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Chemical Experiment in Russian Schools

D. M. Zhilin

Moscow Institute for Open Education, Aviatsionnyi per. 6, Moscow, 125167 Russia
e-mail: zhila2000@mail.ru

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Abstract—Many arguments in favor of chemical experiment, both old and new ones, were put forward. It was demonstrated that chemical experiment is valuable by itself and instrumental in teaching and forms meta-domain skills. The idea that chemical experiment should form concepts rather than illustrate them was substantiated.

Opportunities for chemical experiments in modern Russian schools were considered. Legislation dealing with chemical experiment was criticized for numerous collisions, and possible ways to avoid these collisions were suggested. It was noted that staffing problem could be reduced reasonably by encouraging teachers. For methodological support, which is also crucial, some points of development were indicated (digital laboratories, inquiry learning, and shifting the role of experiment from concept illustration to concept formation). It was stated that the supply of chemical experiment is insufficient but can be optimized by some measures that should be taken by educational authorities.

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Role of Chemical Experiment: Tradition and Modernity

Until the recent two decades the importance of chemical experiment in teaching chemistry was undisputable. However, over the last twenty years, the approach to chemistry experiment in schools underwent fundamental changes. There are several reasons for it. First of all it is the availability of video experiments and programs for carrying out simulations of experiments (during which pupils "carry out" chemical reactions on the screen). The second reason is the increased concern (often excessive) for safety as reflected in attempts to protect the pupils from any possible risk. The insufficient supply, has been preventing chemical experiments for the last two decades, and the culture of chemical experiment in schools degraded significantly.

As a result, some arguments against chemical experiment in schools were put forward, and simulations and videos were suggested as alternatives. In this context, a number of questions arise.

To what extent do pupils need real chemical experiment? Can it be replaced by simulations or videos (and, to what extent if "yes")? If real chemical experiments are still necessary, which side of chemistry teaching ad learning do they affect?

What is the best way of incorporating the experiment into the chemistry curriculum, and what are the criteria of their efficiency?

What is the best way of organizing chemical experiment and what are the criteria of their efficiency?

What is the optimal set of chemical experiments in the chemistry curriculum?

What is the most efficient design of instructional materials for school experiments?

Discussing the choice between chemical experiment, simulation of experiment, and videos one should bear in mind that it is a matter of financial interest of different competitors. Manufacturers of simulation programs and videos promote their products, while manufacturers of the laboratory equipment do the same with their products. At the same time, the teaching personnel may prefer to spend the funds for beautiful curtains rather than for any of the mentioned above.

The Russian pedagogy provides negligible number of answers to the above questions; the same is true of foreign methodological literature. Below, critical review of relevant publications will be presented, along with the author's observations based on fifteen years of experience of organizing chemical experiments at secondary schools in Moscow.

Arguments in favor of "live" chemical experiment will be subdivided into three groups: axiological (experiment is valuable in itself and is an activity of personal significance) [1]; utilitarian (experiment forms inter- or meta-domain skills), and instrumental (experiment is an instrument of constructing concepts and theories of chemistry).

Axiological Role of Chemical Experiment

The axiological arguments in favor of chemical experiment are almost not in Russian and foreign literature.

We could state that chemical experiment may have a value for many students. Chemical experiment is a kind of a puzzle, and for many children, puzzle solving or quest solving through quests on a computer is of extremely valuable, as evidenced by huge sales of quests. Chemical experiment is a real quest which result is not known a priori and thus can be also valuable. Watching events with unpredictable results (e.g., live football matches) is also valuable for many people. Again, chemical experiment can be regarded as an event possessing a value of a similar kind, for which videos and simulations are unacceptable for the same reasons for which watching football on tape delay is unacceptable for football fans.

Also, the aesthetic value of chemical experiment is worth mentioning: Many experiments influence, our perception of beauty (either beneficially or adversely).

The intrinsic value of chemical experiment can be supported by the following observations.

The "Young Chemist" science kits of different kinds undoubtedly have a commercial success. For example, the "Scientific Entertainments" series "Young Chemist" kit developed by the author [2] has an annual circulation of several thousands [3]. This kit predominantely for 8–14 y.o. children, i.e., for children that don not study chemistry at school. Hence, the parents' reason for purchasing a fairly expensive (about $80) kit has nothing to do with school curriculum or certification. Among may available kits for home experiments by "Scientific Entertainments," the "Young Chemist" kit is the most popular.

