Chapter 20
Didactics of Chemistry as a Science: History in Russia

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Abstract This chapter describes the history of didactics of chemistry in Russia. The eighteenth and nineteenth centuries were characterized as a period of tremendous growth in terms of the teaching of chemistry. At the beginning of the twentieth century, a preeminent network of teachers emerged, and their work led to the development of didactics of chemistry as a science. The concept and study of didactics emerged during the first half of the twentieth century and resulted in the elaboration of new methods and curricula. However, by the second half of the twentieth century, didactics of chemistry was in crisis—due to weaknesses in its methods and lack of feedback from teachers—and it lost its scientific basis and turned instead into a set of claims. To revive didactics of chemistry in Russia, old methods need to be revised and proven and their scope revealed.

20.1 Rationale

Didactics of chemistry (literally "methodology of teaching chemistry") is regarded in Russia as the scientific foundation for teaching chemistry. Its subject is the process of teaching chemistry. Its most important foci are

- How to arrange content for effective teaching
- Which methods and modes should be used
- In which forms should the teaching be executed.

In some European countries, this area of science is referred to as "didactics of chemistry" and many English-speaking countries use the term "research and practice in chemistry education." However, there are scientists and teachers who do

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not regard didactics as a valid science. Instead, they treat didactics of chemistry with suspicion and even hostility. This is true in Russia as well as overseas (Scerri 2003).

In Russia, the development of didactics as a science was difficult and controversial. Many interesting ideas evolved, and some of them were integrated into practice while others were abandoned. Because of the language barrier, didactics of chemistry developed in Russia separately from its development in other countries. As a result, the developmental history and outcomes of didactics in Russia oftentimes reiterated findings from other countries, failed to consider problems solved in other countries, and seemed disconnected from the advancements being made in other countries. Unfortunately, the historical account of didactics as a science presents a chronological list of educators and their contributions without considering the larger picture, which includes a dramatic and controversial exchange of ideas not only at the individual level but also at the national level. As a result, most educators are not aware of much of the history behind didactics and thus repeat old mistakes and reinvent old ideas only under new names. This is why we think that the history of didactics of chemistry in Russia will be interesting not only for Russians but also for the international audience.

The task of delivering the Russian experience to the international audience is quite challenging due to language problems. For example, there are several terms in Russian that cannot be translated into English equivalents. Thus, some of the subtleties of Russian didactical ideas will be lost in this article; however, the present article is an excellent first step in introducing the Russian experience and supporting the future of chemistry education across the globe.

We considered the following factors as impacting the state of didactics of chemistry teaching (Телешов 1997):

1. General development of science,
2. Chemistry as a separate subject at schools and tertiary institutions (when and how much),
3. Pre-service and in-service teacher training; teaching chemistry as a separate course,
4. Curricula for chemistry,
5. Learning texts for chemistry: textbooks, problem books etc.,
6. Societies of educators to develop and improve scientific education,
7. Possibilities to discuss didactical and pedagogical problems in press, in circles, and at congresses, meetings, and pedagogical exhibitions,
8. Editions on didactics (periodicals or non-periodicals),
9. Supplies for teachers,
10. Government relations: whether officials take into account the opinion of educators and whether educators are involved in government institutions,
11. Scientists and specialists in didactics who teach, and
12. Research in didactics of chemistry.

Drastic, interrelated, and quite sudden changes in these factors usually are regarded as the beginning of a shift in a historical stage in the scientific development of didactics of chemistry. Also, historical and social contexts are also taken into account.

20.2 Stage I. Pre-Science: Linear Accumulation of Experience (Before 1864)

The first professor of chemistry in Russia was Mikhail Lomonosov (1711–1765), who performed lectures on chemistry in St. Petersburg (1752–1753) for four students who chose chemistry as their focus of study (Ломоносов 1955). He proposed some ideas that could be regarded as didactical. For example, he concluded that the success of teaching requires proper usage of speech.

> One needs to recount speak with a clear and smooth voice, not strong, not weak, not monotonous but raising and lowering, accompanying the speech with motions of head and body. The main achievements of the science should be formulated briefly and plainly and dictate to let the students write them down. The statements should be accompanied with experiments, because the initial point of cognition is a sensory perception (Ломоносов 1952), p. 354.

