

An Integrated Database of Common Chemicals and Chemistry Demonstrations and Student Experiments Used in Hungary

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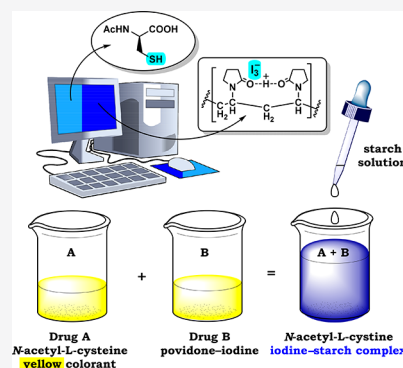
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Supporting Information

ABSTRACT: Chemistry curricula in part rely on the use of laboratory demonstrations and experiments. The complex nature of this kind of educational activity has been posing challenges from the very early days of teaching chemistry. As chemistry is an experimental science, one possible approach to make the teaching of this subject more efficient is to use materials that students encounter in their everyday life. The present paper delineates our efforts to create an integrated database of common chemicals and their use in Hungarian elementary and middle schools. The database combines two seemingly separate but intimately connected fields which has not been accomplished so far: a database of common chemicals and a database of chemistry laboratory demonstration experiments. The two databases with their own idiosyncrasies are connected through a common element, the components present in everyday chemicals. The database offers various levels of searching in both subdatabases and allows pre- and in-service teachers to design their own demonstrations and student experiments, based on common chemicals, that best fit their curricula in context-, project-, inquiry-, discovery-, and phenomenon-based education. The application of our database allows the facilitation of a conceptual change how chemistry and chemicals are contemplated both in and outside school.

KEYWORDS: General Public, Elementary/Middle School Science, Demonstrations, Computer-Based Learning, Inquiry-Based/Discovery Learning, Consumer Chemistry, Reactions, Oxidation/Reduction, Carbohydrates



INTRODUCTION, SCOPE, AND LIMITATIONS

Chemistry stands out of STEM subjects by its extensive reliance on experiments which use chemicals that are typically consumed by the end of the experiments. The organization of demonstration and student experiments poses difficulties for the teachers, such as, lack of time¹ and laboratory space, equipment requirements, access to proper chemicals, their handling and inventory, economic,^{2–4} safety^{5–10} and disposal¹¹ concerns, and administrative burdens to name but a few. This challenge prompted many educators to approach this problem from a pragmatic point of view by using chemicals, equipment, and devices that are available or can be simply transformed from everyday, frequently household materials and tools. The large number of publications on this topic include *inter alia* analytical,^{12–15} electrochemical,^{16–18} synthetic,^{19–24} and isolation²⁵ experiments.

The application of everyday chemicals and simple devices available at home,²⁶ in kitchen,²⁷ garden,²⁸ marketplace,²⁹ and in various stores may help solve some of the above problems and potentially can ameliorate the students' frequently negative attitude toward chemistry.

The above supposed effect is neither self-evident nor automatic. The glorified role of experimentation as a *panacea magna* to improve the learning process of chemistry is not justified, and a more careful approach is required. The main

problems of chemistry education can be described as the difficulties associated with (a) the nature of chemistry itself and (b) the way learners acquire knowledge. Experimental data suggest that the teaching practice in the laboratory does not change as easily toward an open-ended style of teaching as the curriculum projects suggest. Johnstone and Wham claimed that educators underestimated the high cognitive demand of practical work on the learner as the students have to handle a vast amount of information during experimentation, causing an overload on the student's working memory.³⁰ Another issue is the *graduality* in accessing the different abstraction levels. The trichotomous, triplet, or tripartite approach (famously called the Johnstone triangle) differentiates three levels of representations of chemistry concepts: macroscopic, submicroscopic, and symbolic.^{31,32} Proficient use of chemistry concepts assume a constant shift between the different representational domains of chemical thinking as experts (teachers) do,³³ but novices (students) typically face difficulties handling these

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three domains *at the same time*. An excellent way to surmount this obstacle is to start with the macroscopic level, especially at the early school stages, and add on the other levels step-by-step.³² The macroscopic model at its best is experimental work (albeit in an artificial way, but this “artificiality” can be reduced, for example, by at-home experiments using common/everyday chemicals). Once the macroscopic level is secure, one can bring in the representational (symbolic) and then the submicroscopic interpretation. Laboratory work can act as a bridge between the macroscopic and the symbolic representational levels. Johnstone also suggested that curriculum designers and textbook writers should consider the need for a considerable introductory period in which students get familiar with thinking in a scientific way through the use of macroscopic and tangible experiences only.³² There is plenty of good science to be learned without the “interference” of submicroscopic considerations. Chemistry as a macroscopic material science, dealing with the things of every day experience, has much to offer.³¹