The author has been conducting chemical experiment in secondary school no. 192 in Moscow for more than 10 years. The interviewed graduates characterized chemical experiment as being one of the most memorable learning components. They repeatedly emphasize their positive attitude toward chemical experiment but find it difficult to provide adequate explanations.

For five years, the 8- and 9-graders of a biological-chemical class at Moscow secondary school no. 192 have been attending optional lectures which are delivered by the author every week as accompanied by various demonstrations and explanations concerning relevant chemical concepts and laws (this course does not contain assignments for submission).

Tenth-grade pupils of this school can attend optional classes in organic synthesis during two years once in two weeks. When asked by the author about their opinion of possible evaluation of their execution of experiments during these classes, the pupils suggested that no evaluation be done at all, and this resolution was agreed by consensus. Given the fact that the knowledge and skills they acquire during this practical work are virtually not demanded whatever the certification form, the only motivation behind their behavior seems to be the intrinsic value possessed by chemical experiment.

If no practical works are offered to pupils at secondary school no. 192 for a long time, they use to request organizing them.

When asked about the reason for which experiments are conducted in chemistry classes, many of them respond that this is being done "for interest's sake" [4].

As to aesthetic significance of chemical experiment, it can be validated as follows.

While watching or conducting experiments, pupils often express their attitude by exclamations like "wow, it is beautiful!" In this respect, the author made an interesting observation in 2011, when 11-graders of a biological-chemical class had three sessions (in succession) of chemical experiments on a variety of topics that may be encountered at chemistry Olympiads. During experimental studies of the properties of gases and metal salts the pupils tended to respond moderately, but during experiments with "chromium compounds" they violently expressed their admiration, while watching numerous color transitions (despite a great practical experience behind them). Of all the experiments, pupils use to remember best the brightest experiments. These experiments can be both beautiful and unaesthetic. A special survey revealed that, in pupils who finished the practical course of organic chemistry in their tenth grade, the most vivid remembrance was created by synthesis of allyl mustard oil having a disgusting smell. The personal significance of chemical experiment was validated by V.S. Polosin's observations [5] that description of an experiment always arouses scientific interest in pupils. Moreover, during chemistry exams pupils demonstrated the best knowledge of the material whose presentation by Polosin was accompanied by sharing his vivid personal experience. Currently, the personal significance of chemical experiment is being the subject of investigation (and validation) by V.V. Zagorskii.

The above-said allows a simple conclusion: chemical experiment should be conducted, because it is valuable by itself and has a personal significance for pupils. It cannot be replaced by simulation and videos. Naturally, experiments having the maximal intrinsic value and personal significance should be conducted.

General Utilitarian Role of Chemical Experiment

Any experiment provides a tool for interaction with the surrounding world. The ability to carry out experiments and interpret their results is an essential meta-domain skill, which is responsible for the general utilitarian function of experiments. The formation of such skill was emphasized by Polosin [6]. No simulations of chemical experiment can replace real experiment since the latter has a significantly larger number of possible outcomes than does the former. For example, computer simulation of the interaction between $CuSO_4$ and NaOH solutions is limited by the scheme of formation of $Cu(OH)_2$ product. At the same time, real interaction can lead not only to this product but also to copper hydroxide sulfate and hydroxo complexes [7].

An essential role played by experiment in formation of a scientific materialistic worldview was stressed by L.A. Tsvetkov [8]. Unfortunately, no rigorous studies were undertaken in Russia and in Western countries with the aim to examine how chemical experiment in schools affects the "worldview" (for this term, English language does not provide an adequate equivalent; it is sometimes interpreted as the set of beliefs about fundamental aspects of reality). At the same time, Western professionals initiated a survey to elucidate the role of experiment in formation of ideas of science and scientific work [9]. The responses provided by 368 students showed that their comments concerning the real situations were very far from scientific worldview.

A constructivist approach implies a teaching practice reproducing the real scientific work (authentic practice), but the results of this activity are more than questionable. This is primarily due to a working memory overload, because scientific work typically involves manipulation of a large number of complex objects [10].

