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RESEARCH ARTICLE

MAKING THE TEACHING OF CHEMISTRY RELEVANT TO STUDENTS' EXPECTATIONS: A REVIEW

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A R T I C L E I N F O

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A B S T R A C T

The major challenge that confronts chemistry education across the vertical curricular strata is the gap between the high demands that learning chemistry requires and the low efforts that students make partially due to the lack of the relevancy of the teaching methods. Research has indicated one of the basic factors contributing to the lack of student motivation to learning chemistry is low quality teaching methods. This paper reviews strategies to modernize authentic teaching strategies in chemistry through application of organized active teaching models, friendly presentation, utilization of models and analogies, correlation of chemical concepts with everyday life, use of school laboratory and ICT, providing continuous assessment and feedback, and use of concept maps before and after instruction. The review aims to point out ways to effective knowledge construction that can be implemented by chemistry instructors. The goal is to make chemistry teaching realistic and easy to understand in order to motivate students' intellectual curiosity, which in turn leads to learning enhancement regardless of their career choices.

INTRODUCTION

Research has shown that chemistry teaching is out of favor and irrelevant in the eyes of students and their parents, does not promote higher order cognitive skills, leads to gaps between students wishes and teachers methodology is not changing because teachers are afraid of change and need guidance [1]. The most important factor for these social and pedagogical discrepancies is the lack of relevance of chemistry teaching. Although school chemistry programs set out to develop conceptual understanding in students and an appreciation of the way scientists do things, the relevance of the teaching in providing a useful education is under scrutiny. The stress on conceptual understanding and the appreciation of the nature of science tends not to be relevant for functionality in our lives i.e. relevant to the home, the environment, future employment and most definitely for future changes and developments within the society. Rather, the understanding tends to be geared to internal concepts within the subject itself. Concepts such as atomic structure or chemical bonding are almost universally section headings in chemistry courses, yet in daily life, for example - improving the quality of the air for our health, is potentially a much more relevant starting topic.

In the traditional approach, chemistry curricula tend to put the subject first, and applications a poor second. The relevancy of the teaching of chemistry in the processes and products we utilize in society and afterwards in understanding the scientific principles is forgotten. Thus, in terms of relevant conceptual learning, it would seem that current curriculum approaches are not providing the impetus to promote the popularization of chemistry that is expected. It would seem we need to find ways to initiate teaching based on scientific research and societal desires, and then develop the conceptual learning that allows students to appreciate the relevance of the science in their future career. Traditional approaches on how to improve chemistry teaching at the secondary and post-secondary level have been discussed in quite a few books in the area of achieving effective teaching and enhancing students' problem solving skills [2, 3, 4] and novel strategies come out every day in attempts to fill in the gap [5, 6]. However, not many resources address ways to show the relevancy of chemistry. To better understand the issue of relevance of chemistry teaching, it should embrace a relevant chemistry education philosophy, a relevant curriculum, relevant teaching approaches to the teaching of chemistry in schools, relevant assessment and evaluation strategies and relevant professional development for teachers. Teachers need to develop teaching strategies (models) in chemistry well enough in order for their students be able to challenge more demanding concepts in chemistry as they progress along the educational vertical from elementary to secondary school and then to university. Different strategies can be applied to chemistry teaching with the aim of encouraging students to learn chemistry at the macro, sub-micro and microscopic levels [7].

This paper is aimed at exploring and reviewing several means of making the teaching of chemistry relevant to students needs in the context of curricular, pedagogical, social and environmental aspects.

