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Teaching Chemistry by Means of Modern Research

Education is currently undergoing "deep" modernisation. In accordance with this, the main outcomes of educational institutions are not the knowledge itself, but a set of social competences in the most important spheres of life. Learners should adopt a set of socio-political, intellectual, informational and civic competences when they enter "adult life". The teaching of different sciences in educational institutions contributes to the formation of diverse concepts and the development of critical thinking among learners. An important point in the understanding of knowledge should include pupils' acceptance of personal relevance, which leads to an understanding of chemistry as a science in the context of global challenges to humanity. The development of a chemical picture of the world among learners is important for the formation of a scientific outlook and a culture of ecological thinking and behaviour. That's why, the scientific picture of the world would be fundamental for the development of nanotechnology in the educational process.

Key words: chemical education, modern research, history of science, full-time teachers, nanotechnology, educational technologies, modern approach, methodology.

Introduction

Contemporary research is the basis for the teaching chemistry. Different criteria are used to characterize it — criterions relating to different aspects of learning and teaching chemistry. Using contemporary research to teach chemistry requires the incorporation of cutting-edge science into school science lessons. This approach gives learners the opportunity to obtain the developments in research while they are still in the science research laboratories [1]. It includes: reading basic literature adapted to their level [2], meetings with researchers and listening to their descriptions of their investigations, and learning from well-prepared teachers who are familiar with contemporary researchers [3]. This approach allows learners to observe authentically the development of modern scientific knowledge; to get acquainted with the original investigations that are taking place in modern scientific laboratories; to discover who is currently at the forefront of scientists and how they work; and [6]. to understand the nature of modern science.

Dewey John [4] stated: "If we teach today's learners the way we taught yesterday's learners, we are depriving our children of tomorrow". Dewey's well-known statement challenges the science teachers. This problem can be solved by exploring science using modern investigations. According to this approach, modern study and cutting-edge knowledge should be the part of school science curriculum [5]. The exploration of science by integrating contemporary research provides learners with up-to-date information about what science really is. Learners realize that research is about real people who are the same as they are and who follow the same norms of the modern age. They also learn about the open-ended nature of scientific questions that are waiting to be solved based on research (Google Scholar search for "unsolved scientific mystery" reveals about 32,600 scientific papers). The nature of scientific questions involves epistemological conviction, which includes multiple sources and a body of knowledge [6].

Methodology of the research

Modern research covers many fields and is being developed in many different directions. Therefore, in this article, we decided to focus on one example of modern research — nanotechnology [7], which will be referred to as NST (nanoscale science and technology). We will cover different aspects of this approach as they are reflected in nanotechnology education. When it comes to contemporary science topics, there is no existing tradition as to what to teach. Typically, sporadic learning units are developed first. These units represent a partial introduction to a new field based on the knowledge of the developers. In nanotechnology, these may be, for example, units near the AFM (atomic force microscope) [8].

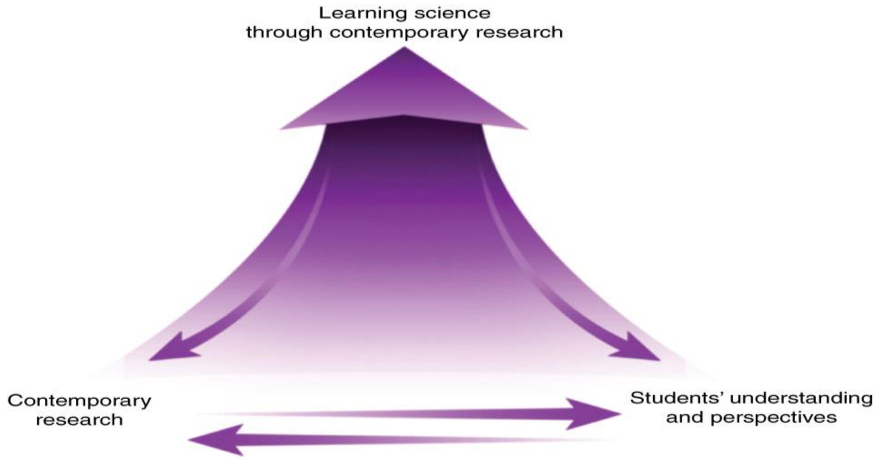

Figure 1: EDM process (education reconstruction model) for developing a coherent education programme in S&T (nanoscale science and technology), adapted from 12.