The significance of formation of experimentation skills in pupils was emphasized by Kiryushkin and Polosin [11], but the chemical experimentation skills are most probably of only secondary importance. What is much more important is that the opportunities offered by chemical experiment can be used for development of technical creativity (designing and assembling the components of experimental setups), but Russian and foreign methodological literature does not consider this issue.

Paradoxically, the aesthetic value of chemical experiment can undergo a smooth transition into utilitarian value. For example, Tchaikovsky [12] treats aesthetic perceptions as underlying the formation of series and similarities in very distant domains (i.e., aesthetic perceptions belong to meta-domain sphere of cognition). Dahlin [13] asserts (drawing mainly upon nondualistic philosophies) that the present theories of science education are characterized by one-sided and exclusive focus on conceptual cognition and concept formation, while neglecting sense experience, and need to be complemented with phenomenological and "aesthetic" perspectives. This would make the transition from immediate lifeworld experience to the idealizations of scientific theories less difficult for learners. The limits of applicability of such "diatropic" approach still remain to be identified, but it may be helpful to certain extent.

Instrumental Role of Chemical Experiment

Soviet school of pedagogy (which was formed before the computer revolution and collapse of the USSR, which factors were specifically responsible for the above-described changes in attitude towards chemical experiment in school) defined a number of instrumental functions fulfilled by chemical experiment. Though fairly reasonable, these functions are for the most part very strongly generalized, which complicates formulation on their basis of consistent practical recommendations with applicability limits indicated. Moreover, experiments to identify the applicability limits for many recommendations were conducted in the USSR and Russia to a negligible extent, and their conclusions were primarily based on undocumented teachers' experience.

For example, Kiryushkin and Polosin [11] assign to experiment the role of a tool of knowledge consolidation and improvement, which allows the relevant concepts to be defined more precisely by identifying the essential features and teaching how to apply the knowledge acquired to solving experimental problems. Tsvetkov [8] interprets chemical experiment as a visualization tool, also playing a cognitive role which, however, is limited to filling gaps in learners' sense experience.

Halbych et al. [14] emphasized the significance of experiment in development of learner's personality through the use of not only mental, but also observational and motor activities. Experiment is helpful in mastering the general working methods and acquiring the skills needed to solve various problems. Also mentioned was the development of decision-making skills, to which end learners need to possess not only knowledge and skills but also the ability to choose the needful skills from among those available. Thereby, experiment contributes to development of learner's competence. Unfortunately, Halbych et al. did not provide any experimental validation of those conclusions.

Thus, the Soviet school of pedagogy fairly clearly tends to place theory ahead of experiment, with the role of experiment in school being reduced to knowledge consolidation, improvement, and application. Some older methodologies developed by Soviet pedagogues (quotation from [11]) recognized the importance of experiment as a tool for learning of new material, but this approach was critiqued for its one-sidedness. Soviet school of pedagogy attaches much significance to goal-setting in the experiment, which goal is to be set by teacher in accordance with the didactic role of the experiment.

However, some observations made by the author (similar observations can easily be made by any teacher) show that the intrinsic cognitive activity of learners does not fit into the framework outlined. For example, when provided with a kit of chemical agents at a chemistry lesson for which a specific goal was set, pupils who have just begun studying chemistry course typically start immediately mixing the chemical agents and asking "what would happen if we mix this with that". After demonstration of an experiment such as, e.g., "ammonia fountain," pupils get enthusiastic about reproducing it. If provided with such an opportunity, they reproduce the experiment with varying success. Better performing pupils use to express a desire to conduct a series of experiments by themselves (typically on preparing substances possessing interesting properties, e.g., sulfur(IV) oxide, mercaptans, nitrogen iodide, etc.). Such learners' behavior does not fit in the concept of a secondary, illustrative role of chemical experiment. At the same time, it perfectly fits in the concept of cognitive gaming activity which, in opinion of Osorina [15], is the driving force of cognition, at least in childhood (according to author's observations, up to 8–9th grades).

The primacy of experimentation in cognition was long ago recognized by Western countries where great popularity is enjoyed by a variety of constructivist approaches exploiting the "natural curiosity" of pupils: discovery learning, inquiry-based teaching. Western pedagogues tend to run to extremes in considering the natural curiosity as the sole driver of learning, which approach was critiqued in, e.g., [16], but it is evidently effective within certain limits.

