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Successful Experiences in Chemistry Teaching in Greece

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SUCCESSFUL EXPERIENCES IN CHEMISTRY TEACHING IN GREECE

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ABSTRACT
In this report effort is made to present an overview of successful experiences in chemistry teaching in Greece based both on bibliographical evidence as well as on teachers' and scientific experts' testimonies. A brief description of the national sources available for Greek teachers in order to get suggestions concerning successful experiences in chemistry teaching is presented. The key competences which students need to develop in order to face successfully the study of chemistry are subsequently presented. These competences are examined in the general framework of the required learning skills for students in the 21st century. Five selected examples of successful experiences in chemistry teaching taken from the Greek educational reality are presented. The reported examples cover all three educational levels (primary, secondary and tertiary education) and their successful learning outcomes have been validated via conduct of educational research. Detailed content analysis of the material of the national workshop on successful experiences has provided evidence for the Greek chemistry teachers and scientific experts opinions on "what constitutes a successful experience in chemistry teaching" and the conditions required for the successful implementation of a novel teaching approach. In addition, several proposals of good teaching practices made by Greek chemistry educators are presented. Finally, the results on the testing by several Greek teachers of 11 teaching resources available in the Chemistry is All Around Network project database are critically discussed. The feedback received by both teachers and students provides evidence for the positive impact of the Chemistry is All Around Network project on chemistry education in Greece.

1. Introduction

What constitutes a successful experience in chemistry teaching? How can a teacher evaluate the effectiveness of a teaching approach? Which are the key competences that chemistry education should aim to develop? These are some of the basic questions which will be explored in this report via selected bibliographical references as well as via the analysis of the experiences of chemistry teachers and by concentrating in the Greek educational context. In this first section of the report we will provide a brief description of the different national sources available for Greek teachers in order to get suggestions about successful experiences in chemistry teaching.

The first such source is the Panhellenic Conference on Science Education and ICT in Education. This is a conference series which is organized every 2 years and it is attended by science educators of all levels (primary – secondary – tertiary education) from all over the country. In this conference, science education researchers, which can be either academic personnel (university professors) or active science teachers (mostly in secondary school but also in primary school) who are simultaneously pursuing a Masters or a Ph.D. degree, are presenting their work mostly via short oral presentations. All papers pass through a peer review process in order to be selected for presentation and publication in the official conference proceedings. So far, a total of eight such conferences have taken place in a period of 15 years (1998-2013) and all conference proceedings are available freely on the site of the recently founded (2011) "Association for Science Education and Technology" (ΕΝΕΦΕΤ – ENEPHET) [1]. The amount of papers presented in every conference of this series is over 100 and at least 30% of them are related with chemistry education. The majority of these papers are related with the design, application as well as assessment of novel approaches for teaching chemistry in secondary school (as well as chemistry related subjects in primary school).

A second useful source with suggestions on successful experiences in chemistry teaching in Greece is the conference proceedings of the conference series organized by the Greek Scientific Association of ICT in

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Education (ΕΤΠΕ – ETPE) [2]. In the period between 1999 and 2012, ETPE has organized a total of 8 Panhellenic Conferences on "ICT in Education" with international participation. A total of at least 100 papers are selected after peer review for presentation in each of these conferences. The topics of the presented papers cover a very wide range of disciplines with science (and chemistry) being one of them. As implied from the conference title, the teaching approaches presented in this conference actively exploit some form of ICT. In parallel with the "ICT in Education", another conference series named Panhellenic Conference on "Integration and Use of ICT in the Educational Process" is organized by ETPE every 2 years starting from 2009. This is a conference which is more strictly addressed to the Greek educators since all papers (also available freely in the official site of ETPE [2]) appear only in the Greek language.
A third possible source of examples of successful experiences in chemistry teaching is the material available at the websites of the Secondary Education Science Laboratory Centers (EKFEs). The EKFE is an educational structure whose main aim is the active support of all aspects of laboratorial teaching of physical sciences to all in-service science teachers in the school units (both primary and secondary) which are within the specific educational geographical district. An EKFE acts as a center for information and update of teachers on new teaching material and resources (including ICT based laboratory applications). There are 58 EKFEs located all over the country and two of them (EKFE Laconias and EKFE Ampelokipon) have also joined the Chemistry is All Around Network as Associated Partners. As an example of successful experiences in chemistry teaching, we may refer to a series of them presented at the website of EKFE Ampelokipon [3]. The presented experiences are the result of the actual testing in class of different teaching approaches, techniques and/or tools by chemistry teachers serving in public secondary schools of this specific area of Athens (Greece).
A fourth possible source of examples of successful experiences in chemistry teaching is material available at the websites of the individual school units or in related educational sites. In these sites, chemistry teachers (especially in secondary school) often upload teaching resources which they have actually tested in their classes. These resources are accompanied by additional material which can significantly aid successful implementation (worksheets, suggestions, even videos of the actual lessons). Two characteristic examples of such sites are the following: i) the teaching resources uploaded at the site of 5th Upper Secondary School (Lyceum) of Petroupolis which is one of main schools participating in the Chemistry is All Around Network Project [4] and, ii) the model teaching lessons (accompanied by videos) that were conducted by chemistry teachers serving in secondary schools of Cyclades Islands during 2013-14 [5].
A fifth possible source of examples of successful experiences in chemistry teaching is material available at privately run educational sites. A characteristic example of such a site is chemview.gr [6].
A collection of good practices in teaching different chemistry topics can be found in the site of the in-service teacher training program known as "Major training" ("Meizona Epimorfosi") [7]. These good practices were produced by trainees (active chemistry teachers in secondary school) of this optional training program which took place between June – December 2011.
Finally, it should be noted that a significant amount of successful experiences in chemistry teaching in Greece can be periodically found in the international literature. Several research papers which explore the implementation of novel approaches in chemistry teaching in Greek schools appear periodically in international journals. In these papers, the interested chemistry teacher (who needs however to have a good knowledge of the English language) can have reliable information on teaching approaches whose "successful implementation" is justified via the conduct of educational research. A selection of such papers is analytically presented in the third section ("Examples of successful experiences") of this report.