Lomonosov changed the Russian view on chemistry. Before Lomonosov, chemistry was regarded as a skill or craft involving the procurement of substances by analysis and synthesis. However, we cannot consider Lomonosov to be the founder of didactics of chemistry as a science because he did not question and check the adequacy of his didactical ideas.

After 1774, chemistry became a mandatory subject at mining school where future mining engineers were taught beginning at age 15–16. Chemistry teaching was supported by chemical experiments that were conducted by the staff of the laboratory or by the students themselves. The students and their supervisors also visited manufacturing laboratories in St. Petersburg and described the chemistry they saw taking place (Соколов 1830). In 1786, "folk schools" (four grades) were launched where some chemical data was included into the subject "Natural History" (Телешов 2004a). The textbook for folk schools was written by Зуев (1786) who based his text on the close connections between science, practice, local geography, and culture. He demanded explanatory reading and conversation, conscious absorption of knowledge, obviousness, and a proper sequencing of topics (Ганелин 1950, pp. 27–32). The first textbook on chemistry was published in 1808 by Шерер; however, it was not intended for use in schools. The first school textbook was written in 1834 by the famous chemist Hermann Henrich Hess (Гесс 1834). Hess claimed that he "tried to describe chemistry in the way that the student understands it without a teacher." He presented inorganic chemistry's main concepts and presented only the well-established facts for organic chemistry.

Around 1836, chemistry was introduced in military schools (that had never before been under the jurisdiction of the Ministry of Education). In 1841, the textbook on chemistry for military schools (Щеглов 1841) was issued, and later, Воскресенский et al. (1852) developed a curriculum on chemistry for military schools. So the curriculum came about after the textbook. At any case, the textbook contained almost all of the information that was known at that time, and all students were expected to learn all of the material.

The future of chemistry teaching in general public schools was much less bright. The only type of public secondary schools in Russia at the beginning of the nineteenth century was the classical gymnasium with its emphasis on ancient languages (Latin and Greek), history, and so on. Science was not the focus of these schools. Natural history was taught in the classical gymnasium; however, in 1828, it was excluded from the curriculum "for apprehension of freethinking development" (Аникеев 1915) and was only returned to the curriculum in 1854.

Until 1861, chemistry had been taught at several universities and higher level educational institutions, military academies, and mining schools. Not only teachers but also scientists (including Hess and Mendeleev) worked at secondary schools (predominantly for extra salary). Later, it was pointed out that their experience as teachers ultimately helped them to later develop more effective chemistry textbooks (Шпачинский 1893).

In the 1800s, experience gained through teaching was preserved as tradition rather than viewed as the result of scientific comprehension. However, it was difficult to maintain even these teaching traditions because the position of chemistry in the curriculum was unstable. The circulation of the textbooks was limited, so teachers and professors did not have a choice in textbooks and often used handwritten notes instead of textbooks. In 1865, the Ministry of Education called for writing textbooks on chemistry and other branches of science. Unfortunately, this directive failed and either no textbooks were offered or the textbooks that were offered were rejected (Георгиевский 1900, p. 52).

The year 1861 is an important date in Russian history. In that year, serfdom was abolished all over Russia and this stimulated both industrial development and public life (including pedagogy). Several pedagogical circles emerged. One of the circle leaders, Nicolay Raevsky, proclaimed the main goal of teaching chemistry in gymnasia to be the confirmation of the laws of chemical phenomena by experiment so students understand the essence of chemical processes. Experiment was the main means of teaching (Телешов 2010). So the idea of inductive teaching, that later influenced inquiry-based, problem-based, and other modern methods of teaching (Prince and Felder 2006) was proclaimed (however not implemented) in Russia in the middle of the nineteenth century. Industrial development meant there was a growing demand for people with good education in STEM ("real education" as it was called at the time). The classical gymnasia that existed during this period could not satisfy this demand. So, in 1864, the system of real schools was established, where the emphasis was on science, engineering, and mathematics, and classic languages were abandoned. Chemistry became compulsory in real schools, so the number of students learning chemistry drastically increased ushering in a new stage for didactics of chemistry.