According to the constructivist approach, which adjoins the cognitive theory in some aspects, most of scientific concepts are based on empirical evidence, and classification allows achieving internal consistency with an area of life experience [17]. This statement was confirmed experimentally in [18] via surveys and tests, which revealed the fact that chemical demonstrations capture learners' attention, stimulate their curiosity, and foster conceptual cognition. The improvement of the conceptual cognition via chemical demonstrations was validated by numerous studies (see, e.g., [19]).

Another important function fulfilled by chemical experiment is that of organizer of a cognitive conflict, which arises when learners observe an event which is at odds with their current understanding [20]. The learners are then encouraged to think about possible explanations and work towards a meaningful understanding of the phenomenon. According to Piaget, learners construct knowledge when they encounter input from the environment: The learner's schemes or mental structures incorporate (assimilate) the new experiences. If newly assimilated information conflicts with previously formed mental structures, the result is disequilibrium, which state motivates the learner to seek equilibrium. Regaining equilibrium results in accommodation which, in turn, leads to development of new mental structures. It should be noted, however, that organization of cognitive conflict is quite a challenge: Cognitive conflict arises not with all learners, and an incompetently conducted experiment can only confuse learners, rather than create a cognitive conflict.

Individual experiment can also create cognitive conflict. As shown by analysis of a dialogue between pairs of students undertaking electrochemistry practicals [21], misconceptions did not constrain the development of students' reasoning.

Of much interest is the experience with organizing a cognitive conflict aimed to bring learners to understanding of the principles of scientific cognition and scientific information processing [4]. Learners are shown a video, in which two batteries are placed into a glass filled with water "for 30–40 minutes," whereupon the water is ignited. Learners are trying to reproduce this experiment and fail; they realize that they are being deceived and that not all the published materials are trustful.

The last thing to be said about the instrumental role of chemical experiment: Provided competent organization with appropriate instructional materials available, a lesson which involves a chemical experiment requires much less effort on teacher's part than does an "ordinary" lesson (this conclusion is based on the author's professional experience, although, to author's knowledge, similar observations were not discussed in literature). The reason is that, during experimentation, the burden of organizing the work and putting into action the learners' thinking process is transferred from teacher to the guidance, and the burden of motivation is borne by the guidance itself.

To summarize, chemical experiment is instrumental in teaching via:

– fostering interest in chemistry;

– providing empirical evidence for conceptual cognition;

– acting as a powerful tool for creating a cognitive conflict;

– facilitating teacher's classroom work via acting as an organizing factor.

Thus, chemical experiment should form theories rather than confirm or illustrate them. This means that experiment should go predominantly ahead of theory. The efficiency of providing visual demonstrations prior to theoretical explanations is very high (for all learners, except for best performing learners for whom the order does not matter), as confirmed by Akhmetov et al. [22]. Unfortunately, this approach to chemical experiments has received very little attention in Russia, except for the case of the study kit [23]. This same approach was taken in development of the "Young Chemist" science kit [2] whose commercial success (as already mentioned) indirectly validates the approach discussed.

Possibilities for Chemical Experiments in Modern Russian Schools

Legislation

For a variety of reasons, sound legislation dealing with chemical experiment in modern Russian school is a hardly discussable matter. One reason is absolute legal illiteracy of the vast majority of teachers, administrators, and low-level staff of public education bodies, and the other, the lack of a coherent legislative policy in the education sphere, supported by the society. In this situation, some legislative provisions, regulations, and law enforcement practices occasionally contradict one another and all this, taken together, contradicts common sense and does not satisfy public interests. In this situation, many teachers and school officials deem it right and proper to make away with chemical experiment.

Ideally, legislation should regulate the following aspects of chemical experiment:

(1) what, and how many, experiments are to be carried out;

(2) how can the execution of these experiments be evaluated and related to learner's certification;

(3) who, and to what extent, will cover the chemical experiment-related expenses (equipment, chemical agents, preparatory activities, etc.);

(4) what measures are to be taken to ensure safety of experiment, without prejudice to its quality;

(5) what measures are to be taken to ensure effective use of equipment items and chemical agents.

Let us analyze the current situation with legislation, based on the aspects indicated.