Student-centered learning in general and inquiry-based learning in particular, when implemented under certain conditions, provides benefits but difficulties may arise in knowledge acquisition and understanding.^{34–36}

Kirschner et al. suggest that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process as problem solving, present in inquiry-based instruction, places a huge burden on the working memory.³⁷ Criswell claims that when students engage in inquiry-based learning with very little structure, scaffolding (providing context, goals, actions, tools, and interactions) helps reduce the degrees of freedom for the learner in a problem-solving task to provide a “bigger picture” (scaffolding situations are those in which the learner gets assistance or support to perform a task beyond his or her own reach if pursued independently when “unassisted”).³⁸ There are several interpretations about what constitutes an inquiry-based approach, and three,³⁹ four,⁴⁰ or even five levels^{41,42} of inquiry have been suggested (e.g., the latter approach differentiates confirmation, structured, guided, open, and authentic inquiry). Many studies address the effectiveness of different forms of inquiry-based learning.

The assumption that presenting everyday (“real-world”) problems can replace “pure” cabinet experiments is not supported as typically most significant real world problems are ill-defined, multifaceted, and open-ended while they rarely possess single or exact outcomes.^{34,35,43} Nonetheless, in the appropriate setting the references to everyday life can serve as initial motivation and reinforcement of understanding as many chemical principles (e.g., acid–base and redox reactions, equilibrium, and energy) have direct relevance to everyday life.⁴³ Thus, it is justified to consider the use of everyday settings in the chemistry education as an important niche application.

METHODS

Literature Survey

To map the available literature on the above topic a systematic query has been carried out using the databases Education Resources Information Center (ERIC), Web of Science Core Collection, SciFinderⁿ, and individual journal repositories (in particular *Journal of Chemical Education* and *Chemistry*

Education Research and Practice) complemented by manual searches and personal collections. The query terms included the expressions everyday/consumer/household/kitchen/culinary/garden/marketplace/real world/at-home chemistry/chemicals/experiments. After winnowing the duplicates and irrelevant hits, over 300 articles, reviews, handbooks, reports, sourcebooks, booklets, curricula, *etc.* have been found, covering almost all fields of chemistry education, ranging from early childhood^{44,45} to high school students.⁴⁶ The obtained sources demonstrate that the concept appeared over the times in different disguises. The earliest embodiment can be traced back to the “home economics”, now called “family and consumer sciences” movement by Ellen Henrietta Swallow Richards (1842–1911) characterized by the application of science to the home, and she was the first to apply chemistry to the study of nutrition.⁴⁷ Looking at examples that are closer to our age we should mention the symposium entitled “Using ‘real world’ examples in the teaching of chemistry” in 1983⁴⁸ and the “Symposium on critical thinking and consumer chemistry” in 1988.⁴⁹ Since then, many papers appeared on various aspects of applying these principles. The recent COVID 19 pandemic-stricken era with extensive campus lockdowns resulted in canceled scheduled practical activities for chemistry students, just to witness a further impetus to this approach.^{50–55} The sudden constraint of switching to online education is well exemplified by a 1000+ pages long special issue of *Journal of Chemical Education* on “Insights gained while teaching chemistry in the time of COVID 19” with over 180 articles enlisting dozens of papers devoted to exploitation of experiments based on household items, consumer products, kitchen settings, and in general, experiments carried out at home.⁵⁶ This fact motivates the urgent reconsideration of the role of classical laboratory experiments in chemistry education.^{57,58}

Regarding the collection of household/consumer chemicals of our database, we must refer to the former Household Products Database hosted by the National Library of Medicine (NLM) of the National Institutes of Health (NIH) in the United States. This database was discontinued in 2019 and absorbed into the Consumer Product Information Database (CPID) maintained by the National Institute of Environmental Health Sciences (NIEHS) of the NIH, U.S. Public Health Service, Department of Health and Human Services and is describing products of the US and Canadian markets. The CPID database currently links over 23,000 consumer brands to health effects and has been designed to educate consumers about chemical ingredients of household products.⁵⁹ Obviously, our database is not comparable with any of the above ones either in scope or in depth, as we are focusing on (common) chemicals suitable for chemical demonstration experiments. Our database lists some traditional chemistry experiments as well that require the use of reagents commonly found in the laboratory, but not in the home.