2. Key competences and their development in chemistry education

Taking into account the constant decline of students' interest in studying chemistry at advanced level, studies are being conducted for exploring the reasons for this phenomenon [8, 9]. In a research study concerning Greece, effort was made to identify factors the influence students' choice not to pursue a chemistry-related career [9]. It was shown that these factors can be organized into four different categories related with the following issues: the nature of chemistry, the instructional content and context, the students' characteristics and the status of chemistry in the Greek educational system and Greek society. More specifically the factors are analyzed as follows: The factor "Nature of Chemistry" includes sub-factors related

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with the difficulties students often face in learning chemistry (eg Abstract and Difficult concepts). The factor "Instructional content and context" includes barriers related to the teaching content and teaching approaches (eg. emphasis on teaching theoretically without practical experimentation or by making no links between chemistry and everyday life), The factor "Students' characteristics" includes barriers such as lack of self-efficacy or interest and finally the factor "Status of chemistry" is related with issues that result in the devaluation of chemistry in the socio-economic framework (eg. few employment possibilities).

The identified barriers to chemistry learning and chemistry-related career choice bring out the importance of taking into account the key competences that students need to develop in order to successfully face the study of chemistry. These competences have to be taken as a reference point for design of new curricula, new more effective teaching strategies as well as new re-structured teacher training programs. In the following part of this section, we will make an effort to present a concise description of the key competences related with the study of chemistry by reviewing relevant international literature.

First, it should be noted that the competences need to be examined in the framework of the required learning skills for students (and teachers) in the 21st century. According to a recent review [10], "new standards for what students should be able to do are replacing the basic skill competences and knowledge expectation of the past". In the 21st century, knowledge is expanding exponentially and is becoming more specialized and at the same time ICT is transforming how we learn, how we work and how we interact socially. Success largely "lies in being able to communicate, share, and use information to solve complex problems" and "in being able to adapt and innovate in response to new demands and changing circumstances". While traditional education models usually focus on learning "identified content" for specific subject areas, the 21st century learning frameworks include learning traditional core subjects in combination with interdisciplinary themes in order to help students develop the following literacies: civic literacy, global awareness, financial literacy, health literacy, environmental literacy and visual literacy.

Concentrating on environmental literacy, it is noted that "in the coming decades, the public will more frequently be called upon to understand complex environmental issues, assess risk, evaluate proposed environmental plans and understand how individual decisions affect the environment at local and global scales". Developing environmental literacy involves, amongst others, understanding the underlying scientific principles related with environmental issues and it is thus closely connected with scientific literacy. Chemical literacy constitutes a major part of scientific literacy which includes, amongst others, skills and abilities that students should acquire in science (ie also chemistry) education. Skills in critical thinking and analytical reasoning in order to be in a position to draw evidence-based conclusions and make decisions are noted to form a major part of scientific (and chemical) literacy.

Taking into account the above mentioned requirements regarding the 21st century students' skills, the German National Educational Standards (NES) for chemistry specify four equitable areas of competence: a) content knowledge, b) acquirement of knowledge (scientific inquiry), c) evaluation and judgement and d) communication [11 – 13]. The two areas of competence which play the most significant role in the development of reasoning skills and decision-making are evaluation and judgement and communication. The evaluation and judgement competence in chemistry is defined as the ability to detect and evaluate chemical topics in different contexts. Research has shown however that the evaluation and judgement competence is influenced by several external factors/aspects with the content knowledge competence being one of them. In fact, it has been shown that high content knowledge influences positively the quality of argumentation and negotiation of socio-scientific issues (SSI). In summary, the evaluation and judgement competence in chemistry is influenced by the following external aspects: i) subject-related aspects which include content knowledge as well as application of content knowledge in chemistry, ii) interdisciplinary aspects which include data quality, knowledge of evaluation strategies as well as application of evaluation strategies and iii) personal aspects which include individual attitudes, social desirability and cognitive abilities. The communication competence includes the following subareas: accessing information, circulating information and argumentation. The competence related with acquirement of knowledge (scientific inquiry) through experiments has been proposed to consist of the following structural elements [14]: a) formulating questions and hypotheses for experiments, b) planning and performing experiments and c) analysis of experimental data and reflection of experiments.

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Concentrating on the cognitive skills and strategies, we note that competence in them is essential for effective learning and storage of information in memory as well as for efficient knowledge retrieval and use in problem solving. In regard with solving problems in chemistry, the following five cognitive strategies have been tested and shown to be required, together with the teaching of content knowledge, in order to achieve more efficient learning and problem solving [15]: a) clarification and clear representation of problems, b) focusing sharply on the goal, c) identification and use of relevant principles, d) use of equations for calculations and deductions and e) use of a step-by-step procedure for the solution.
Finally, we make a special note to the role that representations and visualizations play in chemical education for achieving goals related to the acquisition/understanding of significant concepts as well as goals related to scientific investigation [16]. This role has led to the development of the notion “representational competence” as an important set of skills and practices to be included in the chemistry curriculum. The term “representational competence” describes “a set of skills that students have to develop for constructing, interpreting, transforming, and coordinating domain-specific external representations for learning and problem solving in chemistry” [17]. In the work of Kozma and Russell [16], reference is made to the following five levels of representational competence: representation as depiction (level 1), early symbolic skills (level 2), syntactic use of formal representations (level 3), semantic use of formal representations (level 4) and reflective, rhetorical use of representations (level 5). In the same work, a set of skills constituting the core of representational competence in chemistry is presented as follows:

a. Ability to use representations to describe observable chemical phenomena in terms of underlying molecular entities and processes.
b. Ability to generate or select a representation and explain why it is appropriate for a particular purpose.
c. Ability to use words to identify and analyze features of a particular representation (such as a peak on a graph) and/or patterns of features (for example the behaviour of molecules in an animation)
d. Ability to describe how different representations may express the same thing in different ways and explain how one particular representation might show something unique that cannot be said by another.
e. Ability to make connections across different representations and explain the relationship between them.
f. Ability to take the epistemological position that representations correspond to but are distinct from the phenomena that are observed.
g. Ability to use representations and their accompanying features in social situations as evidence to support claims, draw inferences, and make predictions about observable chemical phenomena.

3. Examples of successful experiences

In this part of the report, we will refer to selected examples of successful experiences in chemistry teaching taken from the Greek educational reality. The specific examples we will refer to were chosen according to the following criteria: a) specific relevance to a chemistry topic taught in a Greek classroom, b) coverage of all educational levels (primary, secondary and tertiary education), c) experimental evidence for the successful outcomes via conduct of educational research and d) validation of the research outcomes via appearance of the successful chemistry teaching experience in an international peer-reviewed journal.