The number and list of chemical experiments are regulated by the State Standard for General Basic

Education (8–9th grades) and the State Standard for Complete Secondary Education (10–11th grades). The currently acting State Standard for Complete Secondary Education contains, among the mandatory minimum requirements, the “Experimental Chemical Basics” section which describes the learning material that can be mastered by learners as part of practical course solely. This Standard also lists the experimental skills to be possessed by learners (even at the basic level). Similar requirements were provided by the State Standard for General Basic Education which was in force until 2011. At the same time, according to the RF Law on Education, schools are free to choose their programs. Thus, if an experiment is included in the approved program, it can and must be conducted. As to experiments that were not included in the school program, their conductance is neither expressly prohibited nor permitted.

The Standard explicitly requires that experimentation skills be formed in learners, but these skills are not checked in any way. Analysis of the approach to organization of their checking in the State Final Certification and Unified State Examination formats reveals a collision of laws: On the one hand, subject teachers are not permitted to attend the final certification examination on this subject, and, on the other hand, they should attend it for safety reasons. This collision could be resolved if subject teachers would be allowed to attend the experimental skill checking phase of the exam. Alternatively, they could prepare experimental assignments with the conditions of their performance indicated, so that nonspecialists could take the necessary measures to ensure the safety of experiment. However, at the moment nobody is concerned with this collision, and final certification examinations in all the formats do not provide for checking the experimental skills of learners.

The situation with legal framework for supply of necessary items for the practical chemistry course is even more complicated. Essentially, no regulation is provided; funding norms are lacking and, most importantly, there is no idea of their underlying criteria. Lists of equipment items and chemical agents for chemistry classrooms are regularly compiled, but they do not have a legal status, and their validity is questionable. For example, the situation with “copper hydroxide” was carried to the point of absurdity: This substance migrates from one list to another, whereas it conversion into oxide on storage prevents its keeping in glassware. However, the biggest legislative problem lies in the lack of coordination (at least as a presumption) of this list with the funding provided. Does the list contain the minimum (i.e., all the equipment items and chemical agents listed should be financed on a mandatory basis plus something extra) or the maximum requirements (equipment items and chemical agents not included in the list should not be funded, and those included, funded to the extent possible), this question remains unanswered.

Fairly obviously, there can be no single list of equipment items and chemical agents for all chemistry classrooms, if for no other reason than because, today, there exist more than ten approved chemistry programs broadly varying in its experimental content. It seems reasonable that this list, with the consumption rates for chemical agents indicated, be specified in the chemistry course program, so that the equipment items and chemical agents could be made part of the study kit. It should be noted that the author prepared a study kit compliant with the list [24], but it still does not have a legal status.

De facto, Russian schools cannot purchase the equipment items they need; if the equipment items and chemical agents are supplied, their funding is provided by educational authorities. It is an intolerable practice when the quality control of the items supplied (including their compliance with didactic objectives) is not exercised. For example, among the chemical agents supplied to some Moscow schools there were “basic copper carbonate,” which did not decompose when heated, and “sulfuric acid,” which look like tar.

The major issue of concern is that of measures to be taken in order to ensure that chemical experiment is performed in a reasonably safe manner. Practice shows that, considering the currently prescribed measures, many teachers (on their own initiative or upon school officials’ demand) tend to refuse conducting chemical experiments. Safety issues are regulated by two documents: “Chemistry Classroom (Laboratory) Safety Guide for General Education Schools under the Ministry of Education of the USSR” (introduced by Order no. 127 of the Ministry of Education of the USSR on July 10, 1987) and “Fire Safety Rules PPB 01-03 in the Russian Federation”. These guidelines seem fairly reasonable on the whole (although there are a number of ill-considered items in the “Rules”). Also, various laws and regulations contain numerous and fragmented articles concerning safety requirements for labor conditions, which virtually do not serve as a guidemark. At the same time, rumors about lawsuits initiated against, and lost by, teachers (not necessarily chemistry teachers) on all sorts of far-fetched reasons are actively circulating in the pedagogic community. Such rumors (especially if justified) suggest that, in reality, the safety issues are not legislated.

In author's opinion, some legal aspects of safety provision in schools need to be discussed here.

