image 11 Dust specks under in the micro scale

Image 12: Bulk gold

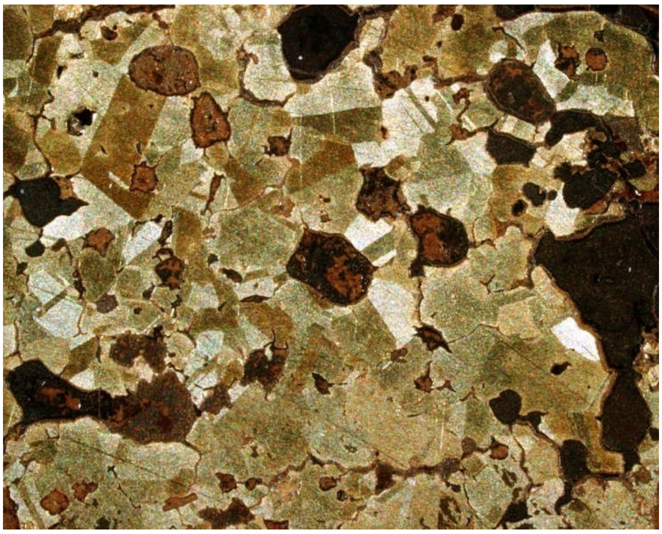


Image 13: A microscope image of the internal structure of a gold nugget

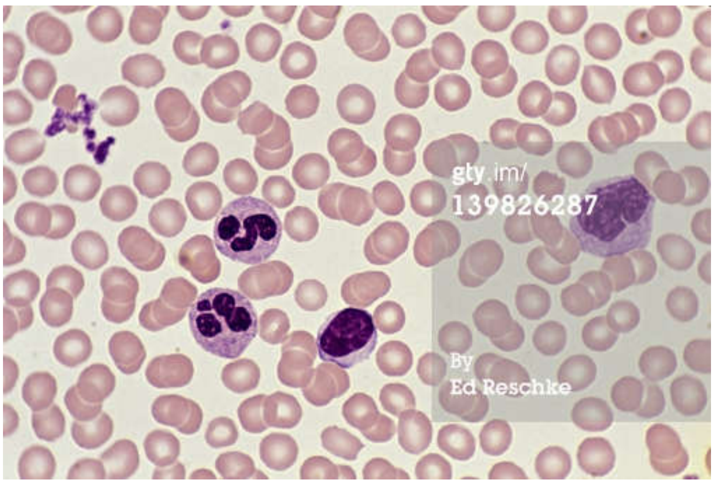


Image 14: Red blood cells and leucocytes under the optical microscope

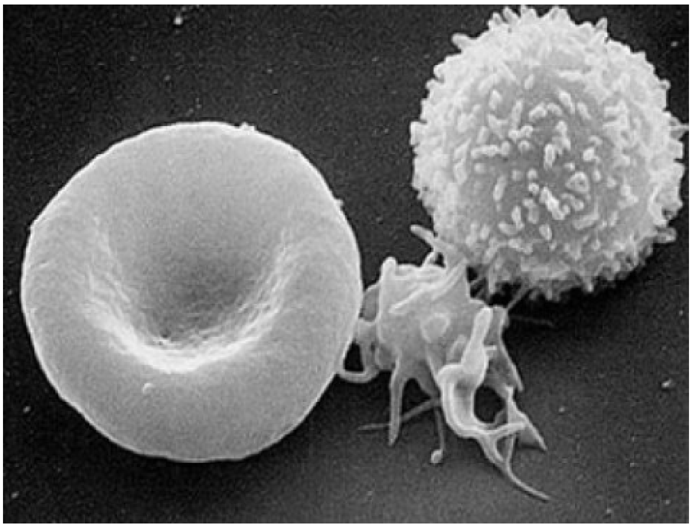


Image 15: T lymphocyte (right), a platelet (center) and a red blood cell (left) under electron microscope

Image 16: Salmonella bacteria in micro scale

Image 17: An optical microscope

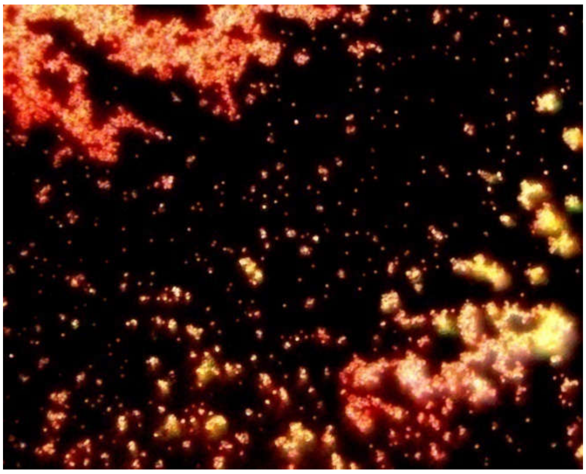


Image 18: Gold nano particles

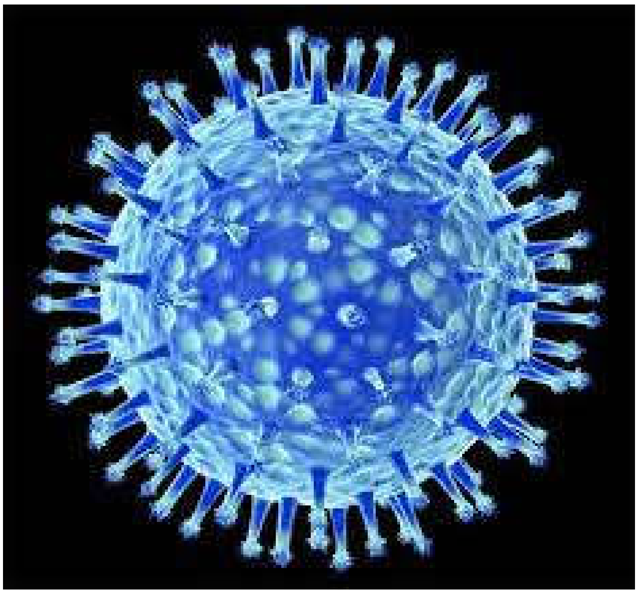


Image 19: Nano sized virus

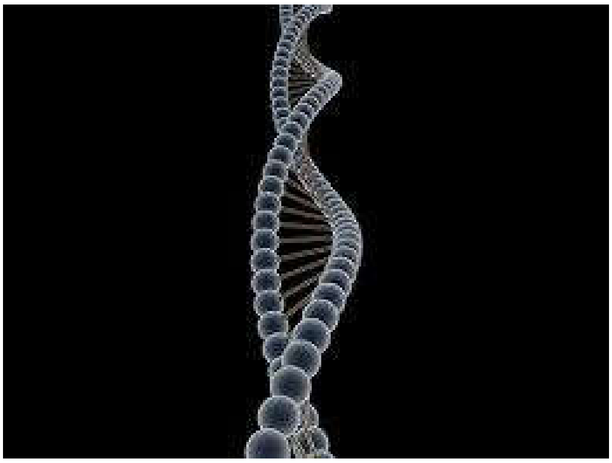


Image 20: DNA helix has a diameter of 2.5 nanometers, picture from an electron microscope

Image 21: The electron microscope,
in particular a Transmission Electron Microscope (TEM)

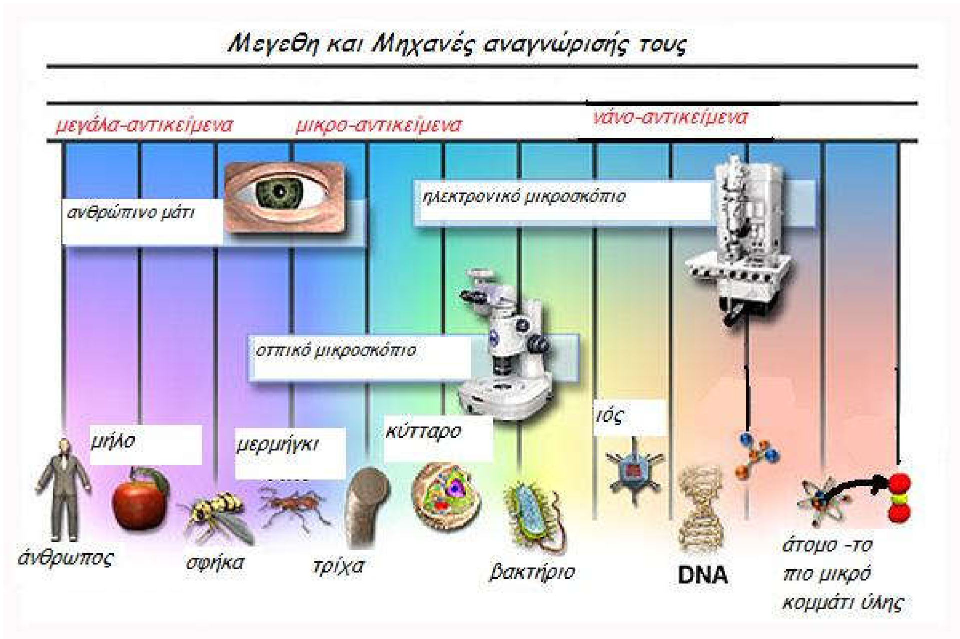


Image 22: Sizes, Scales & Instruments

F.4 Appendix 4

This video was used as an introduction to nano sized objects and nano as a scale during the second intervention for both the experimental and the control group.