3.1 Experience description

The first example of a successful experience in teaching chemistry will refer to primary school and it is based on the research work of Papageorgiou et al. [18]. The teaching intervention involved six one-hour lessons in two matched classes of a Greek primary school. The classes consisted of 16 and 19 students with ages between 11-12 years and were taught by the same teacher. The subject taught was related with phase changes, namely melting and evaporation below the boiling point. The novelty of the teaching approach is related to the fact that it made use of particle ideas (particulate nature of matter) in order to explain the phase change phenomena. In addition, the two matched classes were introduced to the particulate nature of matter via two different teaching techniques: one involved the use of software simulations and the other relied on the “traditional” static representations. The software simulations were developed by the research

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team. Both classes were taught by using the same teaching scheme which was especially developed by the researchers in order to introduce particle ideas to primary school students. Without entering into much detail, we note that the teaching scheme made use of a step-by-step approach which is based on subsumptive learning, ie. progressive differentiation of a more general idea. This learning approach is characterized by a lower intrinsic cognitive load. The teaching scheme used the concept of a “substance” with a characteristic “ability to hold” as the anchoring idea for the particle theory (instead of “solids”, “gases” and “liquids” and forces linked to generic states). The simulations used in class were also developed by taking into account this specific pedagogical context.

The second example of a successful experience in teaching chemistry refers to lower secondary school (“Gymnasio”) and it is based on the research work of Korakakis et al. [19]. This teaching intervention involved the use of three different types of 3D visualizations (namely interactive 3D animation, 3D animation and static 3D illustration) accompanied with narration and text for teaching the subject related to mixtures’ separation to 212 Greek students in the 2nd year of lower secondary school (13-14 years old). The researchers were interested to explore the possibly different contributions of the three different multimedia tools to the learning process, taking into account that “the fundamental question is not whether media affects learning but how to take advantage of the various media so that instructions and learning can be more effective”. The teaching resource was designed, developed and tested in class by the researchers themselves. The multimedia application included the following specific thematic units of the general topic “mixtures’ separation”: distillation, fractional distillation, pouring, centrifugation, filtering, evaporation, paper chromatography, sieving and magnetic separation. The text material was based on the information provided in the school chemistry textbook but was enriched with elements from the Greek and international bibliography.

We will subsequently move on to present examples of two successful experiences in teaching chemistry in upper secondary school, based on recent research publications ([20 - 21]) Thus, in the third example of a successful experience in teaching chemistry we will make reference to the work of Pierri et al. [20]. This teaching intervention aimed at helping Greek 1st grade upper secondary school students (15-16 years old) to conceptualize the relation between the molecular weight of pure substances (namely of five saturated fatty acids) and their melting-freezing points during the ‘change of phase’ phenomenon, by using the Microcomputer-Based Laboratory (MBL) system. The MBL system is a laboratory teaching approach which makes parallel use of computer technology. Literature (see several references in [3]) has provided evidence that it can increase students’ motivation and improve their “perceptions of science concepts and cognitive skills such as observation and prediction”. There was a random selection of 79 students almost exactly distributed between the two genders. Students were prompted to work in groups by using a specific worksheet in order to exchange ideas and reach conclusions while working. Students performed the actual laboratory experiment and at the same time observed the graphics registering the occurring temperature changes in real-time on the computer screen. The students had already been taught theoretically (in class) the phenomenon of ‘change of phase’ and the connection between the molecular weight of a pure substance and the melting – freezing point.

In the fourth example of a successful experience in teaching chemistry we will make reference to the work of Danili and Reid [21], which is also a teaching intervention applied in Greek 1st grade upper secondary school students (15–16 years old). The important role that different psychological factors and cognitive characteristics of the students can play in the process of chemistry learning was taken into account in the design of this teaching approach. Emphasis was given to two specific characteristics: working memory capacity and field-dependence. Working memory capacity is related with that part of the brain where “we hold information, work on it, organize it and shape it, before storing it into long-term memory for further use”. Field-dependence is the ability of an individual to break up a perceptual field (for example a long piece of text) and “separate readily an item from its context”, or in other words the ability to detect the most important information (the “message”) and separate it from the “noise”. In fact, both cognitive characteristics show statistically significant correlation with students’ chemistry scores. Thus, the highest the working memory capacity and the more field-independent a student is, the better is his/her performance in a chemistry test.

The authors of this work [21], chose the topic of atomic and bonding theory and designed a new instructional approach which aims at minimizing the demand for a high working memory, thus making chemistry more

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amenable for all students, irrespective of their working memory space. Some of the features of this alternative approach are the following: a) presentation of the material in a more stepwise fashion, b) use of dialogue boxes, c) careful introduction of pictures, analogies and diagrams always seeking to bring out the "message" and reduce the "noise", d) use of models, e) occasional change of order of presentation of the material, f) lowering the need for note-taking via well organized learning materials, g) effort to build on prior knowledge. The aim was to encourage active learning where the students will interact with the material, draw conclusions, answer questions and complete simple calculations. In addition, group work was chosen deliberately as it can reduce the problems arising from limited working memory space. The experimental design involved the participation of 211 students who were divided into two groups: control and experimental. Both groups were instructed by the same teacher. The traditional teaching approach was employed in the control group. This approach is based on the use of the prescribed textbook and the blackboard. It important to note that the teaching approach applied to the control group did not involve lessening of the material taught. As noted in the relevant publication [21], "The chemistry to be taught was not altered; the way it was to be taught was re-structured".
Finally a brief description of a successful experience of teaching chemistry in tertiary education will be subsequently presented. It is based on the research work of Antonoglou et al. [17]. The teaching intervention is based on a hybrid teaching approach, namely combination of traditional face-to-face instruction and an online web enhanced learning environment, for teaching an undergraduate college chemistry course related with molecular symmetry. The inspiration for this teaching intervention is based on the need for development of representational competence through the support of visuospatial thinking in order to fully understand several fundamental chemistry topics with molecular symmetry being one of them. The web-based teaching material was designed and developed by the authors themselves. In order to complete this task, the authors took into account the guidelines provided by two psychological theories (namely Cognitive Load Theory and Cognitive Theory of Multimedia Learning) for the development of well-designed multimedia learning environments. The hybrid instructional model, being a blended learning system, serves three functions: "enabling (access and convenience), enhancing (using technology to add value), and transforming (change to course design, learn through interactions and activities)".
The main features of the hybrid course are the following:

- Integration of novel molecular visualization educational software to support the teaching and learning of molecular symmetry concepts.
- Deliverance of the online course material in study blocks by the use of the free Content Management System (CMS) Moodle.
- Implementation of online learning activities and formative online assessment (quizzes).
- Provision of multiple forms of resources thus allowing students to select and utilize the materials that are most suitable to them.
- Provision of feedback to preceding and guidance to forthcoming study blocks.
- Provision of synchronous and asynchronous communication tools in conjunction with physical presence impelling students to face common learning objectives and practices in the setting of a learning community.