First, acceptable risk limits should be defined. Since the learning process is a process of cognizing something new, it can never be absolutely safe. During chemical experiment, a skin burn injury may occur in learners, or they can get their cloth burnt through, etc. Is a skin blister with an area of 1 cm^2 an acceptable injury? The author's experience suggests that the vast majority of learners keep their cool in such situations, but their parents sometimes get concerned about these injuries. As a result, safety measures are directed at preventing any possible risk, which goal can be achieved by totally eliminating any experimentation. In this connection, it is instructive to recall that, one year after graduating from school, many young men, after seventeen years of living in a safe environment without acquiring a sense of danger and safe behavior skills, will go to the army which environment cannot be safe by definition. A great many of accidents occurring in the army are due to the lack of sense of danger in yesterday's pupils.

Second, there is a need to consider the individual characteristics, both behavioral and physiological, of learners. Obviously, some learners suffer from allergy, asthma, and other diseases; for them, any contacts with single (or multiple) chemical agents are counter-indicative (the extent of this risk will be taken out of context, and its existence will be simply presumed). Also, it is dangerous to hand chemical agents to some learners who may, consciously or unconsciously, harm others. Both the former and the latter learners' categories (the latter in particular) should not be allowed to take part in experimentation. However, due to the lack of practice of individual work with such learners, they are simply asked to leave the classroom. As a result, because of one or two sick or inadequate personalities the whole class may be left without experiment.

Serious legal problems can also arise in domains which seem to have nothing to do with school matters. An egregious example of the event that affected the situation with the chemical practical course in schools can be found in adoption of the Federal Law no. 3 of January 8, 1998 "On Narcotic Drugs and Psychotropic Substances" and the RF Government Decree no. 681 of June 30, 1998 (as amended on February 6, 2004, November 17, 2004, and July 8, 2006). This law, drafted and approved by chemically illiterate persons, has very serious negative implications for chemical experiment in schools (as well as in higher education and research institutions). It prescribes tough measures concerning the circulation of drug precursors, whose list includes such common substances as sulfuric acid (world production 120 mln tons per annum), hydrochloric acid, potassium permanganate, and some other substances, whose proportion used in manufacture of drugs is vanishingly small compared to other uses. It can only be presumed that it was through an oversight that water, which perfectly fits the definition of precursor given in this law, was not included in the list of precursors.

Another legal problem of critical importance for chemical experiment in school is that of material responsibility, whose uncertainty has serious adverse implications, especially if expensive equipment like digital laboratories is involved. In many schools, teachers are materially responsible for the equipment (on disputed legal grounds and without any compensation). Sometimes, material responsibility is delegated to another person, e.g., managing director (which situation seems strange because, for this person, the only way to control the equipment is to simply lock it). At the same time, standards regulating aspects such as broken glass, as well as wear and loss of equipment, are lacking. Naturally, in this situation, teachers tend to use the equipment to as little as possible extent. Moreover, to author's knowledge, there were cases where the fate of expensive equipment supplied to schools (particularly of digital laboratories) was tracked by prosecutors, which naturally did not make teachers more enthusiastic about its use.

A reasonable solution to this problem can be found in exempting teachers from material responsibility for equipment, presuming good faith of teachers, and considering the possibility of occurrence of design flaws in equipment. In an equipment theft case, the person who stole the equipment, rather than teacher, should obviously be held legally accountable for the theft.

Staffing

Teacher is the person who organizes chemical experiment in schools and, hence, should be able and willing to conduct is. Regretfully, the culture of organization and conductance of chemical experiment has largely become degraded, but there still remain a number of "old guard" teachers who have carried this culture through the years of collapse. Also, there are young teachers who are also interested in chemical experiment. In Moscow, these two generations can communicate by means of qualification upgrading courses established at the Moscow Institute of Open Education. In province, the situation with inter-generation communication is more complicated.

Unfortunately, it is difficult to estimate the proportion of teachers who really conduct experiments in schools. The author carried out surveys of schools teachers in several cities, and all the respondents claimed that they are actively conducting practical works and demonstration experiments. However, some internal contradictions in their responses cast doubt on their credibility.

Most of teachers are highly susceptible to external influences with respect to chemical experimentation, which can be both encouraging and discouraging. For example, the supply of chemical agents to schools stimulates, and the adoption of the Law "On Narcotic Drugs and Psychotropic Substances" and the corresponding decree, virtually prevent conducting practical works.