Apply an Organized Active Teaching in Chemistry (OATC)

Innovative teaching strategies could be used by teachers at all levels of chemistry education to enhance the students' motivation in learning chemistry [8, 9]. One of such innovations is making the teaching of chemistry relevant. This approach can be used by teachers in order to facilitate the learning of students who can apply them in the future when learning about new chemical phenomena described by more abstract concepts. Chemistry instructors should improve students' learning by inspiring their interest in chemistry to expose the fascinating faces of chemistry to students and inspire their curiosity regardless of their career choices. One of these innovative and research based teaching strategies is the organized active teaching in chemistry (OATC). It consists of a well planned, continuous, student centered, and resourceful teaching activity. When teachers use the OATC approach they teach new concepts and connections between them effectively in the social context. The OATC teaching approach is more appropriate for students in the school and home environment, as it facilitates inquiry learning. In this approach, teachers need to consider the following essential points during the teaching-learning process. They must

- divide the teaching period into distinct activities
- concentrate in the effectiveness of the teaching process since it is the most important factor for students' learning,
- set a particular goal for a specific period of teaching
- start teaching the current topic as a problem, so that the learners get informed why they are learning that particular topic.
- present the contents of the topic sequentially, in detail
- present the contents in a different manner, e.g. by flow charts, diagrams, lists, mind-maps, concept maps etc.
- skim the topic again in order to get a more detailed overview, adding knowledge to the previous information
- understand that the process of knowledge testing is important
- assess the understanding of the concept crucially and, if needed, motivate the learner to revise the difficult points. Figure summarizes the components of OATC

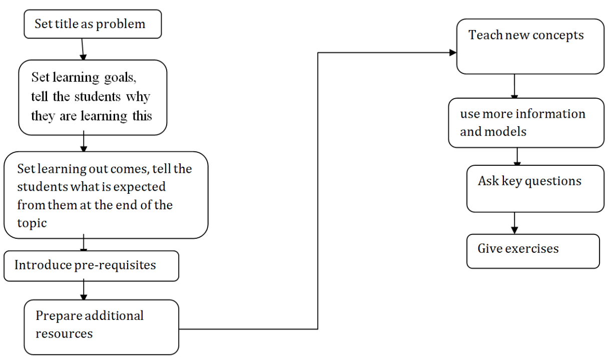

Figure An organized active teaching model

Make presentations Varied and attractive

Presentation is the heart of the teaching process. The best way of getting students excited in chemistry is by presenting it in a dynamic manner such that teachers could make their teaching friendly by creating an environment in which students do not feel threatened and allow them to relax, using cooperative grouping to help students understand that others have the same problems as they do, teaching at a slow pace to help students better comprehend the material being taught, providing extra tutorial sessions so that students are not left behind academically, and paying serious attention to field trips and laboratory activities [10].

Chemistry teachers may support their lectures with the combination of boards and audio-visual teaching aids such as overhead transparencies, Power Point slides and videos, simulated or actual lab demonstrations *etc* that make chemistry more alive and real to the students as our 21st century students are mostly visual learners due to the image-centric, visual world in which they are grown. Students grasp the concepts better if they can picture them. Thanks to the development of computer-related technology, we are able to show pictures of everything, from the giant solar system to a tiny atom, to the students, which in turn induce more straightforward perception. Teachers should also look friendly in their physical gestures and expressions. They better appear smiling, neat, well dressed, and sympathetic to their students; possess a balanced and controlled voice and so on while they are in the classroom.

Illustrate chemical concepts with analogies and models

Analogies play a significant role in human problem solving, communication, and creativity. An analogy's potential to make explanations of new material intelligible to students makes it a powerful tool for educational purposes. Effective analogies motivate students, clarify students' thinking, help students overcome misconceptions, and give students ways to visualize abstract concepts. When they are used appropriately [11]), analogies can also promote students' meaningful learning and conceptual growth [12]. Simply put, analogies compare two concepts or ideas—one that is familiar and one that is less familiar. The familiar concept is often referred to as the *analog;* the less familiar concept, or the concept to be learned, is usually referred to as the *target.* For example, in many biology textbooks, the enzyme/substrate interaction is compared to placing a key in a lock, where the enzyme/substrate interaction is the target concept and the placement of the key in the lock is the analog concept. Because analogies use familiar information to explain unfamiliar information, they are useful constructivist teaching strategies [13]. According to constructivist learning theory, knowledge is constructed as students integrate new information with their pre-existing knowledge base [14]. Proponents of constructivism suggest that students learn science best when they are actively engaged in doing science or in performing activities that allow them to think like scientists. As such, a major emphasis in science curricular reform is a change from a more traditional teacher-based learning to a more inquiry-based, student-centered learning. The followings could be used as rubrics to help preparing analogies to explain difficult concepts:

Does the analog sufficiently illustrate the target?
Do the similarities between analog and target make sense?
Does the student explain the similarities?
Is the analogy scientifically correct?
Does it make sense?
Does the analogy take scientific fact into account?
Does the student illustrate how the analog and the target are different?

Models that show both structures and processes help teachers convey important scientific concepts in chemistry and molecular biology [15]. Designers of these models benefit from knowing how students perceive and comprehend such visualizations. Specifically, instructional developers seek to design visualizations that allow students to learn critical concepts and relationships between these concepts. Students learn molecular chemistry concepts and relations by attending to, seeing, and understanding all the associated elements and the ways that they change and evolve during the process. Because often models are too complex to be quickly understood, learners need to establish accurate mental models to assist in their comprehensions.

Correlate chemical concepts with everyday life

Most instruction in science does focus on helping students accumulate information about scientific ideas, but does not foster development of cognitive skills, nor does it help them learn how to apply the concepts outside of school in the real world in which they live [16, 17]. It is not surprising that most students could not apply their science knowledge learned in schools to everyday-life events, because they do not have opportunity to do so in schools [18]. Whereas, connecting science to students' everyday-life experiences has been an important issue in science education and this should be included in science lessons [19]. Several reasons have been given for incorporating everyday-life experiences and focusing on everyday-life applications of science [20, 21]. Firstly, as argued by Campbell & Lubben [21], everyday-life experiences are a way to make science meaningful to students. Secondly, there is another argument is that if it is wished to educate students as scientifically literate citizens, everyday-life theme related to science is necessary [22]. Finally, it is also an argument about constructivist view on learning in which students' alternative conceptions derived from their everyday-life experiences before the formal instructions has been seen as a starting point in teaching [23]. Similarly, several studies have focused on the effect of including everyday science applications into school science on the students' mastery of school science [20]. However, this study focused on the unexplored area of students' use of science knowledge from teaching in everyday situations. Because of the importance of everyday-life applications, both researchers and teachers wish to emphasize on this issue in teaching science. Although they focused on connecting science to students' everyday-life experiences and taught their students in similar ways, they still fail to provide for students to apply their science knowledge to make sense of everyday situations [16].

Table1 Selected everyday life correlated chemical concepts

Concept	Connection to everyday life
Condensation	Formation of liquid droplets as we breath out on cold mirror surface
Oxidation in air	Fading of news papers, jewelers, statues, roof surfaces
odor of SO_2	Smell felt when a match stick is ignited or gunpowder is fired
Freezing point depression	Melting of ice when NaCl is added to it
Electromagnetism	Radio, television, mobile phones, etc. work based on principles of electromagnetism
Neutralization	Adding lime to acidic soils, swallowing milk of magnesia to relieve gastritis
Polymerization	Manufactured items such as car tires, textile products, plastics
Fermentation processes	Preparation of ethanol from sugar by microorganisms
Diffusion	Enables us to smell while molecules diffuse in the air

Thus, teaching strategy should be developed for teachers in order to provide students to make connection between their knowledge of science and related everyday situations. Coştu [24] has tried to assess the effectiveness of a predict-discuss-explain-observe-discuss-explain teaching strategy using a condensation concept since it is one of many of the everyday life events. Table 1 summarizes a series of examples that can be incorporated in the chemistry classroom.