Database Concept and Structure

Two subdatabases unified under a single web surface have been created by web-aided and manual search of available common chemicals and chemistry experiments prevalently used in chemistry curricula of Hungarian elementary and middle schools. The database has been implemented using Drupal, a free and open-source web content management framework.⁶⁰ The structure of the database is shown in Figure 1. The subdatabase of common chemicals (**Materials**) includes

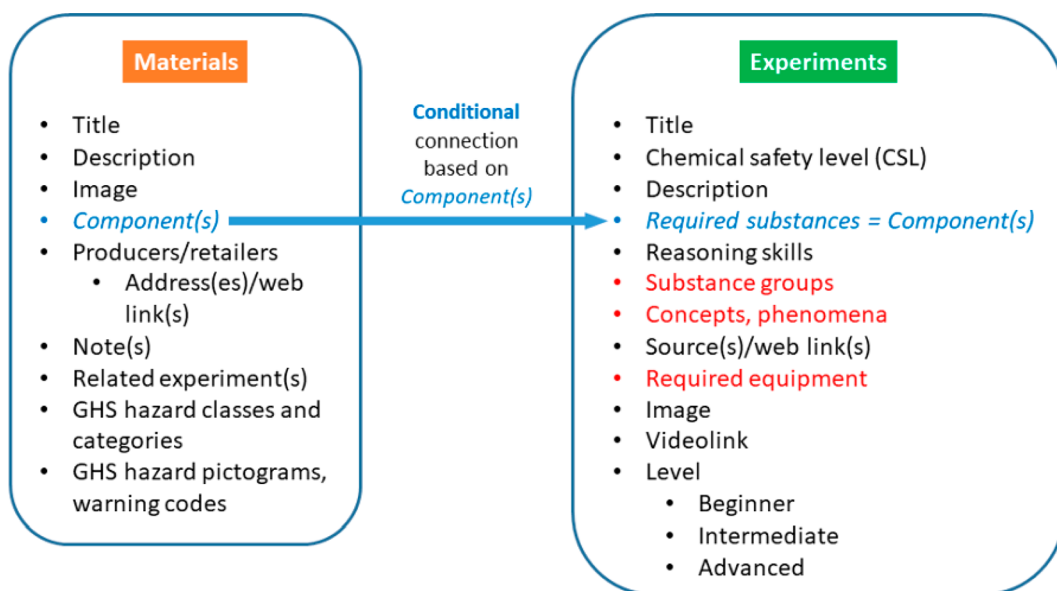


Figure 1. Database structure: the Materials and Experiments subdatabases and their relation.

Figure 2. Record of hydrogen peroxide in the Materials subdatabase

the categories *Title*, *Description*, *Image*, *Component(s)*, *Producers/retailers*, *Address(es)/web link(s)*, *Note(s)*, *Related experiment(s)*, *GHS hazard classes and categories*, *GHS hazard pictograms*, *warning codes*. The subdatabase of **Experiments** includes the categories *Title*, *Chemical safety level (CSL)*, *Description*, *Required substances*, *Reasoning skills*,⁶¹ *Substance groups* (Supporting Information 1, Table 1), *Concepts, phenomena* (Supporting Information 1, Table 2), *Source(s)/web link(s)*, *Required equipment* (Supporting Information 1, Table 3), *Image*, *Videolink*, and *Level* (Beginner, Intermediate, Advanced). The headings *Substance groups* and *Concepts, phenomena* contain a hierarchical thesaurus inspired by Mark R. Leach's Web site⁶² with selected keywords collected from the chemistry curricula of Hungarian elementary and middle schools. One particularly important feature of the **Materials** subdatabase is that it also enlists substances that are typically mixtures rather than pure substances. It is therefore the decision of the database constructor to evaluate whether the

additional substances beside the main component(s) are innocent by-standers or substances that interfere with their desired application in the **Experiments** subdatabase. Therefore, the interlinking of the two subdatabases is not automatic, the connection through the *Component(s)* (in **Materials**, *Required substances* in **Experiments**) has to be done individually case by case (Figure 1). Naturally, single-component pure substances from vendors of commercial chemicals can be seamlessly accommodated in the **Materials** subdatabase, thus the database is suitable for extension into this direction as well.