The NT (nanoscience and engineering) world supported the development of a paper on "big ideas" in ST [9] by Stevens, Sutherland and Krajcik; it was the result of two workshops involving both scientists and teachers. To incorporate an interdisciplinary perspective, scientists and teachers from different scientific disciplines were selected to reach a consensus on what constitutes big ideas in S&T. It is well known, that big ideas are basic concepts which can be considered as crucial and fundamental for understanding the fundamentals of the field (namely the field of nanoscience). They also suggested how these ideas could be introduced into the world's science curriculum. Here are nine big ideas: "size and scale, structure of matter, forces and interactions, quantum effects, size-dependent properties, assembly, instruments and instrumentation, models and simulations and scientific technology and society".

The Israeli study used a diverse methodology [10]. A Delphi methodology of three rounds was applied to reach consensus on the main concepts to be taught in secondary schools. "Eight basic concepts of S&T were identified: size-dependent properties, innovation and applications of nanotechnology, size and scale, characterization methods, functionality, classification of nanomaterials, approaches to nanomaterial production and creation of nanotechnology". This study revealed three concepts of nanotechnology which had not yet been recognized in previous studies. This survey was followed by an additional Delphi study to select the nanotechnology applications recommended for high school [11]. As a result, nanotechnology and education experts suggested five applications of nanotechnology: "nanomedicine, nanoelectronics, photovoltaic cells, nanorobots and self-cleaning".

At college level: Wanson, et al [12] adapted "big ideas" formulated by Stevens, et al to that level. They suggested that nanoscience and engineering (ST) degree programmes should include four aspects or areas of ST (P-N-P-A): "Processing (how nano-objects are made), Nanostructure (how the structure of nano-objects can be mapped and characterised), properties (resulting properties of nanostructured materials/devices that depend on size and surface) and applications (how nanomaterials and nanodevices can be designed and engineered to benefit society)".

The integration of modern research and development into school chemistry curricula has always been a challenge. Professionals who develop modern knowledge and skills are not teachers, and teachers have not encountered the subject during their studies because it was not yet known [13]. This situation leads to the necessity for professional development of teachers that will prepare them to teach modern scientific research in their classrooms. Many courses have been developed in the field of nanotechnology for teachers and teachers' attitudes towards the new field have been studied [14].

A situation in which new scientific knowledge is integrated into the science curriculum can bring numerous benefits. Curriculum developers should consider current learning theories "how people learn". Jones, Gardner, Falvo and Taylor have analyzed the different types of thinking required to understand different concepts of STEM. Children of different ages have different thinking abilities, so different concepts should be taught at different ages.

Other researches have explored different learning environments for teaching specific concepts of S&T. There is no need to replace traditional pedagogy with more appropriate pedagogy. Suitable pedagogy can be integrated in advance. For example, there have been many studies related to learners' difficulties in grasping the concept of size and scale, a concept that is taught in biology, chemistry and physics courses. It is very difficult to understand how small a nano really is, as learners cannot sense objects of this scale with their own minds. Pedagogical research has shown that learners can better understand small size and scale when taught compared to objects with which they are familiar from their everyday life experience.

In addition, by integrating contemporary research into school chemistry lessons, learners can learn about the real researcher who conducted the investigation. These encounters introduce learners to the real process of knowledge development in science, as reflected in the eight core concepts of NST, the creation of nanotechnology, presented by Sahnini and Blonder. Various means are required to organise meetings with active researchers. Learners can participate in a scientific conference and attend a lecture by a researcher. Modern technology can help to engage scientists in learning via YouTube or online courses.

Three examples of learning:

The identified examples do not cover the specific content of the science curriculum; instead, they represent central issues in science education: using and developing models; understanding the relationship between science and technology and understanding the nature of science. We would like to emphasise that other examples can be given.

Example 1. Model development

Modern surveys provide chemistry teachers and learners with the opportunity to critically evaluate their knowledge by comparing it with new scientific findings. The basic concepts of chemistry include atoms and bonds, but when teaching them, teachers usually build models to describe it. Since the time of Democritus's atom and Avogadro's molecule, scientists have sought to observe these fundamental building blocks of nature. This dream came true in 1981, when the scanning tunnelling microscope (STM) was invented [15].