20.3 Stage II. Pre-Science: Networking Accumulation of Experience (1865–1900)

Launching real schools coincided with a jump in the development of chemistry in Europe and Russia. Butlerow (1861) from Kazan University proposed the theory of structure of organic compounds. Менделеев (1869/1926) from St. Petersburg discovered Periodic Law. Both of them used their discoveries not only as a scientific advancement but also as a didactical tool to base the structure of their high school textbooks on organic (Бутлеров 1864/1953) and inorganic (Менделеев 1869–1871) chemistry. In the prefaces to those books, they also presented the system of their didactical ideas. Butlerow claimed that the theory of chemical structure is "a firm basis of a real knowledge when the facts, connected with common ideas, easily go into memory, each on its own place and become chains of a real scientific system" (Бутлеров 1864/1953, p. 11) this anticipated the ideas of cognitive psychology (Reid 2008). He considered atoms as chemically undividable (but divisible by other methods), atoms as influencing each other, and molecules as more than the sum of their atoms (a new formation). According to Butlerow, to know chemistry meant to know facts and theory. Mendeleev acquainted students "with the main data and conclusions of chemistry and their significance for understanding nature and practical activities" and the description of "conclusions with the ways how they were made." Thus, Mendeleev anticipated the ideas of context-based and inquiry-based learning (NRC 2000). However, we cannot consider Mendeleev or Butlerow as the founders of didactics of chemistry for the same reason Lomonosov is not the father of didactics—they did not question the adequacy of their ideas.

The increasing number of students in chemistry at real schools and in natural history in gymnasia mandated an increase in the number of teachers. This large pool of teachers began to share their experiences. In cities with several real schools (e.g., St. Petersburg, Moscow, Warsaw, Smolensk), the teachers arranged pedagogical circles. They influenced the development of didactics since their initial discussions were comprised of new ideas and ways of teaching. The circles then grew into societies (with no division between scientists and teachers), which also discussed didactical ideas in their meetings. In the 1870s, several scientific and pedagogical congresses were held, and about 100 pedagogical museums were opened. All of these developments were the result of teachers with almost no official support.

However, one must understand that the number of teachers involved in these didactic activities was quite small. For example, in Moscow—the biggest Russian city—there were about 10 gymnasia, one real school, and one military school. It would not be an exaggeration to say that the majority of scientists and science teachers knew one another personally.

Unfortunately, the curriculum used in the real schools conflicted with the requirements of the universities that included Latin and Ancient Greek in their entrance exams. So, the graduates from real schools could not enter university, and thus, these schools became unpopular. In 1871, science was excluded from the classical gymnasium curriculum because it was deemed "morally dangerous" (Полянский 1915). In 1890, chemistry as a distinct science was removed from the curriculum in real schools (with some chemistry content still delivered within the physics curriculum). However, in 1890, the Financial Ministry (not the Ministry of Education) established the so-called commercial schools. These schools went from nine in 1890 to 125 in 1900. They were secondary schools that educated students for "blue collar" manufacturing jobs. Chemistry was an obligatory part of the commercial school curriculum.

At this stage, about 20 different school textbooks were being published. Some textbooks were based on Periodic Law (Альмединген 1885; Бекенев 1898; Ковалевский 1880; Лавров and Нечаев 1893), while others did not even mention it. The majority of the authors were scientists who also taught in schools. The first problem book (Панпушко 1887) attached to a textbook (Потылицын 1887) was issued in 1887. Beginning in 1865, the Ministry of Education published a list of recommended textbooks that took into account both "moral" and "scientific" factors. Obviously, the quality of textbooks was weak. Between 1865 and 1900, the Ministry of Education announced three contests for the best textbook; however, none of the eight contestants won the prize for best chemistry textbook (Георгиевский 1900). The circulation of textbooks remained limited, and no formal distribution system existed. As a result, only certain textbooks were available in specific locations and at specific times.

The number of professional teachers (i.e., those who just taught and did not conduct scientific investigations) increased. The increase in the number of teachers increased the demand for teacher training from educational institutions. Consequently, the first courses for pre-service teacher training were also established around that time.

In conclusion, during the second stage, the teaching of chemistry spread throughout the Russian educational system. The number of teachers grew exponentially, and these teachers formed networks for sharing didactic information. It was the prerequisites for emerging didactics of chemistry as a science.

20.4 Stage III. Didactics of Chemistry as a Science (1901–1918)

The first sign of qualitative turnabout was a sudden and simultaneous revision of approach to educational materials. Before 1901, the only type of educational material was the textbook (occasionally with a problem book attached). However, in 1901, a science teacher named Leonid Sevruk issued a didactical pack on science that included not only a textbook for students (Севрук 1901) but also a manual for teachers on how to teach using the textbook (Севрук 1902). This idea was taken up by the majority in the educational field, and even today the majority of the school textbooks are accompanied by teacher manuals.