Staffing problems exist not only at teachers' level but also at the level of educational authorities. The interaction of these two levels relies on the system in which stimulation and support are dominated by requirements and penalties. Nearly always one sees violation of the basic principle of reasonable management: Any requirement should be backed up by appropriate resources.

Chemistry teachers tend to treat all sorts of inspect-tions as a trouble rather than a support (which should be the case if inspections were aimed at efficiency improvement of teaching activities). This presumption of teacher' bad faith, which is tacitly re-cognized by most managers of education, discourages many teachers' from any activity, including experimentation.

Methodological Support

The methodological base of the practical course of chemistry in schools has been undergoing degradation, apparently, since the late 1960s (upon completion of "chemization of the national economy," during which period the chemistry teaching level had increased dramatically). Compared to textbooks of the late 1960s, most modern textbooks do not describe new experiments. Moreover, the authors of many textbooks, who apparently have not practiced chemical experimentation for long time, tend to rewrite techniques from old textbooks, whereby many important details are lost. For example, it is impossible to prepare ethylene, following the procedure described in some textbooks, because the necessary reaction temperature cannot be reached.

Also, in many cases the methodological support for practical classes in chemistry is based on the available equipment and chemical agents, rather than on the didactic value of the experiment. This leads to a vicious circle: Many authors tend not to describe experiments for which appropriate equipment items and chemical agents are unavailable, and those who compile the lists of equipment items and chemical agents to be supplied do not include therein the equipment that will not be used in the experiments described.

However, the main thing is that most textbooks are implicitly underlain by the paradigm of the illustrative role of experiment, while, as shown above, this approach is not the most effective.

At the same time, a number of points of growth in providing methodological support have recently emerged: digital laboratories, research projects, and individual study kits, in which experiment is regarded as being of "paramount importance."

The opportunities offered by digital laboratories allow a number of sections of the chemistry course to be taught at a new level. In particular, explanations to a number of concepts that were earlier perceived as abstractions can be provided through demonstration (especially pH, electrolytic dissociation, and all the related concepts), and quantitative relationships can be introduced. Currently, digital laboratories are used primarily for research project activities, since the majority of study kits (except for study kit [24]) tend to ignore them. Some time ago, manufacturers and suppliers of digital laboratories finally became aware of the need to provide a methodological support to their products, which activity constitutes now the fastest growing line in this sphere.

Along with digital laboratories, research and project activities are currently being promoted in schools. An appropriate, highly detailed methodological support to these activities still remains to be developed (which fact generates negativism toward these activities in the majority of teachers), but it is certainly demanded. However, the development of methodological support to digital laboratories is funded by commercial organizations, and that to the project activity, by unknown entity, which suggests a much slower progress of this area.

Successful development of methodological support to chemical experiment is possible only if the experiment is rigidly coupled with a specific course program. Such an approach was taken in development of the study kit [24] where the experiment is regarded as a basis for teaching chemistry, and descriptions of experiments and laboratory operations are provided directly in the textbook.

Supply

The situation with supply of chemical experiment in modern Russian schools is contradictory. This is due, on the one hand, to the rapid progress with demonstration equipment, achieved over the last 10–15 years, and on the other hand, to ill-considered, inconsistent, and nontransparent supply policy. The lack of legal framework to regulate the aspects of purchasing of equipment items and chemical agents by schools was already mentioned. For nearly twenty years (from the late 1980s to mid-2000s), schools were supplied with equipment items and chemical agents to negligible extent. During this period, a number of schools established contacts with research institutions and received some items unofficially, when laboratories at those institutions were liquidated. At the same time, in the vast majority of schools the equipment got out of order, and all chemical agents were expended. In 2005–2007, many schools were supplied with a lot of equipment in the framework of "Education" national project, but this was done in a largely unstructured manner. Just a few examples: Alcoholic lamps were supplied but alcohol is not supplied to schools in principle. The supply of silver nitrate, which chemical agent is very actively used in school experiments, was 10 g against 50 g of aluminum nitrate, which is not used at all. There were cases when schools received several similar sets of items, each of which contained, e.g., a demonstration model of a crystal lattice, while one model for a classroom is sufficient, etc. After the implementation of the "Education" national project had been completed, the supply of chemical agents to many schools was terminated.