A possibility of using STM and later AFM (atomic force microscope) penetrated into science education. Margel, Eilon and Scherz developed and studied a programme in which learners who had learned about the dispersed nature of matter in high school chemistry were invited to an STM facility for the actual visualisation of atoms. Blonder et al. described in their review other teaching subjects that could benefit from the use of STM (scanning tunnelling microscopy) or AFM. These instruments have very high resolution and in recent studies they have been able to show individual molecules on the surface, chemical bonds and even hydrogen bonds (39). as shown in Figure 2 and Figure 3 [16].

The abstract concept of chemical bonds can be visualized and data can be provided for class discussion about the differences between the model studied and the experimental data, for example, what are the characteristics of each? What can we learn from all of them?

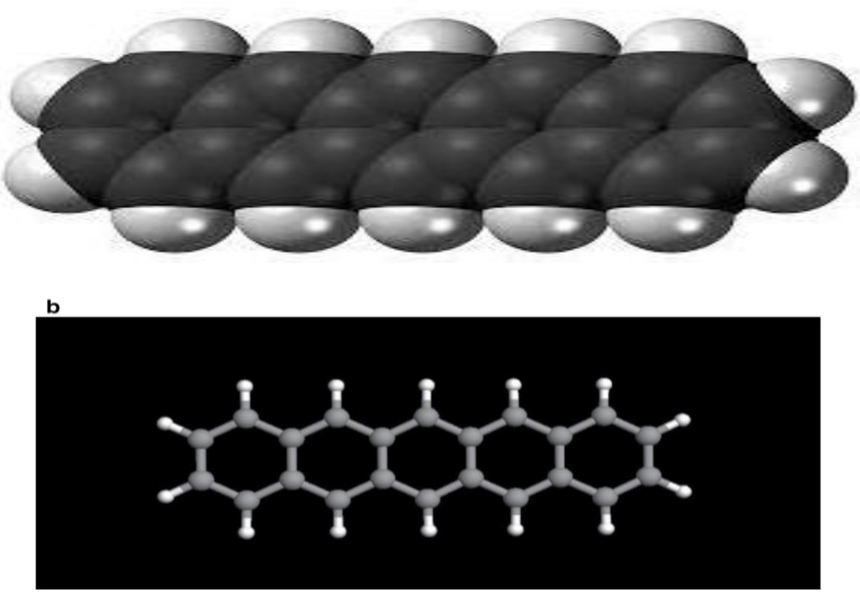

Figure 2. (a) AFM image of pentacene on Cu (111).
(b) Ball-and-stick model of the pentacene molecule obtained from Gross et al., 2009.

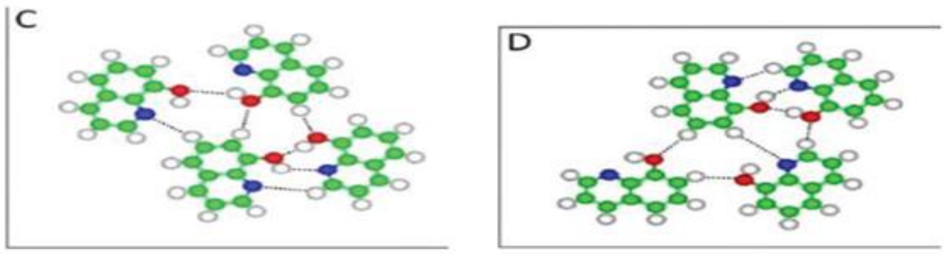

Figure 3. 8-hydroxyquinoline (8-hq) molecules absorbed on the surface

Cu (111) obtained in Zhang, et al., 39. AFM measurements of assembled 8-hq clusters on Cu (111) (a) and (b) constant-height frequency shift images of typical clusters assembled from molecules and their corresponding structure models (c and d). The punctuated lines in (c) and (d) indicate probable H-bonds between 8-hq molecules. Green, carbon; blue, nitrogen; red, oxygen; white, hydrogen.

Example 2. The nature of science.

If we want to provide learners with a realistic image of the nature of science and show them how scientists actually work, we must allow learners to experience a modern, realistic image of science. Scientists work today in interdisciplinary teams and use tools and perspectives from other disciplines to solve contemporary problems. Scientists work with advanced tools.