In 1900, prince and businessman Vyacheslav Tenishev founded in St. Petersburg a private commercial school. Several bright teachers (Valerian Polovcov, Sergei Sozonov, Leonid Nikonov, and Grigory Grigorjev) gathered to teach there. We could state that this circle was a cradle for the didactics of science. In that circle, new textbooks and approaches were discussed. These discussions developed into the first course on didactics of science at St. Petersburg University (launched by Polovcov) and the first textbook on this subject published in 1907 (Половцов 1907).

Polovcov's textbook was met with mixed reactions; however, the arguments were more speculative than evidence-based. Just several quotes (Григорьев 1907): "Teaching is a creation and didactics will never create a good teacher"; "it is useful to get acquainted with methods of other teachers, however it is just a pedagogical practice"; "a teacher has to know what is the content of his subject, its scope, the main principles and which questions should be elaborated in the classroom, however the book delivers didactics by Polovcov rather than didactics of science". Here, the problems of didactics of chemistry are formulated in ways that can be scientifically investigated.

At the beginning of twentieth century, several teacher training courses were established. To become a teacher, one needed a two-year course after graduating from university. The students and professors in these teacher training courses discussed and systematized didactical ideas, and their findings were published (ПК-ВВЗ 1911; ТКУ 1908). The courses in 1904 grew into the Women's Pedagogical Institute (Телешов 2004b) and later, the Pedagogical Academy. In Pedagogical Academy, Sergei Sozonov conducted the "Didactical Conversations" on teaching chemistry (22 h), and Vadim Verhovsky developed the 24 h course "Methodology of Teaching Chemistry in Connection With Practical Works" (ТПУ 1910). These could be considered the first courses on didactics of chemistry in Russia.

The networking of teachers continued and blossomed. In 1902, two pedagogical congresses were held (January in St. Petersburg and December in Warsaw). Journals on didactics were launched (*Science and Georgaphy*, 1896–1917; *Nature at School*, 1907; *Science and Visual Teaching*, 1909–1910; *Science at School, 1912–1915*). In 1914, a grand congress of teachers of chemistry, physics, and cosmography took place, where teachers and scientists discussed terminology.

Specialists in didactics of chemistry collaborated with state commissions that prepared school reforms (ТВУК 1900; МРСШ 1915; МРСШ-ПП 1915). The exhibition of educational equipment was held in 1912 in St. Petersburg. Curricula employing demonstrations and students' experiments were developed. Textbooks for all types of schools were written. Manuals on practical activities and guided tours were written based on the experiences of their authors.

However, the curricula were criticized mainly for their overload. This remains a major criticism even today (Millar and Osborne 2000) despite the fact that preventing overload is one of the main tasks of didactics. “It’s impossible to push the entire curriculum into 2 h a week without rout learning” (РШ 1984). “They try to push all the known scientific data into the curriculum… it will be invincible unless the school refuses scientific systematization in favor of small set of pedagogically useful things” (Добольский 1900). “It is strange that our curricula remain immutable as tables of Covenant… the curriculum is the last thing, not the first” (Созонов 1901). “All the content should be acquired in the degree that the student can use it… meaning that everything superfluous and less important should be eliminated… and the students take all the necessary facts from the handbooks” (Лермантов 1905). “Curricula is nothing in comparison with methods, but nobody discusses methods” (Володкевич 1905, pp. 45–46). “People who develop curricula should take into account the cognitive working abilities of an ordinary student… whereas the authors included there everything they considered important… with no estimation of difficulties in studying… believing that to demand is enough to get executed” (Лермантов 1906).

Thus, by 1917 (the Revolution in Russia), the problems of didactics of chemistry were formulated, the first textbooks were issued, and the first courses were launched. So, one can state that it was at this point that didactics of chemistry emerged as a science.

20.5 Stage IV. Broadening Applications and Struggle Between Didactical Schools (1918–1941)

Just after the October Revolution (1917), the new communist government boosted the education system. It established basic courses for illiterate adults (more than a half of the population) all over the country. Four-year (later changed to seven-year) school became obligatory for every child. Chemistry was included in the school curriculum. Developing national industry required well-trained and highly-educated personnel, so chemistry education was developed in high schools and technical schools as well. Chemistry also fit the communist ideology: instead of “moral danger” it became “a school of revolutionary thinking” (Leo Trotsky).