The course ran for three consecutive academic years and was attended by a total of 105 students (namely 36, 30, 39 students during each year).

3.2 Experience assessment

With regard to the above described first example of successful experience in chemistry teaching [18], the assessment was done via individual interviews of 12 students from each class (6 boys and 6 girls) both before and after the teaching intervention (pre- and post- intervention). By organizing the primary school students' responses into different categories corresponding to different levels of understanding of the particulate nature of matter and to the their explanations of the phenomena of melting and evaporation, it was shown that overall
students made "positive" moves between categories, and many even "made large gains", after both teaching interventions (ICT-based and traditional). However, the results also illustrated the difficulties which are associated with conceptual change, since there were cases of students who could not escape from their

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initial views and created synthetic explanations of the examined phenomena with both macroscopic and microscopic characteristics. In the question "Did the software help?", the analysis of the experimental data indicates that the software provided more help in the case of evaporation, which is the most difficult phenomenon for the students to grasp. It is pointed out however that this type of simulation software should play a supporting role in the instruction and it is "a resource to be deployed by teachers alongside other teaching activities".

With regard to the above described second example of successful experience in chemistry teaching [19], the assessment was done via analyzing the results from the students' answers to a total of nine questions of various types (namely multiple-choice questions, completion of blanks and visualized questions) in the last part of the multimedia application. The validity and reliability of these nine questions was checked via a pilot study which employed a small sample of students (90 persons). Subsequently, small necessary adjustments were made in order to produce the evaluation questions in their final form. The data obtained from the answers of the 212 students of the main study, were analyzed statistically via non-parametric tests since it was found out that the assumptions of the more often used ANOVA approach were not strictly met. The meticulous statistical analysis enhances the reliability and validity of the final conclusions reached in relation with the criteria that need to be met for successful implementation of different types of multimedia application to teaching chemistry in secondary school. Thus the main points of interest resulting after the assessment of this teaching approach [19] are the following:

a) The first main scene of an interactive multimedia application should not contain essential knowledge for the student because the actual learning process is not yet effective

b) Both types of 3D animation (interactive and non-interactive) are more effective in stimulating students' interest relative to static 3D illustrations, but seem to pose a heavier cognitive load and require suitable metacognitive ability by the students.

c) The static 3D illustrations have an advantage relative to both types of 3D animations with regard to the reduction of the required cognitive load; students are given time to control their own learning.

It is thus concluded that "the unilateral use of one of the three types of visualizations does not improve the effectiveness of the learning process" and in fact "the combination of all three types of visualizations in a multimedia application for the sciences is recommended" in order to ensure successful implementation in class.

With regard to the above described third example of successful experience in chemistry teaching [20], the data related to students' perceptions and evaluation of the teaching procedure were collected by using three different methods: videotape recordings, field notes and semi-structured interviews before, during and after the teaching intervention. After data analysis, the researchers classified the extracted student conceptions regarding the specific chemical concept under study into four different categories-types. The effectiveness of the teaching approach is measured via the students' responses into seven different questions before and after their engagement in the experimental procedure (MBL). A statistically significant increase in the percentage of correct answers was observed for all seven questions. More specifically, "after the experiment more students responded correctly to all questions concerning the freezing point of the saturated fatty acids, the relationship of the freezing point to the molecular weight and the description of this relationship". In addition, no statistically significant differences were observed between the two genders. Data analysis of the students' answers during the interviews provided clear evidence for their preference for "sensor use and computer assisted experiments over traditional lab experiments". It seems that the possibility of faster and easier acquisition of various types of laboratory data in real-time, gives students more time "to deal with the concept of the experiment" and thus they are aided to "comprehend more effectively the concepts being studied". Students' motivation to engage in the learning process seems to be stimulated.

With regard to the above described fourth example of successful experience in chemistry teaching [21], the assessment was performed as follows: All students (control and experimental groups) were tested before the teaching intervention in order to define their starting level of knowledge. Statistical analysis was employed in order to check whether there was any significant difference in the improvement between the two groups, and in order to check whether any difference in the (possible) improvement was due to the effect of the teacher. It was thus shown that the average improvement in learning achieved by the experimental group was better than the one achieved by the control group. In addition it was shown that this statistically significant difference in the improvement was not being caused by an interaction between the teaching material and the teachers involved. Consequently, it is argued that this impact was most likely due to the changes made to the teaching material. In conclusion, evidence is provided in support of the view that by re-designing some curriculum materials and teaching strategy in line with the predictions about learning derived from an information processing model, student performance can be improved.

With regard to the above described fifth example of successful experience in chemistry teaching [17], assessment was performed by collecting and analyzing both qualitative and quantitative data by all students during the whole three year period. The data aimed at assessing both the effectiveness of the course as well as the attitudes of the students. In respect with students' attitudes the following results were reached: a) The students had overall a positive attitude towards the usability of the Moodle platform and seemed to categorize it as a flexible learning tool, b) The large majority of the students expressed a positive opinion in regard with the content of the interactive lecture notes and agreed that the availability of both 3D and 2D molecular visualizations had a positive effect on the conceptualization of molecular symmetry, c) The students demonstrate positive attitudes toward hybrid instruction and consider that it provides a learning environment which addresses their needs and expectations, d) Students considered quizzes to be a useful self-assessment tool, and e) The hybrid instructional model enhanced student-student and student – instructor interaction.

In respect with the effectiveness of the teaching intervention, the data indicate greater learning outcomes via the use of the hybrid course, compared to the traditional setting. However, it is not possible to conduct detailed statistical analysis due to the fact that the groups of students were drawn from different cohorts. An additional positive outcome is that a high retention rate during the hybrid course was observed.