Use Laboratory

Chemistry is a laboratory science and cannot be effectively learned without laboratory experiences. Indeed, the identification, manipulation, estimation and recognition of statistical errors, development of reporting skills (written and oral), exercising curiosity and creativity by designing a procedure to test a hypothesis, development of experimental and data analysis skills, applying concepts learned in class to new situations and general use of laboratory equipment are integral parts of the subject of chemistry [25]. The chemistry laboratory represents a wonderful opportunity for making the connection between the unseen microscopic world and the observable macroscopic world in which we live [26]. Laboratory experiences provide opportunities for team building, inquiry-based learning, hands-on activities, and exposure to standard laboratory equipment and technology. Though an excellent laboratory experience will certainly require hours of behind-the-scenes work on the part of the teacher, a laboratory need not have the latest technology to be effective. Many, if not most, of the concepts and principles common in high school chemistry can be demonstrated or discovered through experiments performed with simple apparatus. Of course, all experiments should be evaluated carefully for scientific accuracy, and appropriate safety guidelines and warnings, prior to use in the classroom. Within any given chemistry curriculum, teachers should develop instruction that is student-centered and emphasizes concrete examples of the concepts and principles to be learned. Student-centered lessons place emphasis on the students' learning rather than on the teachers' activities and teaching.

A high school laboratory should have the equipment necessary to conduct meaningful demonstrations and experiments. The physical laboratory environment must be accessible to *all* students. Teachers must understand that students with limited strength or mobility can have a full laboratory experience with appropriate accommodation. Instruction that is student-centered and emphasizes the role of laboratory demonstrations and experiments is the best method to ensure that students develop these essential skills in science. Laboratory exercises should come in three phases: the pre-lab, the lab, and the post-lab phases. In the pre-lab, students consider the concept or principle to be investigated. They predict and hypothesize. Effective pre-lab questions can prompt students to review and recall previously learned material that is pertinent to the lab. In the lab experience, students learn to plan their actions, and to identify and control variables; they observe measure, classify, and record. The post-lab challenges students to analyze and interpret data, evaluate the effectiveness of the procedure, formulate models, and communicate their findings in written and oral formats. In the post-lab, students can also relate or compare the results and concepts to known phenomena. When conducting a laboratory exercise, it is important that the students not know the outcome beforehand. For this reason, it is often appropriate to carry out a laboratory activity before the related concept is presented. Laboratory experiences, whether demonstrations or true experiments, must emphasize and model the investigative nature of science. Students should experience science as it is and not as a simple verification of concepts and principles already taught or assessed. Laboratory exercises should not be in the form of a "magic show," which is not specifically linked to particular concepts and principles of chemistry.

Teachers should consider a variety of factors to make the chemistry as "green" as possible when they are designing or choosing a laboratory activity. This would include consideration of the scale of quantities used, the amount and category of waste generated, and the proper in-class disposal methods for chemical wastes. They should also exercise to produce and use low cost and easily locally available materials instead of waiting someone fulfilling for them [27, 28].

Use Information Communications Technology (ICT)

Bringing ICT into the classroom can have a considerable impact on the practice of teachers particularly when ICT is conceptualized as a tool that supports a real change in the pedagogical approach. Not only do the teachers need to change their roles and class organization, they also need to invest energy in themselves and their students in preparing, introducing and managing new learning arrangements. Teachers also need to determine which applications have added value for learning in their subject area. While doing this they need to be aware that this is not a one-time activity, as the information environment is continuously changing. Perhaps most important and challenging for teachers is determining which basic subject, social and management skills students need to function in such environments. The change can impact on assessment tasks, with new learning environments moving away from summative methods of assessment to formative approaches and open-ended products (such as reports and research papers created by groups of students). These different aspects are time consuming, and result in an increased teacher workload. ICT use and application in the teaching and learning process can reduce the workload. Teachers can be encouraged to share resources with others, locate good practices on the web (where available) and adapt these to their local circumstances. In a number of cases the high workload is caused by teachers wanting to control all the activities of their students, which means answering many questions and running from one student to the other all the time. Teachers can take time to discover that computers do not mean extra work – rather they actually make their work easier. Again, more competent students themselves can be a useful resource, this time for their peers.