From the time of the Revolution through to the collapse of the Soviet Union, teaching of any subject was expected to not only transfer knowledge and teach specific skills but also transfer “communistic” and “materialistic” norms and values. This latter point has been the core problem of Soviet didactics of chemistry and remained an issue up to the collapse of the Soviet Union (mainly because nobody could operationally define “communistic” and “materialistic”).

Didactics of chemistry faced many new challenges. Despite the drastic increase in the number of students and increased requirements for chemical education, in 1923, 42 % of schools did not conduct chemical experiments, and 84 % of schools had no student laboratory experiments (Райков 1923). After 6 years of the Revolution, there were even claims that there was still no chemistry in school (Верховский 1923).

In the 1920s, didactics of chemistry eventually separated from didactics of science. Two competing didactical schools were formed: “Petrograd school” (Vadim Verhovsky) and “Moscow school” (Peter Lebedev).

In 1919, Vadim Verhovsky claimed that the core condition for studying chemistry was broad chemical experiments. “Atomic hypothesis should be delivered only when a student stored enough facts, acquired the basic chemical laws and learned chemical language…. Periodic law should be given only after nonmetals, as a generalization, but not at the beginning, as a dogmatic scheme” (ПП 1919, pp. 77–78). He diminished the significance of curricula claiming that “the best curriculum will give no results if the teaching is not based on experiment… it should be just brief and arranged didactically” (ЕО 1924, p. 324). He specified that such a systematic curriculum required 4 h of classroom and laboratory lessons per week.

On the contrary, Peter Lebedev in Moscow was inspired by the ideas of Dewey (1916) that fit with the spirit of revolutionary innovations. His curriculum was based on “complex themes” of practical significance (in vocational schools that illustrated technological processes) that was close to modern context-based learning with all its attributes (Heikkenen 1988; Gilbert 2006). Each “complex theme” required certain applications that required certain theoretical knowledge. The sequence of topics was determined by the links between the objects—neither scientific, nor cognitive logic. Lebedev only introduced core concepts of chemistry that could be induced from experiments (for example “atom” and “molecule”) in order “not to be didactic” (Шаповаленко 1963, p. 95). Basing teaching of chemistry on practical inquiry activities (close to modern inquiry-based learning), he used a workbook (instead of a textbook) as the main teaching tool (Телешов 2006). Theory, which students were expected to learn independently, was considered supplemental to the experiments.

He criticized Verhovsky’s approach as “bourgeois” because Verhovsky became a professor before the Revolution. Situated in Moscow—the new capital of the country—Lebedev had greater means to influence the Ministry of Education, and his approach prevailed.

In 1931, the Communist Party Central Committee issued a resolution on elementary and secondary school (ЦК ВКП(б) 1931). It stated that “the secondary school doesn’t give enough basic knowledge; doesn’t prepare pupils to technical and high schools; doesn’t train serious well-developed builders of socialism, that can connect theory with practice”. Much later, similar arguments against the constructivist approach were independently repeated in Western literature (Kirschner et al. 2006). The resolution rejected all the constructivist ideas and required systematic curriculum. Verhovsky’s approach fit the resolution. Lebedev’s did not. Verhovsky was put in charge of setting down the systematic curriculum and textbook, which would not be altered for many years (Верховский 1935; Верховский et al. 1935; Верховский et al. 1937; Верховский 1947). In 1931, Verhovsky declared that there were three tasks related to teaching chemistry at secondary school: (a) to acquaint students with the main chemical productions (skills and technical outlook); (b) to link the system of chemical knowledge to the manufacturing process and chemistry as a science; and (c) to develop the Marxist-Leninist worldview, active participants for the communism movement, and masters of machinery. He still argued that the course should be based on first-hand knowledge of chemical processes from factories and laboratories (Верховский 1931).