In summary, the following main conclusions can be drawn regarding this teaching intervention: a) The adoption of a hybrid instructional model for demanding undergraduate chemistry courses (such as Molecular Symmetry) is capable of improving the quantity and quality of students' involvement with the course content throughout the whole semester, b) Via the hybrid instructional model, students are given the possibility for self-regulation, i.e they seem to take responsibility for their own learning. Self-regulation is known to constitute one of the most important motivational constructs. In addition, students are given flexibility for action and reflection in order to enhance their performance and preparedness for the forthcoming assessment as well as for the upcoming in-class meeting. c) The course material was (and needs to be) designed by taking into consideration principles derived from a cognitive approach to learning, aiming to reduce the cognitive load and support visuospatial thinking, d) Even though this successful teaching strategy is applied among undergraduate chemistry students at University, it could also be applicable to secondary school students in order to help them understand abstract and difficult chemistry concepts.

4. The impact of the Project on Successful Experiences

In this part of the report, an attempt will be made to describe the impact of the project on successful experiences in chemistry teaching among Greek teachers, by using the following two sources of information: a) the results of the national workshop on "Successful experiences and good practices in chemistry teaching" and b) the results of the testing of ICT-based teaching resources available in the project database, conducted by the involved teachers in their classrooms.

4.1 Workshop

The workshop on "Successful experiences and good practices in chemistry teaching" took place in March 2014 and it was designed in such a way that it would encourage the interaction between chemistry teachers and scientific experts. There were a total of 15 participants, of which 9 were teachers and 6 were scientific experts. The participants were divided into 4 small groups of 3-4 persons each. In each group there was at least one scientific expert. The group members were given a specific topic related to successful experiences and good practices in chemistry teaching to think on and express their views. At the beginning, they were left free to interact with each other (within the group) for a specific amount of time (ca 20 min). Subsequently, a representative from each group gave a short (5-8 min) presentation of the main conclusions that each group had reached in respect to each discussion topic. There were two main discussion topics during these small-group sessions: a) "What constitutes a successful experience in chemistry teaching?" by focusing on the

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personal experiences/opinions of the participants and the information provided by the Papers and Publications of the project database and b) Proposals for good teaching practices and conditions required for successful implementation of a novel teaching approach.

In addition to the small-group sessions, there was also a workshop session dedicated to the presentation and discussion of the testing of the teaching resources, which was attended simultaneously by all participants as one single group. During this session the main discussion topics included the following: Criteria for teaching resource selection, adaptation of the teaching material, barriers/difficulties during implementation, teachers' evaluation of the teaching experiences, students' evaluation/opinions.

With regard to the question "What constitutes a successful experience in chemistry teaching?" the main aspects that emerged from the analysis of the workshop material are the following:

i) It is important that students are convinced that engaging in chemistry learning can be a rewarding experience and it is up to the teacher to make a systematic effort to provide the reasons on why one should try to learn chemistry. In this context, a proposed good teaching practice is giving emphasis on how scientific knowledge can be connected with everyday life experiences and exploiting interdisciplinarity between different science-related fields such as physics, chemistry and biology

ii) According to the participants' experience, a lesson introduction like a short activity which will attract students' attention and trigger motivation to learn, plays a significant role for a successful outcome from the teaching process.

iii) A successful teaching approach is one that is well organized, that excites students' curiosity and keeps them interested but at the same time achieves significant learning outcomes. It was especially noted that the fact that students exhibit strong interest in class, does not necessarily lead to deep understanding of the material taught. Thus, the necessity for continuous evaluation of the teaching practice was pointed out by the participants. The teacher should constantly receive feedback from the students either directly (via tests and quizzes or by asking students' opinions) or indirectly (via observing students' behaviour and reactions in class).

iv) In a successful teaching approach, strong interaction between all parties (in-between students and between the students and the teacher) has to be achieved. The student must have succeeded in acquiring the competence of setting-up problems/questions and searching ways for finding answers. Engaging in practical activities (lab work) and working in small groups (2-3 people) with pre-assigned specific roles by the teacher are good teaching practices for achieving this goal.

v) The cooperative teaching approach can be successful under specific circumstances. The non-significantly diffuse culture of collaborative effort in Greek society seems to often pose a barrier to the successful implementation of this approach (by both teachers and students).

With regard to the topic related to proposals for good teaching practices and the conditions required for successful implementation of a novel teaching approach, the main aspects that emerged from the analysis of the workshop material are the following:

i) Practical laboratory work is generally considered a good teaching practice. There exist however several barriers for effective implementation. These barriers are related to the following issues: limited allocated teaching time and infrastructure, the pressure to the teacher by the official educational system for "covering the material", the students' perception for lab work as a simple game which does not require any serious learning effort, the students' interest solely in performing well in the national exams for entering tertiary education institutions (taking into account the fact that these exams do not include lab-related exam questions up to this date).

ii) The appropriate incorporation of modern scientific analytical techniques (eg Gas chromatography, Mass Spectroscopy, etc) in school chemistry is also proposed as a good teaching practice. Such practice could induce close collaboration and interaction between the world of academic research (tertiary education institutions and research centers) and the school system. In addition, visits and collaborations with chemical industries could be organized or established (with food industry being a possibility that is also applicable in Greek reality).

iii) The cooperative teaching approach, despite its difficulties in implementation, is considered a good teaching practice as well, with special mention to the fact that it can provide significant positive outcomes to