F.5 Appendix 5

The conceptual hierarchy constructed by the students according to the size of its item.

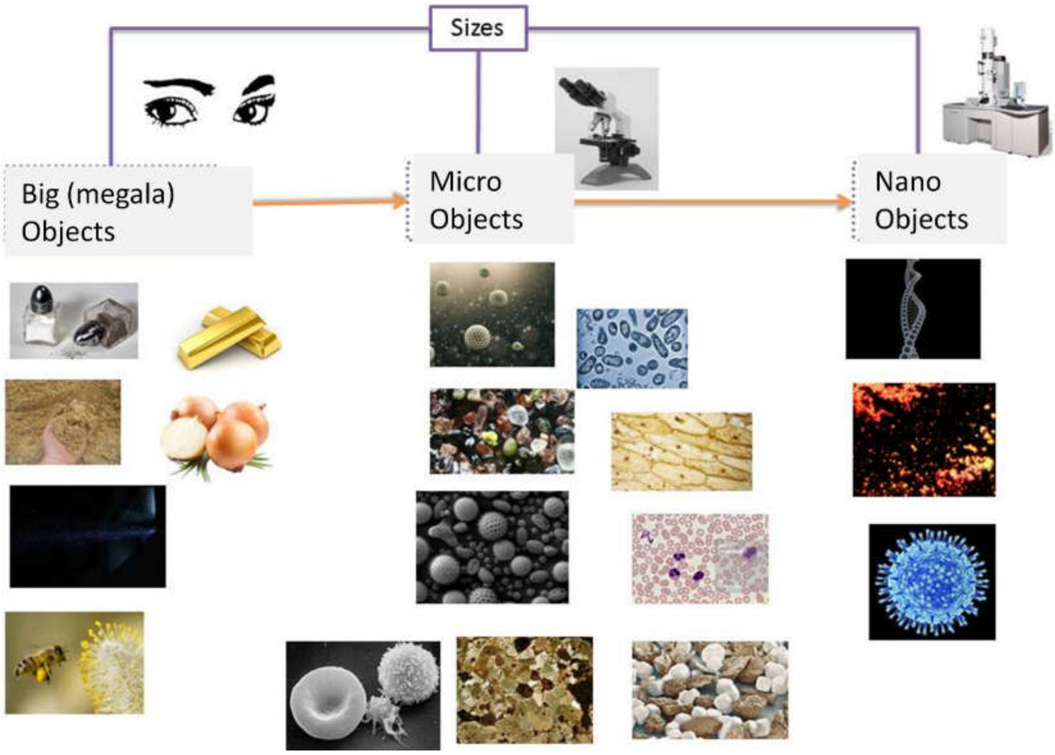


Image 23: The conceptual hierarchy of sizes

F.6 Appendix 6[5]

School:
Class:
Name:

1) Make a representation of the lotus leaf by drawing how it looks like as you look at it with your eyes, an optical microscope and an electron microscope.

[5] Parts from the content of the worksheet concerning the lotus effect was based on educational material employed in the project Science Teacher Education (STED) for in service teacher training in nanotechnology matters, held by the University of Western Macedonia, School of Education. The training was carried out by Leonidas Manou and Anna Spyrtou during the winter semester of 2014-2015. The project is funded by Greek funds and the European Union.

2) Describe with a few words how the structure of the lotus leaf makes it waterproof.

____

____

____

3) Now describe the property of the lotus leaf to be self-cleaned.

____

____

____

4) Make a drawing as well to represent how the lotus leaf can clean itself if water drops on its surface

Now ask from your teacher to provide you with the following materials:

- lettuce leaf
- cabbage leaf
- one piece of broccoli
- one piece of wood
- glass
- a stone
- water
- flour
- syringe

Design an experiment in order to examine which of the materials above demonstrate the lotus effect on their surfaces. In order to describe the experiment take into account the fact that the lotus leaf can clean itself easily and cannot get wet. Remember to use the same amount of water and flour, so that you can be assured that it is the material that counts and not the different amount of flour of water used on them.

Describe the steps you will follow in order to carry out the experiment.

1) Firstly I will

____

2)

3)

4) Make some predictions with your team about which materials will present the lotus effect and why

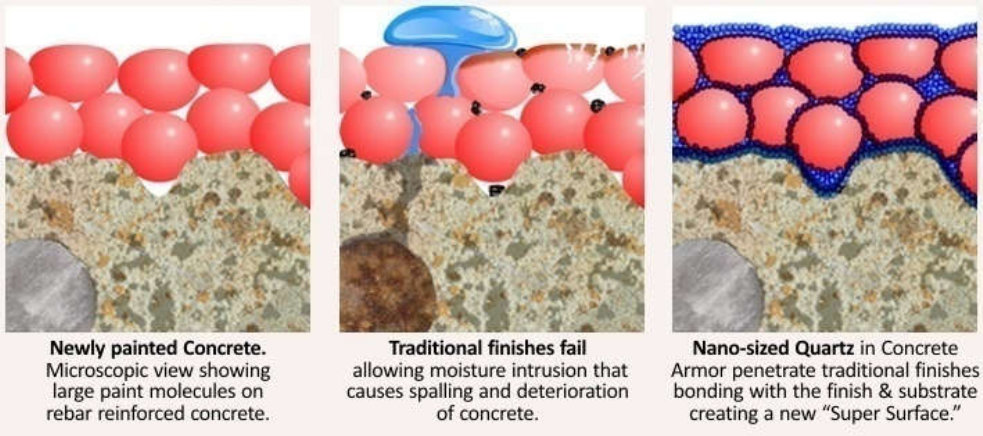
At the following table classify the materials you used in the experiment, based on whether they demonstrated the same behavior with the lotus leaf or not

Materials presenting the lotus effect	Materials that ***does not*** present the lotus effect

Discuss with your group and write down a conclusion in order to explain why a material demonstrates the lotus effect and what does that mean.

At this point you are familiar with the surface of the lotus leaf and its properties. Nano-coatings present the same properties as the surface of lotus leaf since they try to mimic it. Draw how you think the surface on which a nano-coating has been applied might look like.

Observe the following pictures. Try to explain the differences between the two surfaces. They are both concrete surfaces newly painted. On the left you can see how the surface looks like under the microscope where a regular coating has been applied and on the right you can see how the same surface might look with a nano-coating applied. Describe the differences between the pictures.



Draw a picture in order to explain what would have happened if the surface with the nano-coating was dirty and someone spilled water on it.

F.7 Appendix 7

The link provides the reader with the opportunity to watch the simulation of the lotus leaf and the so called lotus effect.

F.8 Appendix 8

The video refers to a particular nano-coating and some of its applications. It was translated and Greek subtitles were added. The text was simplified so that students could understand all information provided. Furthermore, the video was slowed down so that the viewer had enough time to read the Greek subtitles as well.

F.9 Appendix 9

The conceptual map constructed was divided in the end by students' arguments. On the one hand someone could find arguments about using nano-coatings but on the other hand arguments pinpointing their potential side effects. The following arguments are only some indicative of those stated by the students.

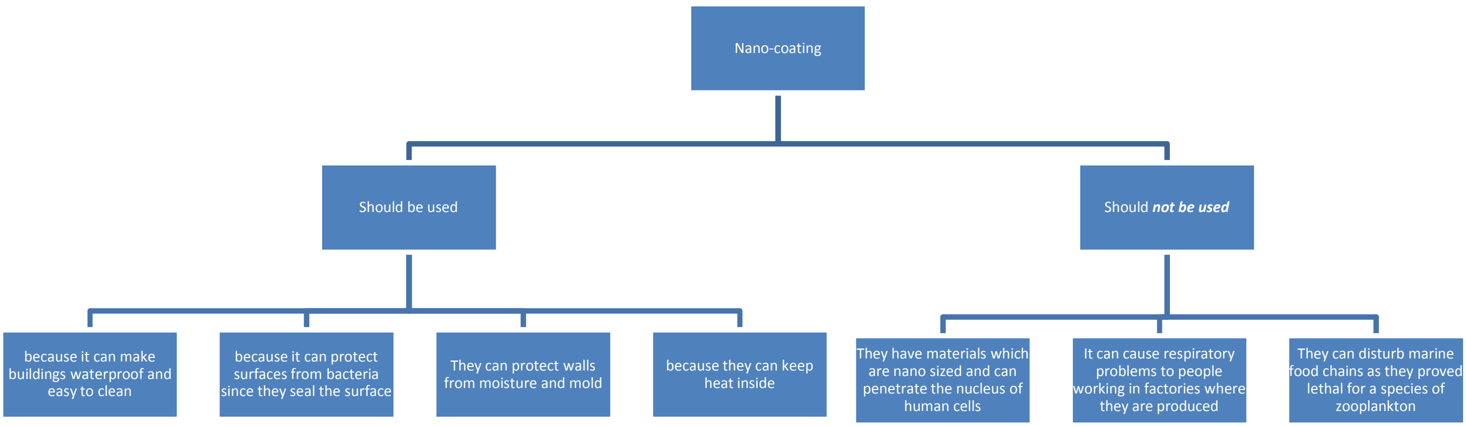


Image 24: An indicative example of how the conceptual map was constructed at the end

F.10 Appendix 10

The purpose of the following pictures was to inform people about nano-coatings. The content of each picture was chosen by the groups of students working together.