Verhovsky involved two representatives from Moscow—Yakov Goldfarb and Leonid Smorgonsky (Lebedev declined to participate) and together they merged the systematic curriculum with Lebedev's workbooks. In 1936, they issued a book called *Didactics of Chemistry at Secondary School* (Верховский et al. 1936) that was more of a manual on how to use the textbook than a textbook about didactics as a science. In 1934, the first problem book that supported the textbook (Гольдфарб and Сморгонский 1934) was published. However, Verhovsky's idea of basing the course on first-hand experience with chemical processes was not broadly implemented because chemical manufacturing was not yet widespread and so first-hand experience in chemical factories was not available to many students.

The number of pedagogical institutions increased. At the end of the 1930s, the first doctoral degrees in didactics of chemistry were awarded. Between 1937–1938, in-service teacher training institutions in Moscow and Leningrad were opened. At the same time, the *Chemistry at School* journal was launched.

By the beginning of the Great Patriotic War (1941), didactics of chemistry in Russia was well under way. The didactic pack consisted of a textbook, workbooks, problem book, and teacher's manual. The system of pre-service and in-service teacher training was also well established. Young teachers who were developing into specialists in didactics began to replace the old school specialists or take up new niches.

20.6 Stage V. Further Expanding (1946–1970s)

After the Great Patriotic War (1941–1945), the educational system underwent rapid development. Further industrialization raised the role of chemistry in the opinion of the authorities to the highest level in history. In 1952, the polytechnic education was developed. In 1956, the eight-year education became compulsory, and in 1958, the program of "chemisation of economy" was put forward by the Communist Party. It required new well-trained personnel. Thus, the number of chemistry lessons was enhanced to 3 h a week. At the beginning of the 1960s, the 10-year education became compulsory. In fact, the task was to teach everybody chemistry in a professional and practical manner. This was the new challenge for didactics of chemistry.

In 1946, the Academy of Pedagogical Science was established. This academy became the primary supporter of research into chemistry education. The next generation of specialists in didactics was trained. Some of them worked part-time in schools. They conducted observations and experiments to reveal successful as well as ineffective ways of teaching. For example, Sergei Shapovalenko and Pavel Gloriozov arranged a large-scale investigation (involving 60 schools) to check the sequence of topics in the course of basic chemistry (Шаповаленко and Глориозов

1952). This investigation resulted in changes to the curriculum. For example, content about acids and bases was separated from content related to nonmetals. Nowadays, the most popular curricula in Russia still follows the sequence of topics recommended by Verhovsky and shaped by Shapovalenko and Gloriozov. Western and Asian chemistry educators focused on the sequence of chemistry topics much later.

Gloriozov investigated the conditions to form practical skills and found out that effective manipulations require the understanding of theoretical background (Глориозов 1959). Dmitry Kirjushkin asked students to draw a burning candle with and without preliminary instructions and found that the number of essential details was much lower in the second case. This confirmed that instructions increase the quality of observations (Занков 1954). This research also confirmed the benefits of guided inquiry over open inquiry (Cheung 2008). At the same time, Konstantin Parmenov was highlighting the confusion associated with teaching and learning color names, equipment names, and so on (Парменов 1959). Kirjushkin enumerated the scientific methods in didactics that were used at that time and pointed out the usual mistakes: description and analysis of experience (often omitting key methodological issues), examination of schools (with loss of results), and pedagogical experiment (with many limitations) (Кирюшкин 1958). Kirjushkin underlined that the methodology of experiments was not well elaborated.

Many enthusiastic teachers detailed their ways of teaching particular topics ("what did we do"). These methods were published in the *Chemistry at School* journal and in specialized books. Шаповаленко (1963) categorized teaching methods and tried to establish their scope (in a speculative rather than evidence-based way). The arguments on categorization took place and no consensus was reached. Unfortunately, the particular methods were soon forgotten because nobody tried to gather them and connect them with the curriculum.

At the end of this period, several textbooks on didactics of chemistry and many reports on teachers' experiences were published. They were partly evidence-based and partly claims-based. The focus was on transmission of knowledge and the transmission of norms and values (the problem that was not solved). However, all these books were practical manuals with little attention paid to methods and discussions on evidence-based theory. The methods of didactics of chemistry were not yet developed. We think that these problems led to the further stagnation of didactics of chemistry.

20.7 Stage VI. Stagnation (1970s–1980s)

At this stage, didactics of chemistry seemingly was still developing. The number of institutions, doctoral dissertations, students, etc., grew. The system of pre- and in-service teacher training institutions worked. The first specialized chemical school (Sergei Berdonosov) was established.