There is no doubt that teachers who use ICT in classrooms have to demonstrate high levels of energy, hard work and perseverance, often in the face of considerable odds [29]. If they are early adopters then they are required to be resourceful and overcome many barriers to make things work. Planning lessons involving computers can take considerable time and demands complex scheduling and resourcing. Therefore, teachers using computers in the classroom should not act in isolation from each other. They need access to resources which will supply ideas and material for different classroom applications, including peers who are also developing their own pedagogies and resources [30]. For a while, computers have great potential in education, they also present teachers with additional obstacles to overcome.

Use meaningful assessments and feedback to Improve Instruction

An assessment is not a "test"; however, a test is one form of an assessment. An assessment incorporates a wide variety of tools for informing and improving instruction, for helping teachers and students improve their understanding of content, and for evaluating student performance and establishing grades. Teachers have a responsibility not to rely only on one or two major assessment tools in their chemistry course. Some students excel in writing, some in math; while others may be strong speakers or artists. Some students are pressured by written exams, and some are not. The evaluation of student learning must use a combination of different assessment tools along with the corresponding planning and follow-up activities.

Biggs [31]) outlined that carefully designed assessment tasks allow students to demonstrate achievement of clearly communicated learning outcomes. The assessment designs should include the following three important elements: the learning out comes must be clear, the learning experiences must be designed to help students achieve those learning out comes, and the assessment tasks must allow students to demonstrate their achievement of the learning outcomes.

Charles E.Skinner [32] remarked that the school mark is one obstacle that tends to separate teachers from students, and students from students. Some way of marking, grading and evaluating pupils' work is necessary, however. In spite of the long persisting criticisms of school marks for unreliability as well as adverse emotional effects upon learners and teachers, the practical reality of certain contributions of effective assessment strategies in promoting individual learner's own realistic conception of himself is recognized. A credible assessment of a chemistry program will be based on information from a wide variety of assessment tools over a span of several years. The gathered information must be carefully examined and must be *used* to enhance student learning and to improve the program. Succinct, meaningful feedback is essential to learning and to sound assessment practice. Feedback that promotes learning can take many forms and teachers are encouraged to research and discuss with colleagues which type of feedback is most suited to their discipline area while addressing the learning outcomes and relevant assessment tasks [33]. Feedback is most effective when it is timely, personalized, empowering, designed to open doors not to close them, analytical, constructive and manageable

Use concept mapping before and after instruction

A concept map is a concrete representation of abstract ideas. It is a diagrammatic or schematic representation of the meaningful relationships among concepts [34]. The more links there are among the concepts, the greater the understanding is shown. Concept mapping is a teaching and learning strategy that has been developed by Novak [35] and which helps students to organize concepts into hierarchies. It has been developed as an outgrowth of Ausubel's [36] theory of meaningful learning which highlights the importance of prior knowledge in the learning of new concepts. Ausubel asserts that students learn meaningfully by building knowledge on the basis of what they already know. In other words, new knowledge (or new concepts) acquire their meanings through relationships with existing knowledge (or concepts) and meaningful learning occurs when new knowledge is consciously related to relevant concepts which the student already possesses [37, 38]. Ault [39] also supports the view that concept mapping enhances meaningful learning by leading students "away from rote learning and toward true understanding of concepts and their relationships." Concept mapping is a useful tool for helping students learn about the structure of knowledge and the process of knowledge production or meta-knowledge [40]. Stice and Alvarez [41] suggested that meaningful learning may be enhanced as a result of students' social interactions during brainstorming, initial mapping, discussions and revisions. Concept mapping has been found not only useful in promoting students' understanding of science concepts but also in facilitating students' abilities to solve problems and to answer questions that require application and synthesis of concepts [42]. Furthermore, concept mapping is seen to promote a minds-on approach to learning. Students are able to construct knowledge in their own terms and hence remember better what they have learned. As a diagnostic tool, concept mapping has allowed the teacher to establish the main ideas held by the students before they begin to experience new material [43]. Such diagnosis has shown the teacher spontaneous reasoning of students as well as their misconceptions (or preconceptions) which might have otherwise gone unnoticed. There is also evidence to show that concept maps can be used for formative as well as summative assessment [44]. One important benefit of concept mapping, among others, to the learner is that it helps the learner about the structure of knowledge and the process of knowledge production. The usefulness of concept mapping to the teacher is that it helps in promoting student understanding of concepts; it also helps in the assessment of student learning, in particular, the diagnostic and formative aspects which enable the teacher to use the maps as starting points in building links between the prior knowledge and new knowledge that s/he intends the students to learn as well as in addressing misconceptions or preconceptions that students may have at the beginning of learning each topic [42].