This concept has three sub-concepts: interdisciplinary science and technology, teamwork and nanotechnology development. This concept reflects the importance of immersing learners in authentic environments and activities that go far beyond scientific facts and experimental results. Learners who participated in the nanotechnology science conference changed their image of a scientist as a result of meeting real scientists at the conference [17].

Moreover, when we introduce learners to modern science, an understanding of which not everyone knows, some part of the nature of science reflects its constantly evolving nature. Learners realize that there are more open questions. This note is a challenge to future scientists to join the research and become the next scholar to explore new areas and find answers to unresolved questions.

Example 3. The relationship between science and technology.

Fundamental science is usually perceived as a provider of knowledge for the development of new technologies. The discovery of new nanomaterials with new properties has led to the development of new applications in many fields. However, in nanoscience, the development of high-resolution microscopy such as AFM, STM and electron microscopy has allowed scientists to see the nanomaterials and nanostructures that they have created in research laboratories. The observation of these products has deepened scientists' understanding of particles at the nanoscale and has led to increased research and development in the field of nanoscience and nanotechnology.

There is a strong emphasis on the relationship between science and society in contemporary research. The European Commission emphasises the importance of responsible research and innovation (EC) values and several science education programmes have been developed and implemented in Europe which integrate EC into science education. These programmes bring contemporary research into science lessons as well as possible ethical dilemmas and environmental influences that are discussed in the classroom.

Motivation and attitudes of learners

On the other hand, the idea that offering topics such as nanotechnology can be attractive to young learners is based on scientific research in the field of education. Several studies have shown that teaching nanotechnology increases learners' motivation to engage in research and scientific careers. Hutchinson, et al. investigated the interest and motivation of secondary school learners in nanoscience concepts and phenomena. For this purpose, learners were introduced to several nanoscale topics and phenomena through four manipulative activities and a series of guiding nanoscale questions. These revealed that the learners were most interested in S&T topics related to their “real world” and everyday life.

Delgado, Stevens, Shin and Krajcik developed a 12-hour learning unit to explore size and scale at a summer science camp. The context of nanotechnology greatly influenced the learners and broadened their knowledge about the size of objects. They became more engaged and interested because the context was relevant to the learners' daily lives [18].

Blonder and Dinur conducted a study on teaching learners for using LEDs (light emitting diodes) in nanotechnology. They found that the number of learners who decided to enrol in an advanced chemistry class at school increased as a result of learning about LEDs. Another study had similar results. At a longitudinal study which summarised the professional development of chemistry teachers who had developed a module on nanotechnology and evaluated it in their classroom was reported that the integration of nanotechnology increased learners' motivation to learn chemistry.

It is worth mentioning that nanotechnology increases the motivation of both male and female learners to pursue careers in science and does not create a gender gap. We can feel the enthusiasm of a high school student saying: "We actually have seen atoms with our own eyes!" and realize the motivational impact of modern science on learners.

Discussion

Teachers should be trained appropriately in trying to implement each of the two approaches. Regarding the integration of the topic of modern research into school chemistry, teachers who were formally educated before the development of the new field do not have the necessary content knowledge to integrate the modern field into their teaching. As it was mentioned above, in the context of the historical approach Arons argued that many chemistry teachers do not spend sufficient time discussing the nature of the scientific process and, as a consequence, miss opportunities to instil critical and exploratory thinking skills.

While discussing the integration of the topic of contemporary research, we have to mention several problems: the problem of content, the teachers' belief in their ability to learn and then teach advanced modern science (belief in self-efficacy) and the stage at which teachers have to adapt the new topic to their classrooms. When we developed an advanced course on nanotechnology, they were able to successfully pass the knowledge test. However, they felt that their understanding of nanotechnology was not deep enough to teach the content to their learners [19].

In order to fill this gap, we developed and implemented a three-phase model to support teachers in learning contemporary content and adapting it to their classrooms. It is important to note that we have found that the model created a better environment where teachers could develop their knowledge of the content, their belief in effectiveness to achieve a deep understanding and adaptation of the content to their classrooms.

In addition to this task, we have found several opportunities by presenting teachers with a contemporary topic. Modern content reintroduces teachers' enthusiasm for the subject they teach [20] and they can pass this enthusiasm on to their learners. Teachers participate in professional development courses to learn the latest material. These courses provide an opportunity to use non-traditional teaching methods when teaching new content.