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both low and high achievement students at the same time. Most participants reported higher success rate when the student teams were made with the guidance of the teacher.
iv) Two additionally proposed good teaching practices were the interdisciplinary teaching approach and the targeted use of ICT for teaching fundamental chemistry topics. With regard to the latter approach, participants made reference to topics such as stereochemistry which are of central importance in understanding chemical phenomena (for example organic chemical reactions) but are usually taught insufficiently and in an unattractive manner.
v) The use of e-learning platforms and their possible advantages in promoting chemistry learning and teaching was extensively discussed among the workshop participants. Experience shows that the most obvious positive outcome from this teaching technique is that it helps the teacher get more easily feedback on the effectiveness of the teaching process taking place in class.
vi) Participants agreed that for the successful implementation of an alternative/novel teaching approach it is important that students are gradually trained to work with the fashion that is required from the specific approach. Thus, it is important that students get introduced to non-traditional teaching approaches (eg. cooperative teaching) from an early age starting from primary school.
vii) Finally, special emphasis was put on the need of helping students focus their interest and effort in understanding the specific chemistry (science) concept under study in order to avoid creation of confusion and chaos in their minds. Attracting students' interest and creating enthusiasm are undoubtedly desirable characteristics of a successful teaching approach. However, quite often students tend to get overenthusiastic and get the (false) impression that they can easily approach and explain everything they observe in nature. This can lead to the opposite effect, ie. aversion towards science. Thus it is up to the teacher, as a central actor in the official educational process, to constantly reminding his/her students that scientific knowledge is built slowly and systematically.
Finally, with regard to the testing of teaching resources available in the project database, the following main points can be made by analyzing the workshop material:
i) The following teaching resources were presented and discussed among all workshop participants: Chemsketch 12 Software, BBC School Science (GCSE level – Units related with fuels and polymers), Phet (applications on stoichiometry, atomic structure, chemical kinetics), Virtual Chemistry Experiments, The Periodic Table of Videos and Chemical Compound of the Month. The presentations were made by the teachers who actually tested the resources in their classes during the recent six months of the project period. There was extensive discussion on the adaptation of the teaching resources for the use in class, difficulties encountered during implementation and students' opinions regarding the specific resources.
ii) With regard to the adaptation of the teaching resources the involved teachers pointed out the use of worksheets, the discussion with the students of the English terminology (which in most cases acted as a motivating factor) and some difficulties they encountered in their efforts to use simulations for teaching chemical kinetics concepts.
iii) With regard to the implementation difficulties, all teachers agreed that in the higher grades of upper secondary school where the score achieved in the chemistry course plays a significant role for the students' future professional career, students are reluctant in getting involved in alternative teaching approaches because they feel that they will not learn what is needed in order to perform well in the final exam.
iv) With regard to students' opinions and learning outcomes, the general conclusion reached is that overall students gave positive feedback and that a careful organization of the material may lead to more efficient learning than the traditional teaching approach.

4.2 Testing of ICTs

A total of 11 teaching resources available in the relevant project database were tested via the involvement of 12 teachers from 10 different schools (7 upper secondary and 3 lower secondary). In the following paragraphs, we will refer separately to the results from the testing of each teaching resource, by providing a brief description of the work carried out by the teachers in their classes, a report on the teachers' considerations about the utility of the tested resource as well as the students' opinions. The information presented is based either on the written teachers' reports (already uploaded on the relevant section of the project portal) or on individual oral interviews provided by the teachers.

The testing of the teaching resource available with the name “BBC School Science” in the portal database was conducted in 2nd grade (16-17 years old) upper secondary school students. Two specific teaching modules were tested, namely “Fuels from crude oil” and “Polymers from oil”. The aims (learning objectives) of these two teaching activities were briefly the following: use the general molecular formula of alkanes and alkenes and write the corresponding structural formulas, relate the number of carbon atoms of an alkane with its physical state, explain the distillation and polymerization procedures and relate the properties of polymers with their molecular structure. Due to the fact that the teaching resource is available only in English, a short explanation of the English terminology was given to the students as well as a short amount of time (5-10 minutes) to get familiar with the English language. Each activity was executed twice by the students and discussion between the students and the teacher took place between the two implementations. Students largely enjoyed the activities, even during the first execution, despite the fact that they were not available in Greek. In fact, based on the report of the students’ and teacher’s experience the use of the English language did not seem to pose any serious barrier neither to the teaching/learning process. On the contrary, the specific groups of students (two classes with 25 students each) overall seemed to be intrigued by the possibility of improving their level of understanding of English via these activities.
The careful design of the downloadable material of each activity (short videos with pictures in combination with music) was very useful in capturing the attention of even the least motivated students. Students stated they had a pleasant and interesting learning experience. Based on the results of a test prepared independently by the teacher and administered immediately after the end of the activities in order to evaluate the degree of accomplishment of the activities’ learning objectives, the specific teaching practice can be characterized as successful.
The testing of the teaching resource available as “Chemsketch 12 Software” in the portal database was conducted in 1st grade (15-16 years old) upper secondary school students. This teaching resource is related with basic organic chemistry topics such as structure of organic compounds, organic nomenclature, stereochemistry and functional groups. The learning objectives involved drawing different types of formulas of organic compounds, alkanes’ nomenclature, studying of the tetrahedral carbon atom structure in alkanes and of the ring structure in single-ring cycloalkanes. In order to make the students realize the usefulness of this software in understanding organic chemistry topics, each one of them (21 students in total) worked separately with his/her own computer (ca. 30 % of the students brought their own personal PC due to the limited number of terminals at the school’s computer lab). In addition, a worksheet - prepared independently by the teacher involved – was necessary for successful implementation which is translated to achievement of the learning goals and coverage of the need for a manual in the Greek language.
The level of knowledge as well the students’ attitudes related to the use of simulations and other ICT based applications in natural science lessons, were evaluated before and after the testing of the teaching resource, via the use of a questionnaire designed by the teacher. The main findings related to the effectiveness of the specific teaching resource are the following: i) students found the drawing of 3D chemical structures both interesting and amusing, ii) students managed to derive logical assumptions correlating chemical structure (microscopic level) with chemical reactivity (macroscopic behaviour) [namely correlation of cycloalkane’s ring strain with heat of combustion values], iii) students successfully employed the software in order to derive the names of the organic molecules under study and at the same time evaluate their own knowledge in organic nomenclature.
The main results related with the student’s opinion on this resource are the following: i) the large majority (ca. 80%) found the resource “extremely interesting” while the rest 20% found it simply “interesting”, ii) all students found the software user friendly, iii) all of them (but not to the same degree) intend to employ “ChemSketch” in the future in order to study the stereochemistry of chemical/biochemical compounds, iv) a large proportion of the students (ca. 50%) would prefer to only be exposed to the resource but not to use such type of non-standard teaching approaches systematically in class, because they fear that in this way they will not have time to study in depth and learn well the vast amount of material they will be tested on in the final national exams for entering tertiary education institutions.
From the above it is concluded that taking into account the special characteristics of the Greek educational framework and environment, this teaching experience is evaluated positively.