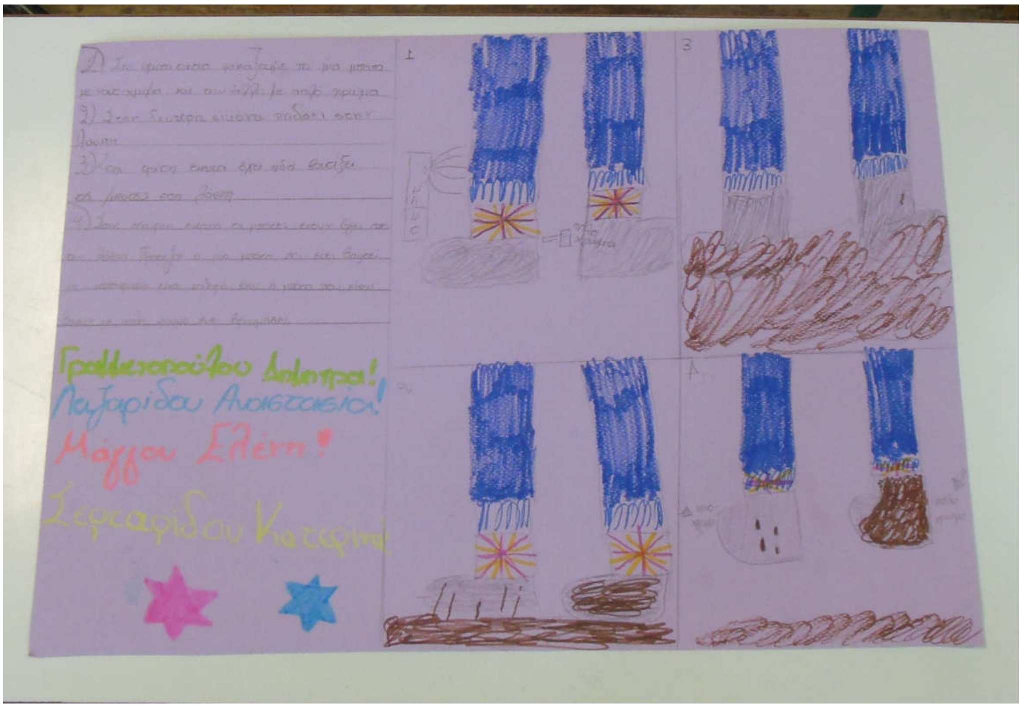


Image 25: This image portrays a pair of boots. On one of them nano-coating has been applied. The text near the picture explains the procedure how the boot will remain clear instead to the untreated with nano-coating boot.

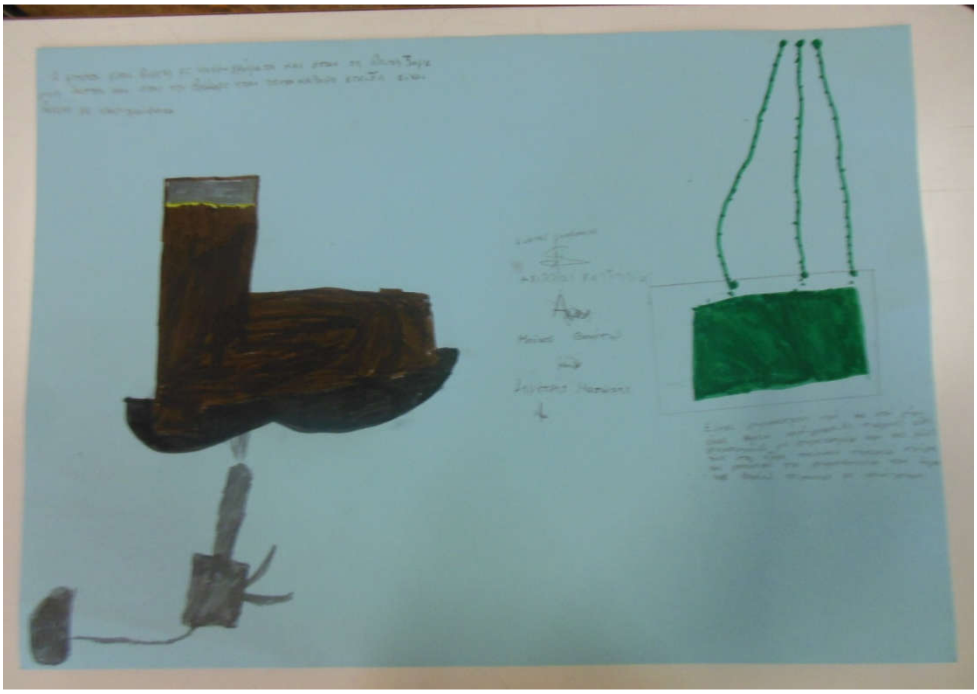


Image 26: This is a picture with some highlights of the video students watched about nano-coating and here they present and explain what is happening to the coated surface

Image 27: This is the special mask and uniform students proposed as a solution to the dilemma story. With a few lines students explain how these means can protect humans from nano-coatings

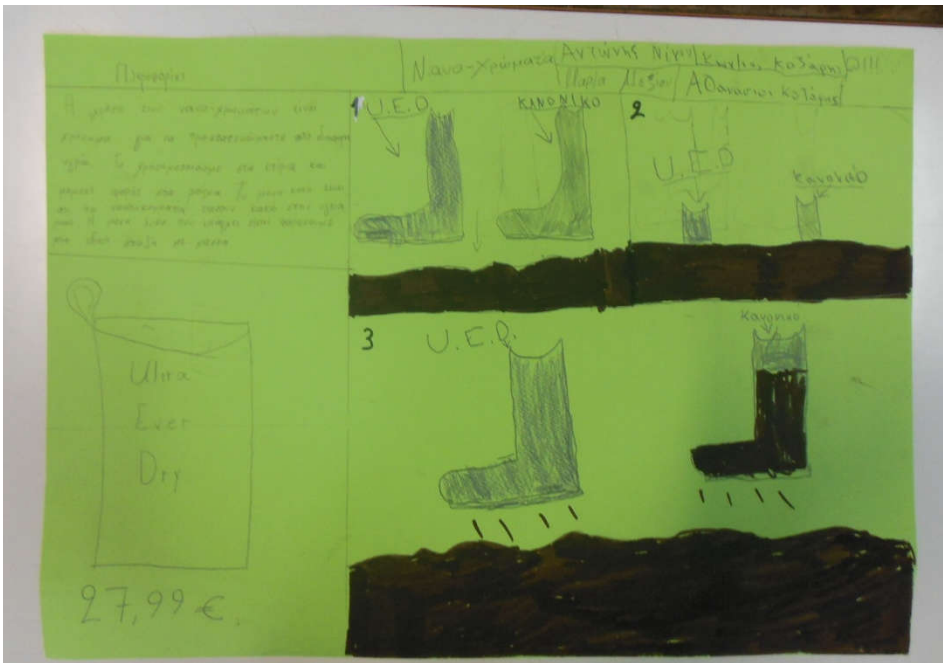


Image 28: Here the students decided to present an advertisement about nano-coatings

Image 29: This group decided to draw a poster depicting the dilemma story and suggesting at the end how nano-coatings should be used in the factory.

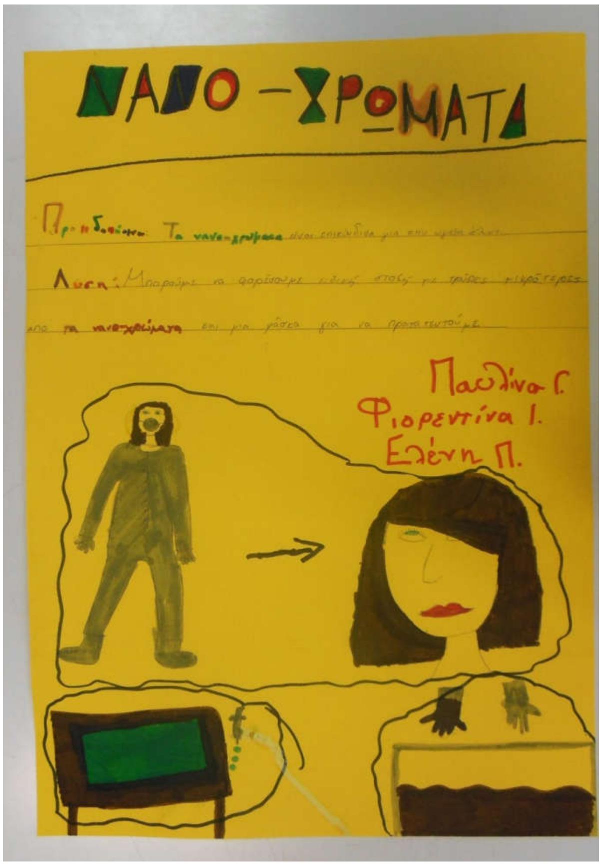


Image 30: At this picture the group decided to display two examples of nano-coatings applications, provided a warning about the side effects nano-coatings can have to human health, as well as a solution. They suggested that special uniforms

and masks which would have smaller holes than the size of nano materials would protect humans.