However, at this time didactics of chemistry did not generate new ideas. The culture of didactical investigations degraded with fewer and fewer reports on didactical observations and experiments and more and more speculative articles being published. Throughout the whole history of didactics in Russia, curricula were considered adequate if they were officially adopted. Methods were considered adequate if they were accepted by other teachers who tested them (or tried to test them). This might have been a fair system if open and authentic feedback had been permitted, but there was no feedback loop. So the confirmation of acceptance of the methods often was inadequate.

Professional teaching of chemistry to everybody failed—chemistry became less and less popular. The attitudes of society toward education changed. Earlier, education had been perceived as a good social elevator that motivated students. So early work in didactics assumed that students would naturally pursue education and put in the necessary effort. Even the textbook on didactics issued in Цветков (1981) used the words "motive" and "motivation" only five times in 209 pages (including "social motivation" in context of career-guidance). In the manual to the school textbook (Ходаков 1980), these words were not mentioned at all. Psychological aspects of didactics were also neglected.

20.8 Stage VII. Degradation (Since the 1980s)

When the old school specialists in didactics aged, they were replaced with less talented people who worked in pedagogical institutions just for salaries (that was true for all the branches of didactics). A strong hierarchy of specialists in didactics was established. Now information within the system flowed only one way: ideas came from the top of the hierarchy (chiefs of the institutions) and flowed to the bottom (research fellows and teachers). The top specialists did not value or even perceive information "from the ground" and instead regarded their own isolated and unidimensional work as absolute truth.

The new general books just repeated old ideas, eliminating the need to present evidence of effectiveness (e.g., Чернобельская 2000). The texts contained no doubts, discussions (except for terminology), evidence, or even descriptions of what would happen if a teacher did this or that: "While investigating physical properties the following algorithm is used: a teacher shows the specimen and asks to enumerate its physical properties" (Космодемьянская, Гильманшина, p. 41). Very often the expectations were arrogated to the students as their real actions: "… why there is no general formula of volatile hydrogen compounds for alkaline metals in the Periodic table? The students reasonably answer that they don't form volatile compounds." (Габриелян 2001, p. 8).

By this time, the whole society faced a problem that eventually led to the collapse of the Soviet Union: imitation instead of action. Didactics also faced this problem: the specialists pretended that they did a tremendous job when in reality, they did nothing. They began to use obscure quasi-scientific language ("For binary ways of integration the adequacy [a key to a lock] of integration processes in learning to integration processes determined by a teacher in course of teaching is typical") (Пак 2004, p. 256). Many of their statements could not be verified, such as "It will be good, if a teacher will repeat with the pupils what is the allotropy and by what causes it is recalled" (Габриелян 2001, p. 12). Very often the new works contained old ideas under new names.

> Collective system of learning, collective teaching each other, collective lessons, adaptive learning system, groups of different ages, couple-centered learning technology, technology of natural education–all of these new methodsl boiled down to the same thing: students taught each other (Громыко 2011).

We should add that these "new" ideas were implemented by Bell and Lankaster at the beginning of the nineteenth century (Rayman 1981). The majority of articles on didactics of chemistry resembled "scientific spam" and seemed to be published just to get a degree or a line in a report. The requirements for degrees in pedagogy fell to their lowest level (Фельдштейн 2011).

Thus, through the end of the twentieth century, the majority of practical teachers lost any respect toward didactics treating it as phrase-mongering and in-service training—as wasting time. The best teachers admitted in public with no shame that they did not read pedagogical literature—it was very difficult to find something useful amidst the rubbish.

Chemistry became one of the most unpopular school subjects. In 2012, only 8 % of graduates chose to take the Unified State Exam in chemistry. Only 9 % of them got an excellent score whereas 11 % failed (ФИПИ 2012). We ascribe this to the degradation of didactics of chemistry. The content of chemistry remained the purview of specialists in chemistry and was not relevant to the general public. The chemical experiment was almost totally eliminated and this further decreased interest in chemistry (Zhilin 2013)—chemistry turned into something about chemical symbols. Among all the methods of teaching, only lectures and problem solving remained.

