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What Constitutes a Successful Experience in Teaching Chemistry? Characteristic Examples from the Greek Educational Context

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Abstract

In the first part of this work, a brief literature review is made on the issue of what is meant by "successful teaching experience". Research has provided evidence for specific components that influence "success" namely beliefs for self-efficacy, feedback, possibility for student self-regulation and active participation, possibility for inquiry, collaboration, differentiation in ways of students' learning. Subsequently, in the second part of this work a set of five examples of successful chemistry teaching experiences is briefly presented and critically analyzed. In all cases, the "success" of the presented teaching strategies is justified via educational research. Among the selected successful chemistry teaching experiences, one refers to primary school (use of particulate nature of matter for teaching phase changes), one refers to lower secondary school (use of different types of 3D visualizations for teaching mixtures' separation methods), two refer to upper secondary school (parallel use of laboratory experiment and ICT for teaching physicochemical properties of fatty acids, minimizing working memory load for teaching atomic and bonding theory) and one refers to teaching at university (blended learning -hybrid instructional model for teaching molecular symmetry and group theory). The Greek examples provide evidence for the need of concurrent use of a carefully selected variety of teaching strategies, techniques and materials in order to readily enhance the effectiveness of chemistry (and science) teaching.

1. Introduction

What actually constitutes a successful teaching experience? Is it an effective teaching strategy which aims to enhance understanding of chemistry concepts or chemistry specific language? In essence what constitutes a successful experience for one person is every action that provides the basis for positive change in self efficacy. Self efficacy theory is based on the hypothesis that successful experiences lead to a sense of being able to cope in a potentially stressful situation [1]. Bandura [2] declares that self-efficacy can be fostered through observing success, experiencing success, persuasion techniques, and positive emotional tone. In addition, feedback is also a crucial component that aids the successful experience.

On the other hand, successful experiences alone do not raise efficacy beliefs. Instead, personal and environmental factors, which include cognitive processing of previous performance, perceived task difficulty, effort on task, and help received from other people, influence the formation of self-efficacy beliefs [3]. In all cases, students with relative high self-efficacy have better performance in chemistry courses than those with relative low self-efficacy [4].

During the past quarter-century, research in education has provided a deeper understanding of how students learn science and of the knowledge and skills required for academic achievement. This knowledge is invaluable to teachers in guiding instructional decisions, and has implications for science education at all levels. Taking into account that individuals learn in a variety of ways, it is necessary to provide for student differences through the purposeful use of a variety of teaching strategies that nurture the diverse ways that students learn. Ideally, these strategies enhance students' learning by a) stimulating active participation by all

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students; b) attending to the different ways students learn; c) providing opportunities for students to experience authentic scientific inquiry and to collaborate with others in diverse groups and settings. It is important to recognize that not every strategy can or should be applied in every teaching situation. Instructional strategies are tools to be used in designing and implementing instruction in a way that supports and enhances learning. It is important to note that strategies may be used concurrently; for example, instructional technology strategies may be used to enhance the context for learning. Well-designed laboratory experiences incorporate a number of effective teaching and learning methodologies including inquiry and manipulation strategies. A teacher's task is to determine what preconceptions and knowledge the students bring to the classroom, what concepts and skills they need to learn, and what support structures need to be provided in order for them to meet the learning goals. It is the role of the teacher to judiciously select from a variety of strategies and techniques those which will most effectively enable learners to develop deep understandings of the topics and meet the intended learning targets [5].

A successful teaching approach must be justifying the "success" via the conduct of educational research. Hence, every implementation of a teaching strategy or a teaching resource needs evaluation in order to be characterized as a successful experience. In the second part of this paper some examples of chemistry teaching approaches developed and evaluated in the Greek educational context will be presented.

2. Successful experiences in Greek chemistry classrooms

The complex nature of the chemistry subject has been identified as a factor that makes chemistry understanding difficult for the students. Chemists are using various types of chemical representations in order to communicate chemical thinking. The representational competence is a set of skills that students have to develop in order to be able to learn and solve problems in chemistry and the development of which is (or should be) a major goal in chemical education. Hence, the role of visuospatial thinking in order to fully understand several fundamental chemistry topics is important. Research has shown that the conventional lecture in which students are mostly passive listeners and which employs traditional 2D static illustrations, poses large difficulties in students' comprehension of chemical concepts which are "not only complex, but also abstract and dynamic such as in molecular symmetry" [6]. Consequently, several chemistry educators have developed 3D ICT based molecular visualization tools which can be valuable "as supporting learning materials". What is needed however is "an innovative and effective integration of educational technologies for teaching and learning chemistry" [6].

In a research project which lasted three years, evidence was provided for the capability of a hybrid instructional model in positively affecting both students' attitudes and outcomes in a demanding undergraduate chemistry course, namely "Molecular symmetry and Group Theory" [6]. The teaching approach employed is a combination of traditional face-to-face instruction and an online web enhanced learning environment. The web-based teaching material was designed and developed by the researchers themselves. 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 results showed that the adoption of the model is capable of improving the quantity and quality of students' involvement with the course content throughout the whole semester. 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 an important motivational construct. 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. The study provides evidence for the importance of the social factor (establishment of a learning community) in creating and maintaining students' motivation to learn. The presented successful teaching strategy ("hybrid instructional model") is applied among undergraduate chemistry students at University. However, it could also be applicable to secondary school students, in order to help them understand abstract and difficult chemistry concepts by combining different visualization tools with traditional face-to-face instruction.