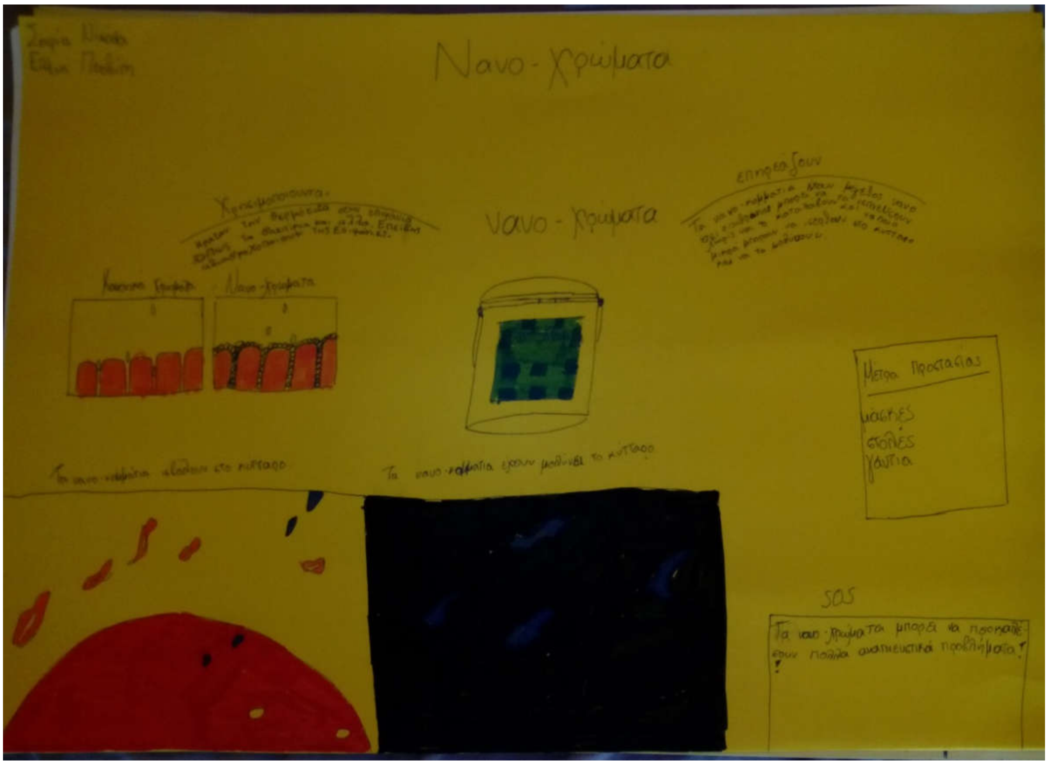


Image 31: This poster can be divided in three parts. On the left side one can see how a nano-coated surface would look under the microscope in comparison to a regular coated surface. Furthermore, students with a small text described how nano-coated surfaces can be protected unlike the regular surfaces. On the right side of the picture they provided another text explaining potential hazards of nano-coatings and they also draw at the bottom a human cell and the nucleus and how nano particles penetrated them. In the middle and right of the picture they suggested means of protection.

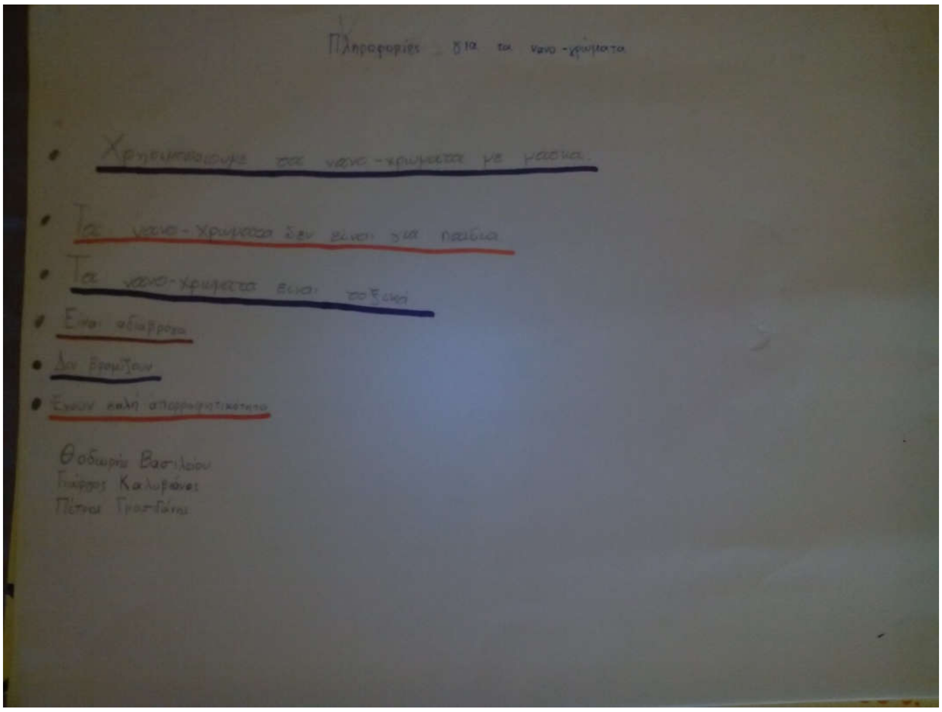


Image 32: Here some arguments are provided on whether one should or shouldn't use nano-coatings

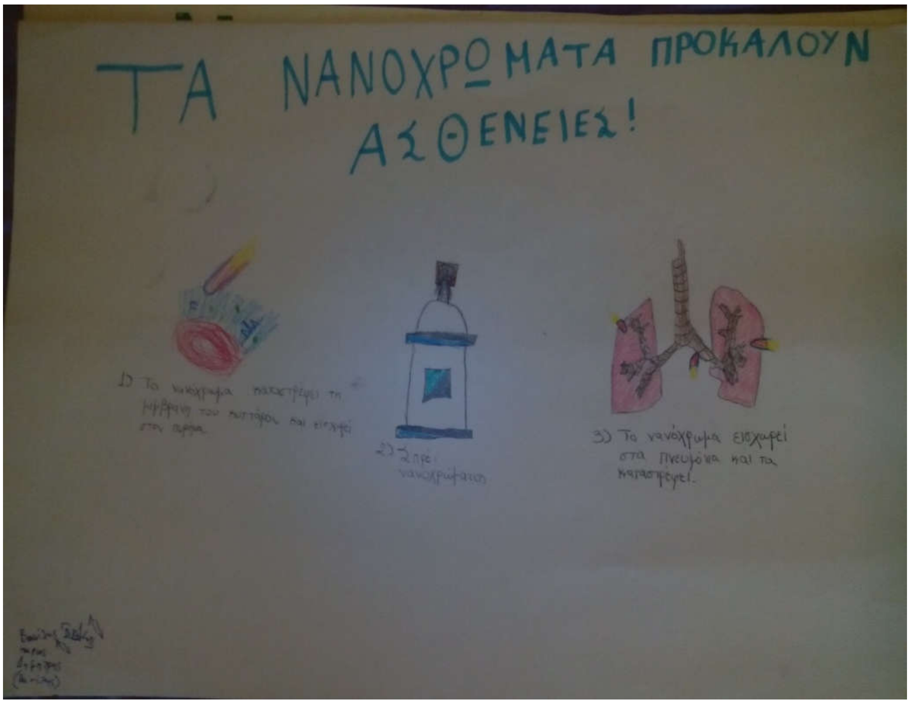


Image 33: This picture at the left presents a nano particle penetrating a cell and its nucleus. In the middle the students drew a nano-coating spray and at the right part of the picture they drew human lungs which are "infected" by nano materials. The poster is entitled as "nano-coatings cause diseases"

Image 34: This poster is divided in two parts. At the right one it is suggested that nano-coatings should be used only with protection measures. On the left side of the poster it is suggested that nano-coatings could induce diseases.