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The teaching resource "Phet" (namely the modules "Reactions & rates" and "Reactants, products and leftovers") was tested by two teachers (independently) in upper secondary school students.
In the "Reactions & Rates" simulation (applied in 15-16 year old students of 1st grade upper secondary school) the learning objectives included the following: explore the microscopic aspect of reactivity (collisions between particles), explore the concept of reversible reactions, explore the factors the affect the rate of a reaction. The students were urged to work in small groups of 2-3 people sharing one computer. Students faced no difficulty in running the simulations due to their familiarization with computers and the availability of the simulation in the Greek language. They expressed positive opinions related to the interactivity aspect of the application and seemed to enjoy working cooperatively. As pointed out by the teacher involved, once the students get used to this type of teaching approach both the learning outcomes and their motivation to learn can be enhanced significantly. It can be thus deduced that learning chemistry via ICT can become a more "permanent" mode of teaching which can produce successful outcomes, once enough time and effort is invested in encouraging the students to get involved in the process.
The "Phet" simulation related to "Reactants, products and leftovers" (applied in 16-17 year old students of 2nd grade upper secondary school), is designed to provide students with a conceptual understanding of limiting reactants, rather than practice at solving algorithmic problems that require mass/mole conversions. More specifically the simulation relates the real-world example of making sandwiches to chemical reactions by using space-filling models to represent the reacting particles. The intended learning outcomes include the following: describe the meaning of a limiting reactant, identify the limiting reactant in a chemical reaction given the initial amounts of two reactants and the chemical equation, apply the law of conservation of mass in a chemical reaction, use the concept of limiting reactant for predicting either initial amounts of reactants or amounts of products and leftovers after completion of a chemical reaction.
With respect to the effectiveness of the simulation and students' opinions the following points were made by the teacher:
i) Students enjoy the simulation as a game and at the same time they are aided largely in understanding and applying the conservation of atoms and the production of different molecules according to the mole ratio of the chemical equation. Molecular models are very helpful in understanding chemical equations (chemical symbols).
ii) Students achieve very good understanding of the concept of the limiting reagent. The simulation makes successful use of an analogy (sandwich making).
iii) The simulation helps alleviating certain students' misconceptions (such as "the reactant with the least relative amount is the limiting one") and difficulties (such as the confusion of the coefficients in chemical reactions with the subscripts in the chemical formulae).
Challenging the students to play a game (via the use of the simulation) aiming at achieving the best score in the lab group and a post-lab homework assignment are two additional features which were developed and implemented by the teacher and increased further the successful implementation of this teaching resource. In addition, specific weak points of the simulation that need attention were identified by the teacher involved and they are reported in the corresponding section of the project portal (Teaching Resources → Testing) in order to ensure increased effectiveness in in-class application of the resource.
The testing of the teaching resource available as "Materials for Special Uses" in the portal database was conducted in 2nd grade (16-17 years old) upper secondary school students. This is a teaching resource related with organic chemistry and more specifically polymer materials. Via the implementation of this teaching resource it is anticipated that students realize how the results of chemical research can find useful applications in everyday life. The resource provides the possibility for examining in detail the properties of some absroptive polymer everyday life materials such as food products and baby nappies, in a safe environment and get impressive educational results. In parallel with chemistry knowledge, students got the opportunity to get more accustomed with English terminology since some parts of the resource (eg. Introduction) were not translated into Greek and were presented in the original English language. In this way they students get introduced to the habit of searching for scientific information from a much wider variety of resources.
Students were urged to work in small teams of 3-4 four people with each team working in a different material. After conducting the experiments, there was a short discussion session guided by the teacher and

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subsequently all teams prepared a written report of their experimental results and a short presentation which they gave in front of their rest of the class. With regard to the effectiveness of the teaching approach proposed by this teaching resource, the educational results were very positive. As noted by the teacher involved, organic chemistry is a demanding subject and specific chemical concepts (such as absorption, polymer structure, etc) were approached more easily by the students via an enjoyable and fun activity. The cooperative aspect during the implementation of the teaching resource seemed to enhance the learning outcome and gave students the opportunity to complement each other. On the contrary to what mostly pointed out during the workshop (see above) students were left alone to compose their own small teams and the collaboration worked out quite smoothly. Two additional issues which corroborate the successful application of this teaching approach are the following: a) students realized that they can have easy access to new interesting information related to practical applications of chemistry in everyday life which cannot be found in a standard textbook, no matter how well it is written and b) students got the opportunity to successfully practice multidisciplinarity (chemistry and English language terminology).

In regard with the students' opinions on their involvement in this type of teaching approach these were largely positive and in some cases enthusiastic. The analysis of the evaluation questionnaires provided to the students gave, in summary, the following results: a) The resource attracted students' interest to a large or very large degree with special mention given to the videos of live experiments, the pictures, as well as the additional material that can be downloaded from the different available links within the resource, b) Students thought the resource was structured in a simple and user-friendly manner and found it mostly more enjoyable than a book due to the lively presentation. They also appreciated a lot the fact that they were given a lot of new information about existing or potential practical applications which cannot be provided by a book. In general, they thought that chemistry becomes more accessible and easy to understand via the use of ICT-based teaching resources which are designed in a way that is not tiring and boring, c) Students on average found useful the possibility of interacting with their classmates in an effort to understand what is happening in an experiment.

The teaching resource appearing with the name "The Wonderful World of Chemistry" in the project database, was tested in 2nd and 3rd grade students of lower secondary school (13-15 years old). This is a teaching resource with topics related mostly with introductory general chemistry, such as atoms and molecules, solutions, mixtures, chemical reactions (stoichiometry), acids and bases, basic concepts of carbon chemistry and classes of organic compounds. By using this resource, the main learning objectives were the following: a) understanding basic chemistry concepts via images, videos of experiments, short interactive ICT-based quizzes and exercises, b) promotion of cooperative learning via participation of small groups of students in virtual laboratory activities and c) expansion of students' knowledge on chemistry applications in different fields. The teaching resource was used as a supplementary teaching tool accompanying the standard chemistry textbook. With regard to the learning outcomes achieved, it is noted that the use of the resource triggered discussion and argument exchange in-between students as well as with the teacher. The resource provides a good opportunity for exposure of the students to lab-related activities in a straightforward and attractive manner and also very suitable if there is limited available time and/or infrastructure or in the case of dangerous experiments. However, one of the possible drawbacks of this type of teaching resources is the fact that students tend to treat it as "something odd" or "a simple game" which is not a real class where they have to actually learn something. The inexperienced or inadequately-trained teacher may thus "lose control" of the class due to some students who will find an excuse for not paying attention, make noise and distract their classmates. In order to avoid such situations which pose barriers to successful implementation, it is proposed that the use of the software is accompanied with a relevant worksheet (which has to be prepared independently by the teacher). In addition, the students should work in quite small groups (ideally in pairs) which requires the availability of enough terminals in the computer lab. With regard to the students' opinion on the resource, it is noted that they seemed in general very satisfied from their involvement with it and showed large interest especially during watching the videos.