Moreover, because of the unstructured approach, schools were supplied not only with modern equipment items but also with clear anachronisms. For example, electronic balance with a sensitivity of 10 mg can be purchased now at an absolutely affordable price of ca. one thousand rubles, but schools are persistently supplied with much more flakey and difficult-to-handle beam balance. As a result, learners "take great pains" over this balance, instead of practically studying the relationship between the masses of the reactants and the reaction products. One of the domestic manufacturers is still trying to promote wooden trays (almost the same that could be seen in XIX century laboratories) for individual work at schools. Also, some manufactures tend to pack glassware and chemical agents in foam which absorbs everything getting thereon and soon becomes useless. All this takes place against the background of long-existent technologies for treatment of dense chemically resistant plastic which is free from the above-mentioned shortcomings. The chemical agents are often supplied in bags unsuitable for storage, while much more convenient plastic jars have long been produced for these purposes. Schools are supplied with heavy and fragile pharmacy glass vials with closing plugs; they take much space on the laboratory tables and, most importantly, can be opened only in a manner such that nails contact the chemical agents stored therein. At the same time, there have long existed plastic vials with hermetically sealed lids, which do not create these problems. Such examples are many.

Today in Russia there are a negligible number of domestic developers of demonstration equipment, of which, to author's knowledge, two or three companies are engaged in the full cycle, including research, development, and manufacture. However, even they (except for "Scientific Entertainments") prefer to manufacture the same equipment for years. Also, the activities of "Scientific Entertainments" are more strongly focused on school course of physics. All other suppliers tend to purchase most of equipment in China. It should be noted that "Scientific Entertainments" has established contacts with Russian teachers and work to satisfy their demands, while in the case of Chinese manufacturers such feedback is lacking.

Because of nontransparent mechanism of supply of items for chemistry classrooms, many valuable domestic developments in the field of interest have not been introduced in schools simply because their developers do not know where to apply to. For example, several years ago domestic company "Sovplim" developed an individual exhaust system which allows removing gaseous products directly from laboratory tables. The introduction of this system would allow conducting experiments in which the asphyxiating or foul-smelling gases are released, which would significantly expand the capabilities of individual experiment. However, a mechanism of practical application of this development in schools is lacking.

A separate problem with supply of chemical experiment is that of pricing. Comparison of the prices of chemical reagents in the kits for school course with those of the chemical agents offered individually shows that they may differ fivefold. Nearly the same (or even greater) differences exist between the prices of equipment purchased in China and in Russia.

Nontransparent pricing policy, ill-considered list of items, and the occurrence of abundant obsolete equipment on the market are responsible for inefficient supply of chemistry classrooms. This same finance could be used much more efficiently for organizing chemical demonstration in school. To this end, the selection and payment principles for items intended for chemistry classrooms need to be completely revised. The finance for purchasing equipment and consumables should be allocated directly to schools. The set of equipment items should be adjusted to the needs of specific, rather than abstract, school chemistry programs. Essentially, items to be supplied should be made part of study kits. Compilers of lists of equipment items should quickly respond to the emergence of new equipment on the market, whereby the needed pace for manufacturers' activities would be set. Such efforts are being undertaken now, but the development of equipment suited to a study kit is a very challenging task because of conservatism of Russian developers.

CONCLUSIONS

The above-said suggests a contradictory status of chemical experiment in modern Russian schools. Though degraded in its most part, chemical experiment exhibits a number of "points of growth," whose correct and systematic development could bring it to a level appropriate for its being an effective promoter of pupils' learning. To this end, the following measures should be taken along multiple lines simul-taneously:

(1) Develop a transparent and stable legislation, clear to all the parties of the educational process, to regulate the following aspects: measures to promote effective implementation of chemical experiments (with efficiency criteria indicated); funding criteria and mechanisms; acceptable risk limits for learners' health, measures to keep the experiment within these limits, and responsibilities of the parties involved (including learners) in cases of going beyond these limits; and material responsibility of the parties involved. This legislation should be based on the presumption of value of experiment.

(2) Provide methodological support in the form of study kits in which experiment is treated as a basis for cognizing concepts and theories of chemistry.

(3) Develop a flexible system of supplying chem.-istry classrooms with necessary items, adjusted to specific study kits.

(4) Encourage teachers and carry out teachers' retraining.

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