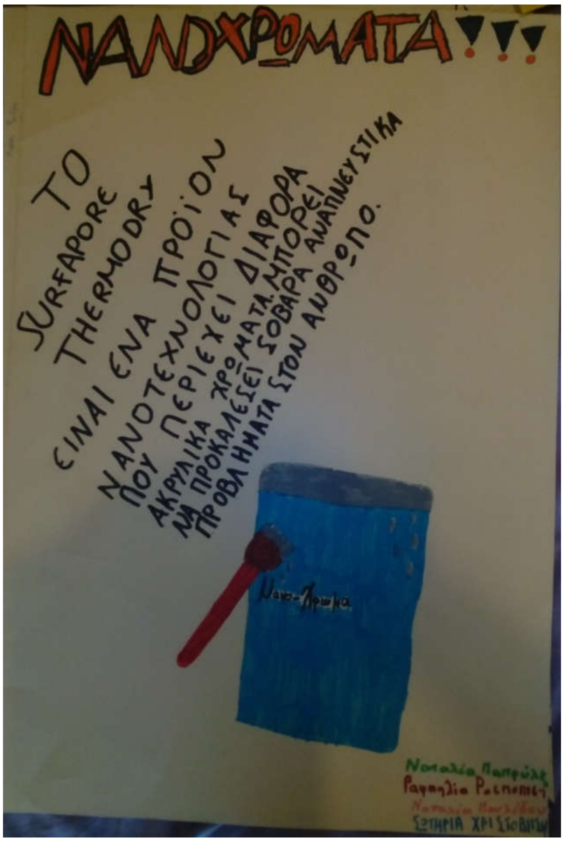


Image 35: This picture is more of an advertisement about nano-coatings suggesting as well that they can expose humans to respiratory problems.

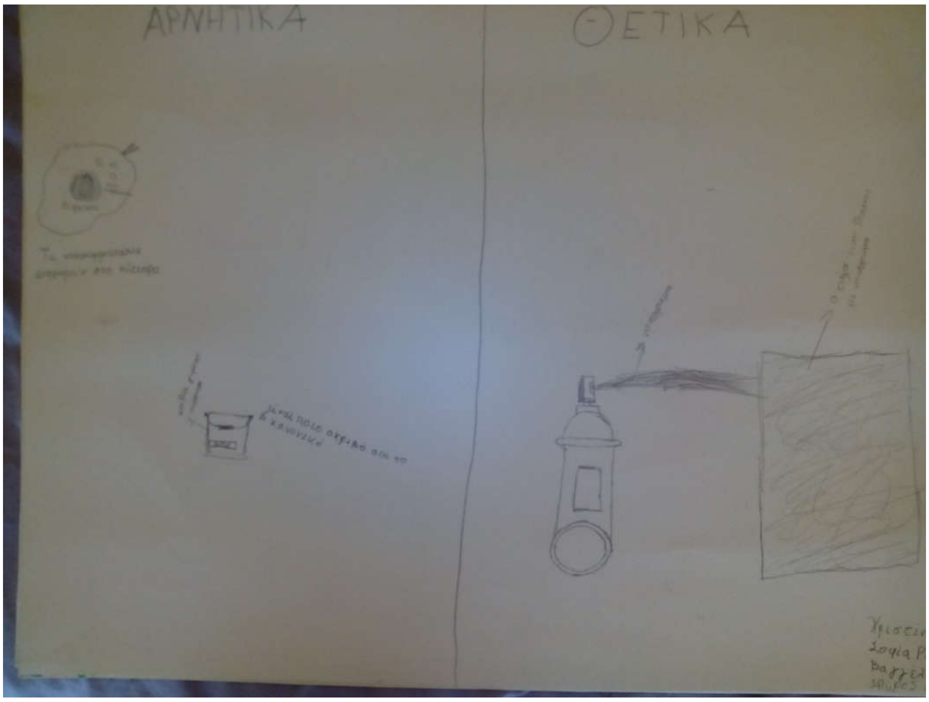


Image 36: This picture can also be divided in two parts. On the left side, the side effects are presented while on the right the advantages of using nano-coatings are presented.

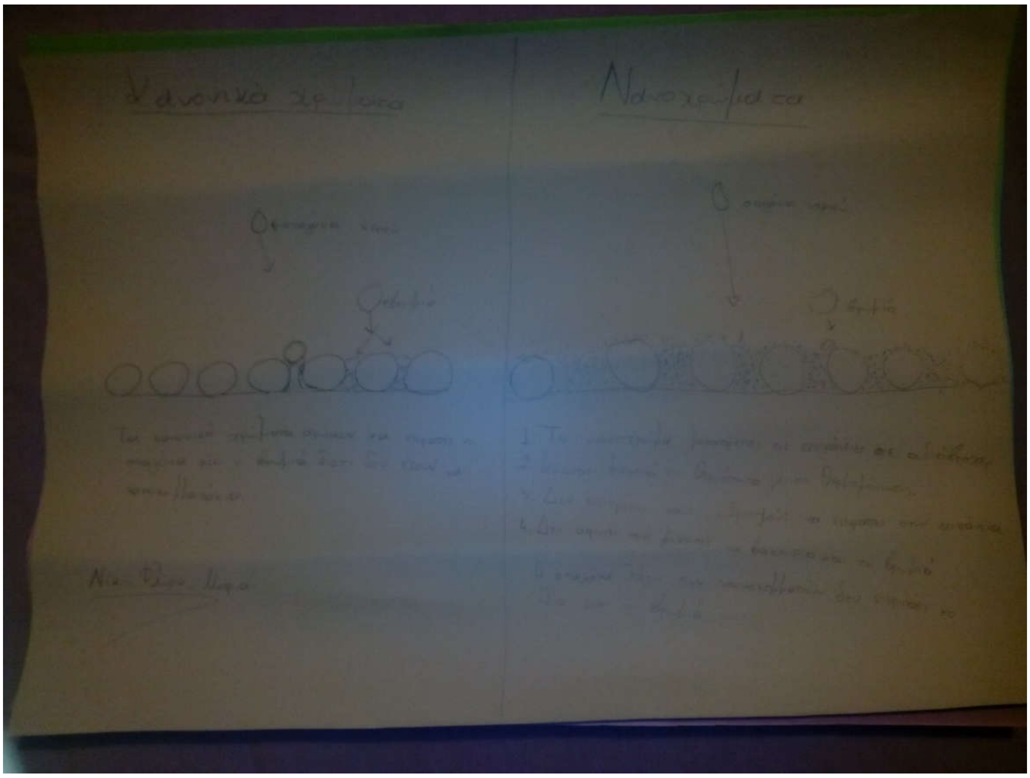


Image 37: This poster illustrates how regular coatings and how nano-coatings would look under the microscope. Moreover, the students explain the differences between the two coatings since nano-coatings display the lotus effect.

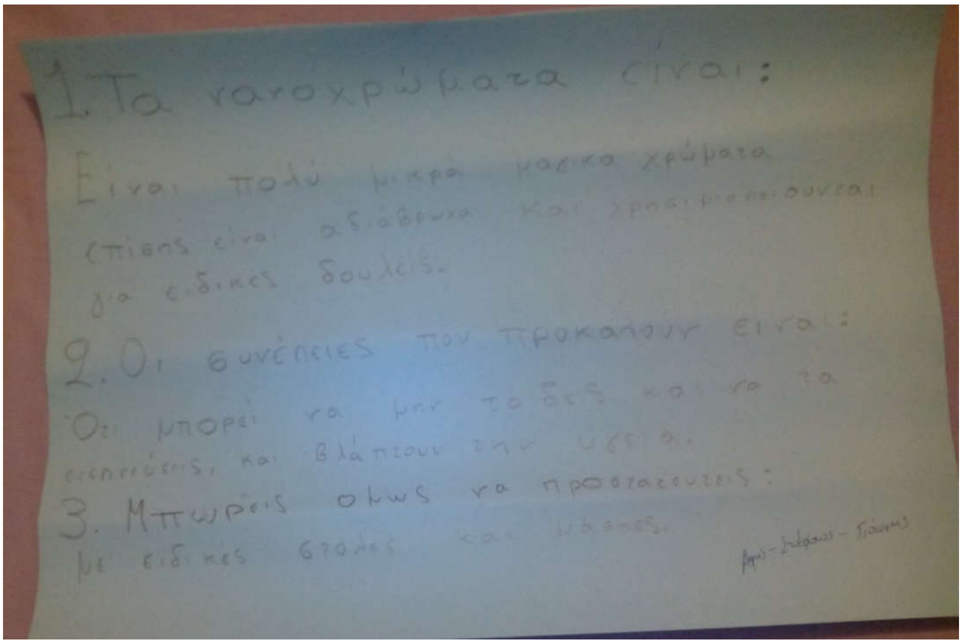


Image 38: At this poster students try to define nano-coatings, suggest their side effects and propose a solution to protect oneself.