The teaching resource appearing with the name "Learn Chemistry" in the project database, was tested in 2nd grade students of lower secondary school (13-14 years old). More specifically, the teacher involved incorporated the unit related with Venn diagrams, available in the resource, into teaching a more general topic related with electrolysis of water and fuel cells as a possible future energy source. During this class, the

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teaching resource (Venn diagrams) was employed in order to evaluate whether students are able to differentiate between the concepts of chemical elements, chemical compounds and chemical mixtures. According to the teacher's experience, a short independent introduction is needed at the beginning, so that the students understand the concept of Venn diagrams. Once they get the grip of the concept, they actually enjoy using them, as it is a practical new way of categorizing data without the need to use charts or tables. In addition to the students, several colleagues also expressed very positive opinions on the use of Venn diagrams, after having attended the testing of the teaching resource live via teleconference.

The teaching resource available with the name "Chemistry at Home" at the project portal database was tested independently by two teachers in students of 3rd grade of lower secondary school (14-15 years old) and 1st grade of upper secondary school (15-16 years old). In both cases, testing took place in the form of a school project in the course of one school semester. The activities of this teaching resource aim in helping students to develop basic scientific qualities such as logical and analytical thinking. The activities refer to experimental procedures that can and actually were very easily reproduced in class, by using exclusively materials that can be easily found in a common grocery store. Some of the specific learning objectives of the activities performed by the students are the following: a) comprehend how factors like reactants' purity, reaction's temperature and reactants' concentrations affect a chemical reaction, b) simulate the procedure of a food analysis, like the procedures used by analytical chemistry labs, to determine the presence or not of an ingredient, by using materials which are common household items and not chemical reagents, c) comprehend that it is easy to prepare, with materials existing at home, a product similar to a commercial product, which is industrially prepared (more specifically toothpaste) and d) relate the use of chemistry to everyday objects, to perceive the chemical reactions causing silver or silver-plated objects to tarnish and to comprehend chemical reactions' reversibility.

The students were encouraged to work in small teams which had been set up in collaboration with the teacher. In the end of the semester, students performed all experimental procedures live in front of the students of the whole school. Besides performing the experiments, they also gave detailed explanations of the scope and aims of each experiment as well as theoretical background of the chemistry concepts behind each experiment. In addition, students were urged to use the links provided in the resource in order to get more in depth and diverse information on the subjects under study, which they did with pleasure and a lot of success. In general, the students expressed very positive opinions regarding their experience with the "Chemistry at Home" teaching resource. As noted by the teachers, the most successful result of the testing was the very active involvement of the less good achievers among the students who in most cases developed strong motivation and self-esteem for engaging in chemistry learning. Chemistry is a subject which is considered traditionally difficult among the student population.

Three additional teaching resources available at the project portal database, namely "The Chemistry of Things", "The Periodic Table of Videos" and "Chemical Compound of the Month" have been tested with varying degrees of success in upper secondary school students. The resource "The Chemistry of Things" was proven very useful in exciting students' curiosity and interest at the beginning of a class, since it is composed of very short videos on specific everyday life materials and situations in which chemistry plays a very significant role. The language barrier (use of Portuguese) was solved via the possibility offered by the resource to incorporate and even edit (for syntax mistakes) Greek subtitles. The same applies for "The Periodic Table of Videos" which however created some difficulties to the students related with the English language employed. Finally, the resource "The Chemical compound of the Month" was especially praised by the teacher involved in its testing for the immense amount and variety of accurate chemical information provided which can be exploited from all types of students, both very high and very low achievers in science courses. The fact that it is available in Greek and it is produced by academic personnel makes it a very useful tool for every teacher who is interested in enriching his/her teaching practice based on a reliable resource.

5. Conclusions

Summarizing the information provided in the previous sections the following conclusions can be reached:

a) Greek chemistry teachers can get suggestions for successful teaching experiences by accessing the papers freely available in the proceedings of national conferences dedicated to science education and ICT in

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education. These papers related to implementation and evaluation of novel approaches for teaching chemistry-related topics both in primary and secondary school Greek classrooms. Additional suggestions can be found in official websites of school units and secondary education science laboratory centers (EKFE), in privately run educational sites and in papers appearing in international journals.

b) The key competences that students need to develop in order to face successfully the study of chemistry can be organized in four main areas: content knowledge, acquirement of knowledge, evaluation and judgement, communication. In addition, there is requirement for the development of certain cognitive skills. Special reference needs to be made to the development of representational competence, which is a term used to describe "a set of skills and practices that allow a person to reflectively use a variety of representations or visualizations, singly and together, to think about, communicate, and act on chemical phenomena in terms of underlying, aperceptual physical entities and processes" [16]. Systematic work for the development of all necessary key competences has to start from an early age (primary education).

c) Examples of successful experiences in chemistry teaching in Greek classrooms include cases in all educational levels, ie primary, secondary and tertiary education. The reported experiences usually involve the combined use of different teaching approaches, techniques or tools (for example ICT together with practical laboratory, different types of multimedia applications, web-enhanced learning and traditional face-to-face instruction). It is thus concluded that a successful teaching experience often requires the simultaneous use of multiple teaching approaches. In all cases, it is important that experimental evidence is provided regarding the successful learning outcomes of a teaching experience via conduct of educational research.

d) Greek chemistry teachers and scientific experts have provided significant insights with regard to "what constitutes a successful experience in chemistry teaching" and made proposals for good teaching practices as well as for the conditions required for the successful implementation of a novel teaching approach. Practical laboratory work, the cooperative teaching approach (despite its difficulties in implementation), the exploitation of interdisciplinarity, the targeted use of ICT have been some of the proposed good practices. The need for gradually introducing and training students from a very young age (starting from primary school) via the use of non-traditional teaching approaches (eg. cooperative teaching) was especially pointed out.

e) Several teaching resources (11 in total) available in the Chemistry is All Around Network project database have been tested by Greek teachers in their classrooms. The majority of the resources involved the use of some form of Information and Communication Technology (ICT) and constituted a novel teaching experience for the involved teacher. Teachers provided significant input regarding the conditions for successful implementation of the tested teaching approaches and asked feedback from their students as well. Overall, positive opinions were expressed by both teachers and students.

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