Moving into the role of multimedia learning, researchers note that the relevant studies "have not taken into consideration important factors that could influence the appropriate selection of media and have thus failed to yield conclusive multimedia design guidelines" [7]. They note that the "empirical studies that focus on the impact of 3D visualizations on learning are, to date, rare and inconsistent". For example, there is contradictory experimental evidence on the usually assumed superiority of animations in relation with static graphics. Korakakis, Pavlatou, Palyvos, & Spyrellis [7] undertook a systematic effort for assessing quantitatively the effectiveness of a specific type of teaching resources, namely multimedia 3D visualizations. Their study examined whether the use of three different types of 3D visualizations (namely interactive 3D animation, 3D animation and static 3D illustration) accompanied with narration and text contribute differently (or similarly) to the learning process of 13-14 year old students in science courses. A chemistry-related teaching topic was used, namely "the different methods of mixtures separation". The statistical analysis of the results was based on a sample of 212 8th grade students (2nd year of lower secondary school) in Greece. The results showed that 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. Both types of 3D animation (interactive and not) are more effective in stimulating students' interest relative to static 3D illustrations. Moreover, both types of 3D animations tend to pose a heavier cognitive load on the students and require suitable metacognitive ability. On the other hand, the static 3D illustrations have an advantage relative to both types of 3D animations in regard with the reduction of the cognitive load. It is therefore deduced that "the unilateral use of one of the three types of visualizations does not improve the effectiveness of the learning process". Instead, "the combination of all three types of visualizations in a multimedia application for the sciences is recommended" [7].

Two teaching interventions aiming at primary school students' understanding of melting and evaporation below boiling point via the use of the particulate nature of matter were evaluated as successful experiences [8]. One intervention made use of a software simulation and the other of a traditional "static" representation of the particles. Both interventions were based on a teaching scheme suitable for young pupils (9-11 years old) that were developed by researchers. The scheme makes use of a step-by-step approach which is based on subsumptive learning (progressive differentiation of a more general idea) and has a much lower intrinsic cognitive load. The results of this study illustrated the difficulties which are associated with conceptual change, since there were cases of students who could not escape from their initial views and created synthetic explanations of the examined phenomena with both macroscopic and microscopic characteristics. In the question "Did the software help?" the experimental data indicated that the software provided more help in the case of evaporation, which is the most difficult phenomenon for the students to grasp. However, the researchers note that the simulation software should play a supporting role in the instruction and it is "a resource to be deployed by teachers alongside other teaching activities" [8].

Another research aims at assessing the effectiveness of a specific teaching intervention (namely the performance of a chemistry experiment with parallel use of computer technology – MBL system) in improving 10th grade (15-16 year old) students' understanding of the relation between the characteristics of pure substances [9]. The students were prompted to work in groups by using a specific worksheet in order to exchange ideas and reach conclusions while working. The data related to students' perceptions and evaluation of the teaching procedure were collected by using three methods: videotape recordings, field notes and semi-structured interviews before, during and after the experimental procedure. A classification of the student conceptions regarding the chemical concept under study into four different types was a result of the study. Moreover, the results showed that "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" irrespective of their gender. In addition, the students seemed to prefer the performance of the experiment with the aid of the MBL system.

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An alternative teaching approach was applied in a chemistry topic that is considered difficult for the students, namely atomic and bonding theory, and effort was made in order to evaluate its effectiveness in comparison with the traditional approach [10]. The evaluation of the teaching approach brings out the important role that different psychological factors and cognitive characteristics of the students can play in the process of chemistry learning. The study focuses on two specific characteristics: working memory capacity and field dependence. First, the relationship of these two psychological factors with the performance in chemistry tests was examined with a sample of 105 10^{th} grade Greek students (15-16 years old) which they took the same chemistry test, while their working memory capacity and field dependency were measured (via the Digits Backwards Test and the Hidden Figure Test, respectively). Both cognitive characteristics show statistically significant correlation with students' chemistry scores. In the next step, the possibility of improving chemistry learning via a new instructional approach which aims at minimizing the demand for a high working memory irrespective of the students' working memory space was explored. The aim of the proposed approach is to encourage active learning via a process in which 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 10^{th} grade students who were divided into two groups: control and experimental. Overall, the results provided evidence in support of the view that by re-designing some curriculum materials and teaching strategies in line with the predictions about learning derived from an information processing model, student performance can be improved.

Even though the above presented examples of successful chemistry teaching experiences were conducted in the Greek context, the results reached and the proposals made in relation with curriculum re-design and adoption of new teaching strategies, could be applied (and/or tested) to other countries as well. Finally we need to point out that the examples from the Greek educational context, also provide evidence for the fact that the effectiveness of chemistry (and science) teaching can be readily enhanced via the proper parallel use of a carefully selected variety of teaching strategies, techniques and materials.

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