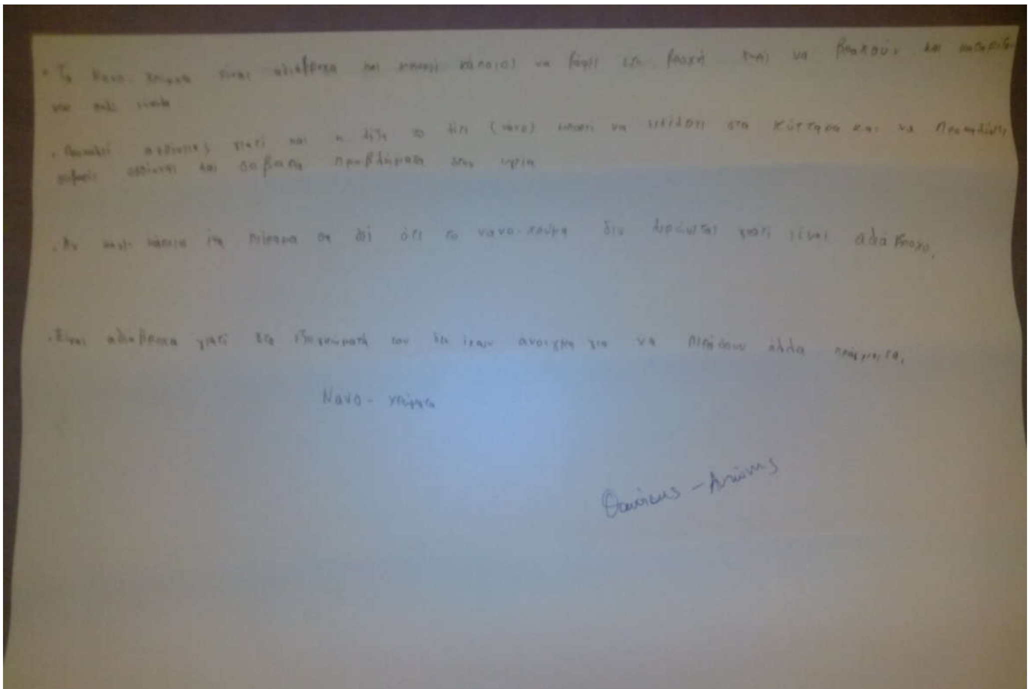
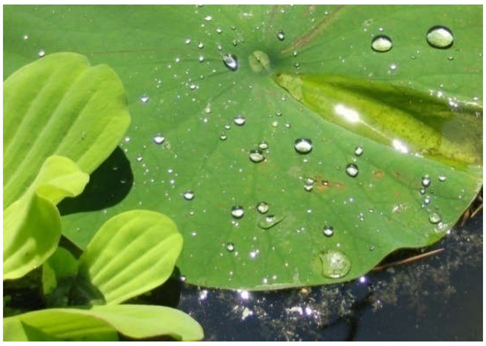


Image 39: This poster provides information on how nano-coatings could protect the surface from moisture, bacteria and dirt.

F.11 Appendix 11[6]

School:
Class:
Name:

The following pictures present two wet leaves of two different plants. Can you find the basic difference between these two leaves?

____
____
____
____

Now ask from your teacher to provide you with the following objects. Take the syringe and fill it with some water. Make each object wet and observe the shape of the water droplet. Be careful to use always the same amount of water.

- lettuce leaf
- cabbage leaf
- one piece of broccoli
- one piece of wood
- glass
- a stone
- water
- syringe

Can you predict why on some objects the water drop has a spherical shape?

____
____
____

[6] The content of the worksheet concerning the lotus effect was based on educational material employed in the project Science Teacher Education (STED) for in service teacher training in nanotechnology matters, held by the University of Western Macedonia, School of Education. The training was carried out by Leonidas Manou and Anna Spyrtou during the winter semester of 2014-2015. The project is funded by Greek funds and the European Union.

Classify now these objects according to the shape of the water drop on their surfaces.

Use the following objects once again. Design an experiment and describe the steps you will follow in order to prove which one of these objects can be cleaned more easily. Use flour in order to make the objects dirty. Use the same quantity of water and flour.

- lettuce leaf
- cabbage leaf
- one piece of broccoli
- one piece of wood
- glass
- a stone
- water
- syringe
- flour

Now describe the steps you will follow in order to perform the experiment:

1) First I will….

2)

3)

Perform the experiment and write down your observations:

Were all the objects cleaned the same way? Can you assume why this is happening?

In the following picture you can see how the lotus leaf looks like with naked eyes (image 2). Then next pictures (images 1, 3 & 4) illustrate the lotus leaf under the microscope.

Image11: The lotus leaf

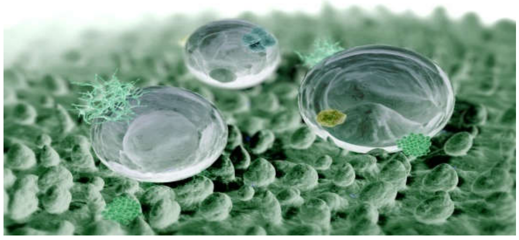


Image12: A Wet land dirty lotus leaf under the microscope

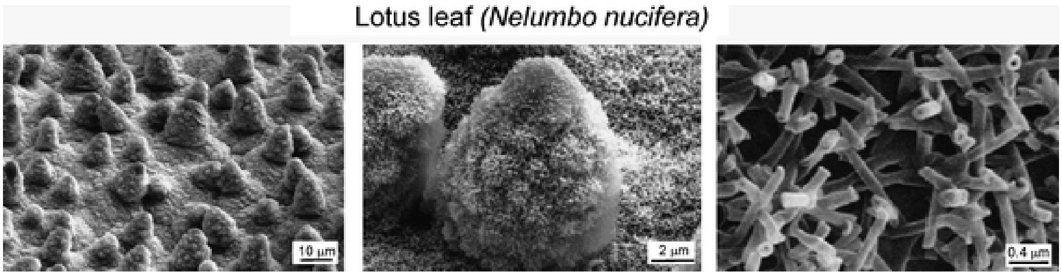


Image13: The lotus leaf in the micro- and the nano scale

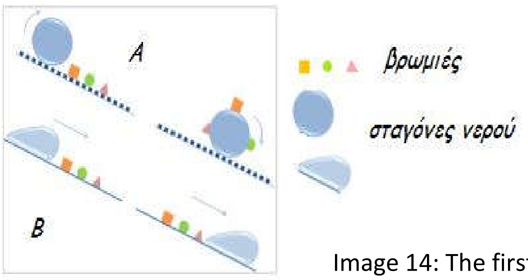


Image 14: The first surface (A) is a leaf which can be easily cleaned while the second one (B) cannot be cleaned with the same way

Describe how the surface of the lotus leaf looks like under the microscope.

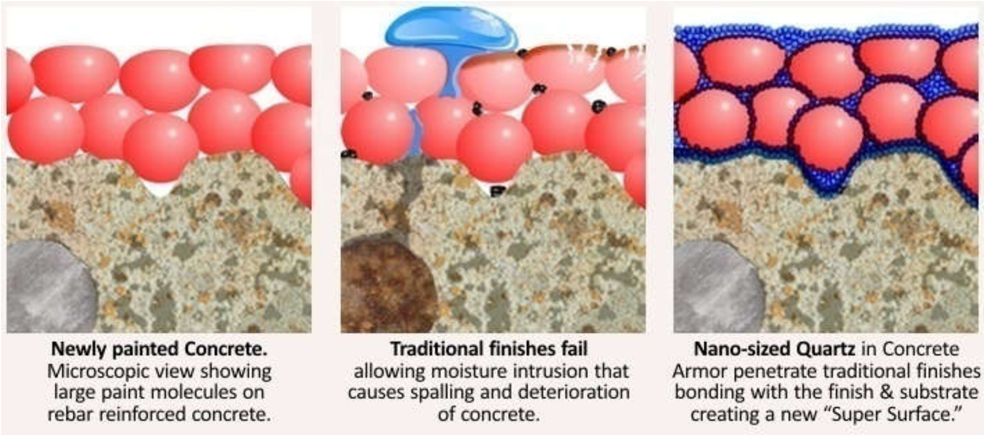
Describe now how the structure of the lotus leaf surface keeps the leaf dry

Can you explain in a few words how the same structure of the lotus leaf surface can keep preventing the leaf from getting dirty? (If you find it easier you can also draw a picture)

Write now a conclusion justifying the way the materials used in the experiments above behave:

The structure of the lotus leaf is mimicking a technological application, namely the nano-coatings. When nano-coatings are being applied on a surface this surface becomes waterproof and self cleaned exactly like the lotus leaf. Could you make a drawing to explain how a nano-coated surface could look like under the microscope?

Now observe carefully the following picture. These are two concrete surfaces applied with a regular and a nano-coating. Can you describe the differences between them?



Can you make a drawing to describe what would happen if the nano-coated surface was dirty and you wanted to clean it with water?

F.12 Appendix 12

Boy: .... Girl: .... Code number: ....

Birth Date: ……………

Date: ……………..