Be a professional teacher learner

Teacher quality is placed at the very centre of learning. Researches [45] consistently highlight the quality of teachers as a key determinant of variation in student achievement [46, 47]. These researches assert that, in order to be effective, teachers need a deep understanding of their subject area, knowledge of how students learn specific subject matter and a range of strategies and practices that support student learning. The research also affirms that engaging teachers in high quality professional learning is the most successful way to improve teacher effectiveness [48].

Furthermore, teaching is a dynamic profession and, as new knowledge about teaching and learning emerges; new types of expertise are required by educators. Teachers must keep abreast of this knowledge base and use it to continually refine their conceptual and pedagogical skills. The field of inquiry that has had most significance for teachers and teaching is that of how students learn. The growing evidence about student learning forms a compelling case for engaging teachers in highly effective professional learning and has profound implications for what is taught, how it is taught, and how learning is assessed [49].

Possess professional and personal qualities that a good teacher should have

The quality of an educational system cannot exceed the quality of its teachers [50]. Teachers of chemistry are expected to be well qualified. It is expected that any qualified chemistry teacher has completed specific training in chemical and laboratory preparation and safety, including the ability to conduct hazard reviews of laboratory experiments and class demonstrations. Safety training is critical for any chemistry teacher, for his or her own legal and physical protection, and, of course, for the safety of all students. In addition to their qualifications, chemistry teachers need to be equitable in a sense that they do research on best practices aimed at teaching and reaching all students, transform and adapt instructional practices to promote student learning, serve as equity role models in their classrooms and in the larger community, recognize and teach to their students' strengths, provide a learning environment focused on trust and fairness; and connect with the culture of their students, the students' families, and the community. Chemistry teachers are also responsible for adhering to ethical conduct within the scope of their practice in the classroom. Ethical chemistry teachers model within their instructional practices a safe and productive learning environment with equal opportunities for all students, and present course content without "distortion, bias, or personal prejudice." They shall refrain from misrepresentation of self and others, and not engage in fabrication, falsification, or plagiarism of ideas or information. A good quality teacher is one who has a positive effect on student learning and development through a combination of content mastery, command of a broad set of pedagogic skills, and communications/interpersonal skills. Quality teachers are life-long learners in their subject areas, teach with commitment, and are reflective upon their teaching practice. They transfer knowledge of their subject matter and the learning process through good communication, diagnostic skills, understanding of different learning styles and cultural influences, knowledge about child development, and the ability to marshal a broad array of techniques to meet student needs. They set high expectations and support students in achieving them. They establish an environment conducive to learning, and leverage available resources outside as well as inside the classroom. They always try and take care in minimizing or avoiding students' misconceptions in their academic subjects. They give and receive feedback genuinely with a purpose of continuous improvement [51]. Personally, chemistry teachers should look neat, healthy, and friendly and smiling, well dressed, should be fluent in their speech, good noise proportional to class size, and have genuine relationship with their colleagues and students.

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