At the beginning of the 2000s, Russia's educational system was a mess with reform on top of reform hindering true progress. The most vivid example involves the first educational standard (with emphasis on content) that was implemented in 2004 and the second standard (with emphasis on meta-subject skills) that was implemented in 2012. Students entered school with no standard but finished school according to the second standard. Such decisions were made without the benefit of scientific investigations and turned didactics just into a tool for supporting decisions. The most common title for an article or conference presentation was "Bla-bla-bla in context of requirements of the new education standard."

Thus the outcome of didactics of chemistry mostly turned into unfounded claims and scientific spam. The result was a very low level of chemical education.

20.9 Prerequisites for the Renaissance

Currently, chemistry is part of the curriculum at eighth and ninth grade (2 h a week) and tenth and eleventh grade (1 h a week at the basic level and 3 h per week at the specialized level). Chemistry is still not a popular subject, and this remains a great challenge to the didactics of chemistry. On the other hand, in the 2000s, a small stratum of well-off people who appreciated the benefits of good education arose. They wanted to provide their own children with a solid and comprehensive education and were willing to pay for it. They were not interested in the opinion of the authorities and wanted to pay only for the teaching methods that worked. Now they are the main demanders of didactics of chemistry as an evidence-based science, encouraging development of new methods and requesting establishment of the effectiveness of old methods (e.g., Zhilin 2014).

In the early 1990s, many people with scientific backgrounds began teaching in schools. They did not have a pedagogical education and thus reinvented the old methods and repeated the same old mistakes. The most common of them being teaching chemistry by beginning with the structure of atoms (Кузнецова 2012). Their enthusiasm along with the enthusiasm of a new generation of specialists led to the development of new teaching methods and discussions on didactical problems however, without discussing the scope of these new methods (Берсенева 2004). A few specialists still develop didactics at the scientific level and/or successfully implement new practical ideas. Each of them deserves a separate article. Various problems are currently under study: understanding limitations of ICT in teaching chemistry (Mikhail Dorofeev), taking into account the system of values of individuals while teaching chemistry (German Fadeev), developing creativity while teaching chemistry (Pavel Orzhekovsky), determining estimation abilities in chemistry (Elena Volkova), involving motivated pupils in scientific work (Sergei Semenov), teaching chemistry using natural cognitive activity (Elena Vysotskaya), investigating informal education (Vyacheslav Zagorsky), and so on. However, their findings are not connected with each other and impact only a small number of teachers. Important Western ideas, first of all—cognitive models (Reid 2008) and Johnston's triangle (Johnstone 1999) are almost unknown in Russia.

Influenced by sociology and psychology, didactics of chemistry is about acquiring new methods (e.g., the interview). There are attempts to use quantitative assessment tools (for example item response theory); however, they are often used erroneously. For example, very often the t-test is used without checking normality of distribution. Even while processing the results of the Unified State Examination, claiming to use Item Response Theory, the final score is calculated based on the total score (ФИПИ 2008) whereas item response theory requires recalculation based on the test scores for each item (Yu 2014). However, these problems are at least beginning to be raised and discussed.

Today, an enormous set of teaching approaches and methods are available. Some of them are more successful and others are less effective. Some of them are old methods just given a different name. Some of them are just spam. The main challenge of contemporary didactics is to put all of these methods in order and find their scope using evidence-based tools. This necessitates the establishment of a database of the methods already described.

Currently, there is a demand for a renaissance of didactics of chemistry. There are challenges for a revived didactics, but there are skilled people who are able to meet these demands. However, there is currently no system in place to encourage people to do the work necessary to move the didactics of chemistry forward.

20.10 Conclusions

Didactics of chemistry as a science emerged in Russia at the beginning of the twentieth century as a result of (a) accumulated experience in teaching science (and teaching chemistry in particular) and (b) networking between a relatively small number of motivated teachers. It developed during the first half of the twentieth century elaborating new methods and curricula. However, the limited number of methods that were used and the hierarchy of specialists working independent of feedback led to stagnation of didactics in chemistry—it collected a profound set of methods but their scope was not discussed. The claims became less and less founded and the ideas became less and less applicable to real teaching. Currently, we can speak about a small number of specialists in didactics of chemistry who treat it as a science but cannot speak about didactics of chemistry as a scientific system that significantly influences chemical education.

Despite the current state of didactics of chemistry, a large set of teaching methods has been accumulated. To revive didactics of chemistry, we should revise the methods and reveal their scope using evidence-based tools. The creation of a database of the available methods is one of the essential tasks yet to be completed.

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