Some questions concerning science related issues are following. Read them carefully and then give an answer. We would like you to answer these questions according to what **you** believe is right. Please justify your choices. Thank you in advance for your help.

If we cut bulk gold in smaller pieces which we can still be able to see with our eyes, what is their color going to be? Why is that?

___

___

___

If we cut the previous pieces in even smaller pieces will they keep the same color? Why?

Materials keep the same color no matter how small we cut them? Why is that?

There is a piece of wood and a piece of glass. We pour a glass of milk on them. Then we take a piece of cloth and try to clean it. Which will be better cleaned, the piece of wood or the piece of glass, or maybe both? Why?

We are in the country side and we want to make a salad. But we must choose between cabbage and lettuce since we do not have much water in our disposal. Which one will be better cleaned? The cabbage, the lettuce or both will be better cleaned? Why?

If I spill a drop of water on a smooth piece of glass and on an absorbent piece of cloth, the shape of the water droplet will be in both cases the same? Why is that?

If I spill a drop of water on a cabbage leaf and on a lettuce leaf, the shape of the water droplet will be the same? Why?

If I spill a drop of water on a cabbage leaf and on a broccoli leaf, the shape of the water droplet will be still the same? Why is that?

John went to visit his father at work. His father showed him a microscope and John felt excited. He wanted to see how the smallest object on earth would look like under the microscope. However, his father showed him an onion cell telling him that this is the smallest object he could see with this microscope. Which is the size of an onion cell so that his father could take it and place it under the microscope? How was it possible to see it?

____

____

____

Is the onion cell the smallest object on earth? Are there even smaller items on earth? How would they be like? How are they called?

____

____

____

If the smallest object John could see under his father's microscope was an onion cell, then how those objects which are even smaller could be seen?

____

____

____

I apply a coating on a wall and on the iron railings of the porch. However, the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will be best cleaned, the wall or the iron railings? Why?

____

____

____

I apply a coating on a wall and a special coating on the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will be best cleaned, the wall or the iron railings? Why?

____

____

____

I apply the special coating on both the wall and the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will be best cleaned, the wall, the iron railings or maybe both surfaces will be cleaned the same? Why?

____

____

____

Imagine you have gone fishing in a lake. You have forgotten to take water with you and there is no drinking water around you. You can find water only in the lake. Would you drink water from the lake, yes or no? Why would you or why wouldn't you?

Could you drink the water if you cleaned it first?

How could you clean the water?

When are you going to be sure that the water is completely clean and you can drink it without getting sick?

John says that there is a special filter which can clean water even from bacteria. Is this possible? What kind of filter is that? How is this happening?

F.13 Appendix 13

Table 13: The established criteria for the classification of responses (0: irrelevant; 1: intuitive/naïve; 2: alternative; 3: scientific) are presented.

	Question	classification	Criteria
1	If we cut bulk gold in smaller pieces which are we still able to see with our eyes, what is going to be their color? Why is that?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	Change in property is not correlated with size/ Change in property is correlated with the instrument that caused the change/ No change in property because of the objects' value/ Change in property is caused by the instrument used for observation e.g. microscope/ No change in property/ Property change because of light/ No change in property because the smaller pieces come from the same material/
		2	Change in property is correlated with size but it's not sufficiently justified (reference to size is also accepted by means of observation e.g. optical microscope=micro)
		3	Change in property is correlated with size and justified by the fact that the electron cloud at the surface of a gold particle reflects different wavelengths of light depending upon their frequency. The bigger or the smaller the size of the particle the more different are the wavelengths of light reflected.
2	If we cut the previous pieces in even smaller pieces will they keep the same color? Why?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	Same with the previous question

		2	Same with the previous question
		3	Same with the previous question
3	Materials keep the same color no matter how small we cut them? Why is that?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	Same with the previous question but generally speaking and not about gold
		2	Change in the property depends on the size/ Change in the property depends on the material/ The above arguments are accepted without justification
		3	Change in the property can depend not only on the size of the material but at its nature as well. Justifications might vary depending the nature of the material
4	We are in the country side and we want to make a salad. But we must choose between cabbage and lettuce since we do not have much water in our disposal. Which one will clean better? The cabbage, the lettuce or both will clean better? Why?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	Both will clean because belong to the same ontological category/ The cleanliness property is related to the objects' size and surface (even or rough)/ Cleanliness property is related to the quantity of the object (many leaves)/ Cleanliness is related with every day experience Answers here might refer to one or both vegetables
		2	Projections on the surface of the leaf help water drift dirt / Although we can see the surface even and smooth with our eyes it has projections on its surface which repel dirt (reference to either cabbage of lettuce)
		3	Cabbage will be cleaned better because displays the lotus effect. The projections on the surface of the leaves restrain dirt on the top. The water droplets have a spherical shape due to these projections and eventually when they roll off the leaves, they collect the dirt along the way.

5	If I spill a drop of water on a smooth piece of glass and on an absorbent piece of cloth, the shape of the water droplet will be in both cases the same? Why is that?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	The droplets will have different shape because the surfaces are different (absorbent or even surface)/ The droplets will be different because on glass they will spread while on the absorbent piece of cloth will disappear (absorb)
		2	The droplets will not be different because the surfaces do not display the lotus effect/ The droplets will be different because one of them display the lotus effect
		3	The water droplet will not have the same shape because they are both hydrophilic surfaces meaning that the water droplet is not shapes as a sphere (acceptable if the non existence of the lotus effect is mentioned but explained in terms of the shape of the droplet) but the nature of the material is different (absorbent or not)
6	If I spill a drop of water on a cabbage leaf and on a lettuce leaf, the shape of the water droplet will be the same? Why?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	The surface is responsible for the shape of the droplet (even or rough)/ The shape of the surface is responsible for the shape of the droplet (round or straight)/ The ontological category of the surfaces is responsible for the shape of the droplet (both vegetables nothing changes)
		2	Reference to the projections on the lotus leaf but incomplete justification(e.g. the cabbage leaves have some projections like the lotus leaf)/ Reference on the spherical shape of the drop but incomplete justification Incomplete reference to the lotus effect (e.g. the cabbage leaf displays the lotus

			effect and the shape of the droplet will be like a sphere)
		3	The cabbage leaf displays the lotus effect and as a result due to the (nano) projections on the surface of cabbage leaves the shape of the droplets will be spherical unlike the lettuce. The lettuce leaf does not have projections on its surface and as a consequence the shape and as a consequence it does not present the lotus effect and the droplets won't be spherical.
7	If I spill a drop of water on a cabbage leaf and on a broccoli leaf, the shape of the water droplet will be still the same? Why is that?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	The surface is responsible for the shape of the droplet (even or rough)/ The shape of the surface is responsible for the shape of the droplet (round or straight)/ The ontological category of the surfaces is responsible for the shape of the droplet (both vegetables nothing changes)
		2	In both cases the droplets will be alike because both surfaces have projections on their surfaces
		3	Both vegetables behave like the lotus leaf because they have (nano) projections which convert the shape of the drops into spheres.
8	John went to visit his father at work. His father showed him a microscope and John felt excited. He wanted to see how the smallest object on earth would look like under the microscope. However his father showed him an onion cell telling him that this is the smallest object he could see with this microscope. Which is the size of an onion cell so that his father could take it and place	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	The cell is quite small but he manages to see it because he used the microscope/ Its size is big enough in order to be able to remove it and observe it in the microscope/ He sliced a piece and place in the microscope for observation/ He placed the entire onion under the microscope
		2	Referring to the onion, it is nano sized

	it under the microscope? How it was possible to see it?		object which can be observed with the electron microscope/ The onion is small enough but the microscope magnifies it and in this way it can be observed easier/ He took a piece of the onion and on its surface he observed the cell/ It is the proper microscope for this object's size
		3	The size of the cell is micro and he managed to see it because he took an onion peel and placed under the optical microscope with which one can observe objects of the microscale. Under the microscope he could see that the onion peel is consisted of cells
9	Is the onion cell the smallest object on earth? Are there even smaller items on earth? How would they be like? How are they called?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	Reference to objects of the macroscale as the smallest/ Reference to non existence of smaller objects/ Reference to objects of the microscale as the smallest on earth
		2	Reference to objects both on the micro and nano scale which are still incorrectly classified according to their size
		3	Reference to objects which are nanosized or even smaller, belonging to the atomic scale (the answers should depict the right conceptual hierarchy of the objects)
10	If the smallest object John could see under his father's microscope was an onion cell, then those objects how are even smaller how could be seen?	0	I do not know/ I do not answer/ irrelevant answers (e.g. the weather is fine)
		1	With glasses/ with our eyes/ with magnifying glasses/ with special instruments/ we can't see them/ they do not exist
		2	With optical microscopes/ with better microscopes/