We have found that teachers are adapting these non-traditional approaches for learning when they teach nanotechnology. This finding is reasonable because teachers tend to teach the same way they were taught. As Putnam and Borko explained: "How one learns a particular set of knowledge and skills, and the situation in which one learns, become a fundamental part of what one learns". However, we also found that teachers were transferring alternative approaches to learning (such as using a learning model, integrating videos, using learner-centred pedagogy, and creating and presenting student poster exhibitions) to other topics in the science curriculum. This transference proved to be sustainable over a five-year period.

Conclusions

We believe that both methods of teaching and learning, either through contemporary research or using a historical approach, should be integrated into the chemistry curriculum and that teachers should be familiar with both. This is supported by an ongoing study comparing the conceptual understanding of the properties of gas by pupils who were taught in a historical or contemporary context, and no significant differences were found between the two groups.

As it was said earlier, each approach: deals with elements important to chemistry education, i.e. the development of models, the relationship between science and technology or the nature of science, it has its own specificity and contribution to chemistry education, and it complements the other by presenting the sequence of development of science in general and chemistry in particular. We invite teachers to become familiar with both the modern research approach and the historical approach. However, as previously discussed, teachers should receive intensive and comprehensive training before adopting either or both approaches. They should receive appropriate guidance and support on what to teach and how to teach, addressing historical aspects or contemporary research.

Various aspects of a comparison between two different approaches to the teaching of chemistry have been considered here. However, there are additional parameters that have not been discussed here that are important for comparison, e.g. philosophy of science (56) and subject-oriented philosophy of chemistry (57; 58). Another point that has been briefly mentioned and needs more attention is the epistemological beliefs of the science teachers and learners, which can be developed through the two approaches. We hope that the other researchers who feel that the discussion is relevant to their studies in science education will contribute to this important topic.

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Заманауи зерттеулер арқылы химияны оқыту

Қазіргі уақытта білім беруде «терең» жаңғырту жүріп жатыр. Осыған сәйкес білім беру мекемелері қызметінің негізгі нәтижелері білімнің өзі емес, өмірдің маңызды салаларындағы маңызды әлеуметтік құзыреттер жиынтығы болып табылады. Студенттер әлеуметтік-саяси, зияткерлік, ақпараттық және азаматтық құзыреттердің белгілі бір жиынтығымен «ересек өмірге» енуі керек. Білім беру мекемелерінде әртүрлі ғылымдарды оқыту әртүрлі ұғымдарды қалыптастыруға, оқушылардың сыни ойлауын дамытуға ықпал етеді. Білімді түсінудің маңызды сәті химияны ғылым ретінде білуге жетелейтін, адамзаттың жаһандық мәселелері контексінде және өте өзекті болып табылатын студенттердің жеке маңыздылығын қабылдау болуы керек. Білім алушылардың ғылыми дүниетанымын, экологиялық ойлау, мінез-құлық мәдениетін қалыптастыру үшін дүниенің химиялық бейнесін дамытудың маңызы зор. Осыған сәйкес әлемнің ғылыми бейнесі оқу үдерісінде нанотехнологияны дамыту үшін іргелі болмақ.

Кілт сөздер: химиялық білім, заманауи зерттеулер, ғылым тарихы, штаттық мұғалімдер, нанотехнология, білім беру технологиялары, заманауи тәсіл, әдістеме.

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Преподавание химии посредством современных исследований

В настоящее время в образовании происходит «глубокая» модернизация. В соответствии с этим основными результатами деятельности образовательных учреждений являются не сами знания, а набор важных социальных компетенций в важнейших сферах жизни. Обучающиеся должны вступить во «взрослую жизнь» с определенным набором компетенций: социально-политических, интеллектуальных, информационных и гражданских. Преподавание различных наук в учреждениях образования способствует формированию разнообразных понятий, развитию критического мышления у обучающихся. Важным моментом в понимании знаний должно стать принятие личной значимости учащихся, что приводит к познанию химии как науки, в контексте глобальных проблем человечества и является чрезвычайно актуальной. Развитие химической картины мира у обучающихся важно для формирования научного мировоззрения, культуры экологического мышления и поведения. В соответствии с этим научная картина мира будет основополагающей для развития нанотехнологии в образовательном процессе.

Ключевые слова: химическое образование, современные исследования, история науки, штатные учителя, нанотехнологии, образовательные технологии, современный подход, методология.