			"Supermicroscopes"/ Professional microscopes/ "Nanoscopes"
		3	Electron microscopes
11	I apply a coating on a wall and on the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will be better cleaned, the wall or the iron railings? Why?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	The surface (e.g. even or rough) is responsible for the cleanliness of the coating and not the coating per se
		2	The coating is responsible for the cleanliness of the surface and as a result both will clean the same
		3	Both surfaces will clean the same way (or won't be cleaned at all) because the coating in the micro and nana scale allows the intrusion of dirt and moisture
12	I apply a coating on a wall and a special coating on the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall or the iron railings? Why?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	The waterproof surface won't clean because it repels water/ The even surface will clean better
		2	The waterproof surface is easier to clean (without any further justification)/ The wall will clean better because he has these small projections which will sustain dirt and when the water drops roll off they will carry the dirt along
		3	The iron railings will be cleaned better because they are painted with a special coating which makes the surface waterproof and behave like the lotus leaf/ The iron railings will be cleaned better because they are painted with a special coating which "adds" nano projections to the surface turning it into a waterproof surface. These projections sustain dirt on the surface and when the water droplets roll off the surface they carry the dirt along
13	I apply the special coating on both the wall and the iron	0	I do not know/ I do not answer/

	railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean better, the wall, the iron railings or maybe both surfaces will clean the same? Why?		irrelevant answers (e.g. the weather is fine)
		1	The surface (rough or even) is responsible for the cleanliness and not the coating/ Both surfaces won't be cleaned because the coating is waterproof and repels water
		2	The waterproof surfaces will be better cleaned clean better (without further justification)/ The waterproof surfaces will clean better because the water can clean them more easily
		3	Both surfaces will clean because this coating added nano projections to the surface which do not permit the dirt and moisture intrusion protecting the surfaces for a long time/ Both surfaces will clean because this coating applied on them makes them behave like the lotus leaf (waterproof and self cleaned)
14	Imagine you have gone fishing in a lake. You have forgotten to take water with you and there is no drinking water around you. You can find water only in the lake. Would you drink water from the lake, yes or no? Why would you or why wouldn't you?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	No you can't drink the water because you can be sick or even die/ You can't drink the water because it dirty/ This water is not drinkable/ The water is salty or sweet/ You have to clean it first
		2	You can drink it if you clean it from dirt (without specifying the size of the junk/garbage or classifying it in macroscale e.g. fish, plastic bottles, leaves from the trees)/ You can drink it if you clean it first using a strainer
		3	You can drink it if you clean it from microorganisms and bacteria/ You can drink it if you filter the water first so that microroganisms and bacteria infect your body/

			You can't drink it unless all the microorganisms which can penetrate your cells has been removed
15	Could you drink the water if you cleaned it first?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	No I still would not be able to drink it (any reference denoting that even if you could clean the water by any means it could still infect you)
		2	Yes I could drink the water if I had removed the junk and garbage from it
		3	Yes I could drink the water if I had first removed every microorganism from the water so that nothing could infect me
16	How could you clean the water?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	You can't/ Using some cotton (as a strainer)/ Using strainers/ Using a net/ If it was cleaned through the aqueduct
		2	I could use water filters
		3	Filters which can restrain any size of microorganisms and clean the water from everything/ Using nanofilters
17	When are you going to be sure that the water is completely clean and you can drink it without getting sick?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	I will never be sure/ The water cannot be cleaned/ I will consider the color of the water/ When it would have been processed in the aqueduct, the drains or with special machinery
		2	When all junk and garbage have been removed (objects from the macro scale)
		3	If I could check the water with electron microscope/

			When objects and materials of the smallest size have been removed
18	John says that there is a special filter which can clean water even from bacteria. Is this possible? What kind of filter is that? How is this happening?	0	I do not know/ I do not answer/ irrelevant answers e.g. the weather is fine
		1	This does not exist/ He is lying/ Science has not advanced that much its techniques/ I would have known/ It a water filter which removes junk from the water (junk which are macro sized)
		2	Nanofilter/ Nanofilter which kills microorganisms and bacteria/ It is a filter which sustains bacteria/ It is a filter that kills bacteria
		3	Nanofilters which have nanosized holes so that every bigger object or material is sustained and only water can pass through

F.14 Appendix 14

Table 14: Means and Standard Deviations of students' conceptual change between groups, within measurements and for each question of the generative questionnaire

Question	Group	Time					
		Pre measurement		Post measurement		Follow-up measurement	
		M	SD	M	SD	M	SD
If we cut bulk gold in smaller pieces which we can still be able to see with our eyes, what is going to be their color? Why is that?	Experimental (N=44)	1.00	.000	1.27	.451	1.20	.408
	Control (N=37)	.97	.287	1.32	.709	1.38	.492
If we cut the previous pieces in even smaller pieces will they keep the same color? Why?	Experimental (N=44)	1.02	.263	1.25	.534	1.34	.479
	Control (N=37)	1.05	.229	1.32	.669	1.51	.559
Materials keep the same color no matter how small we cut them? Why is that?	Experimental (N=44)	1.05	0.569	1.25	.651	1.43	.501
	Control (N=37)	.97	.372	1.19	.845	1.43	.603
We are in the country side and we want to make a salad. But we must choose between cabbage and lettuce since we do not have much water in our disposal. Which one will be better cleaned? The cabbage, the lettuce or both will clean better? Why?	Experimental (N=44)	.91	.291	1.61	.722	1.55	.663
	Control (N=37)	.89	.315	1.70	.777	1.46	.650
If I spill a drop of water on a smooth piece of glass and on an absorbent piece	Experimental (N=44)	1.07	.587	1.68	.471	1.80	.408

of cloth, the shape of the water droplet will be in both cases the same? Why is that?	Control (N=37)	1.19	.518	1.43	.555	1.65	.538
If I spill a drop of water on a cabbage leaf and on a lettuce leaf, the shape of the water droplet will be the same? Why?	Experimental (N=44)	.98	.263	1.55	.820	1.41	.622
	Control (N=37)	.92	.363	1.57	.689	1.32	.709
If I spill a drop of water on a cabbage leaf and on a broccoli leaf, the shape of the water droplet will be still the same? Why is that?	Experimental (N=44)	.93	.334	1.57	.759	1.48	.698
	Control (N=37)	.86	.419	1.59	.686	1.41	.644
John went to visit his father at work. His father showed him a microscope and John felt excited. He wanted to see how the smallest object on earth would look like under the microscope. However his father showed him an onion cell telling him that this is the smallest object he could see with this microscope. Which is the size of an onion cell so that his father could take it and place it under the microscope? How it was possible to see it?	Experimental (N=44)	1.02	.628	1.18	.922	1.30	.734
	Control (N=37)	.84	.688	1.49	.804	1.16	.727

Is the onion cell the smallest object on earth? Are there even smaller items on earth? How would they be like? How are they called?	Experimental (N=44)	1.73	1.065	2.34	.963	2.45	.730
	Control (N=37)	1.08	.862	2.19	.877	2.00	1.000
If the smallest object John could see under his father's microscope was an onion cell, then those objects how are even smaller how could be seen?	Experimental (N=44)	.93	.695	2.05	1.219	2.52	.731
	Control (N=37)	.89	.699	2.43	1.068	2.57	.728
I apply a coating on a wall and on the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall or the iron railings? Why?	Experimental (N=44)	.95	.302	1.00	.528	.98	.151
	Control (N=37)	1.00	.000	1.08	.547	.97	.164
I apply a coating on a wall and a special coating on the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall or the iron railings? Why?	Experimental (N=44)	1.41	.693	1.34	.834	1.43	.545
	Control (N=37)	1.27	.652	1.43	.765	1.35	.716

I apply the special coating on both the wall and the iron railings of the porch. However the weather is windy and dust makes them dirty again. I take a wet piece of cloth in order to clean them. Which one of the two surfaces will clean the best, the wall, the iron railings or maybe both surfaces will clean the same? Why?	Experimental (N=44)	1.05	.608	1.32	.639	1.34	.680
	Control (N=37)	1.00	.527	1.32	.709	1.27	.693
Imagine you have gone fishing in a lake. You have forgotten to take water with you and there is no drinking water around you. You can find water only in the lake. Would you drink water from the lake, yes or no? Why would you or why wouldn't you?	Experimental (N=44)	1.00	.374	1.11	.443	1.52	.792
	Control (N=37)	1.08	.595	1.32	.580	1.43	.929
Could you drink the water if you cleaned it first?	Experimental (N=44)	1.55	.663	1.55	.730	1.48	.821
	Control (N=37)	1.32	.530	1.43	.603	1.38	.828
How could you clean the water?	Experimental (N=44)	.84	.645	1.30	.823	1.77	.677
	Control (N=37)	1.43	.801	1.59	.985	2.05	.815
When are you going to be sure that the water is completely clean and you can drink it without getting sick?	Experimental (N=44)	1.02	.505	1.11	.722	1.36	.718
	Control (N=37)	1.11	.567	1.03	.799	1.57	1.144

John says that there is a special filter which can clean water even from bacteria. Is this possible? What kind of filter is that? How is this happening?	Experimental (N=44)	.84	.479	1.09	.802	1.20	.632
	Control (N=37)	1.03	.600	1.22	.821	1.57	.867