SAFETY ISSUES

In principle many chemicals are potentially hazardous therefore the safety issues have to be treated seriously.⁶³ There is a 78-pages long *Guide to safe experimentation, storing and handling of chemicals* available in the database and the User



Figure 3. An example of a **Materials** subdatabase query for 'iodine'.

guide also contains safety information (Supporting Information 2). Household chemicals encompass a wide range of substances from harmless (e.g., food) to quite dangerous goods (strong acids, bases, oxidants, etc.) therefore we maintain a nuanced approach to characterize them in the database. Thus, the safety issues associated with the database are addressed on the level of **Materials** and **Experiments** subdatabases as well. The safe handling of chemicals of the **Materials** subdatabase are subject to the European Regulation (EC) No. 1907/2006⁶⁴ concerning the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) and the Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of December 16, 2008 on Classification, Labeling, and Packaging of substances and mixtures (so-called CLP regulation).⁶⁵ The labeling of chemicals employs the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) along with the Safety Data Sheets (SDSs).⁶⁶ These regulations are in harmony with the approach of the European Chemicals Agency's (ECHA) Classification and Labeling Inventory (C&L Inventory)⁶⁷ and that of the American Chemical Society's RAMP strategy (recognize hazards, assess risk, minimize risk, and prepare for emergencies).^{68–70} A record with safety information in the **Materials** subdatabase is shown in Figure 2.

The safety aspects of the **Experiments** subdatabase are gauged according the *Chemical Safety Levels* (CSL) scale elaborated by the American Chemical Society.⁷¹ This classification distinguishes four safety levels (the increasing numbers warn of growing concern):

CSL1 (laboratory hazards equivalent to typical household use of chemicals);

CSL2 (laboratory hazards equivalent to academic lab settings—restricted hazardous chemical inventory; well-established procedures in place);

CSL3 (moderate or varying laboratory hazards within a narrow range—open hazardous chemical inventory; evolving procedures) and

CSL4 (novel hazards or severe established hazards—high hazard chemicals or processes with well-established procedures).

The majority of experiments in the **Experiments** subdatabase falls into category **CSL1** or **CSL2** with a few in **CSL3**. In each case, the **CSL** classification is used to denote the apparent risks associated with a given experiment. The experiments in the database are intended primarily for laboratory use. Only those that are classified as **CSL1** level experiments using *harmless household items* (e.g., food ingredients) can be recommended as at-home experiments.

RESULTS

The Peculiarities of the Database

The database is accessible at the Web site <http://edu.u-szeged.hu/ttkcs/vegyszer/> and it has four levels of access, two of which are publicly available:

- browsing without ID
- employing with an ID that can be obtained using the *Request new password* link or at the following e-mail addresses: betyargabor@gmail.com; kovacs.lajos@med.u-szeged.hu).

The remaining two access levels are for inputting, editing, and maintaining the database integrity (Supporting Information 2, *User Guide*).

The two subdatabases at the moment contain 245 chemicals and 100 experiments and the number of records is growing steadily. Both subdatabases feature rich searching, importing, exporting, and report-generating features. In a typical scenario the teacher looks for an experiment in the **Experiments** subdatabase that fits the current class hour of a given curriculum, and by querying the database through keywords, browsing, etc. one finds the pertinent experiments that enlist the substances based on (common) chemicals and the necessary equipment. By generating a report (Supporting Information 3, Report), the desired experiment(s) can be executed in off-line situation as well. Alternatively, simple querying/browsing in the **Materials** subdatabase gives

incentives how to illustrate critically a particular chemical concept or phenomenon starting from a common chemical occurring in our daily life. The revelation that substances are present in every parts of our civilization and they are not just subject of in-school chemistry activity can have a significant effect on how this discipline is viewed and can help bring about conceptual changes in chemistry education with the limitations outlined in the Introduction.

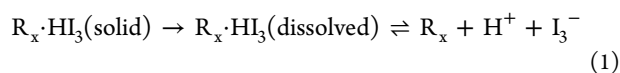
The following case studies demonstrate how this unique database can be used in chemistry education by highlighting the employment of everyday materials that normally are not part of chemistry curricula, largely based on experiments applying pure chemicals. The database presents experiments for demonstration and for standalone student exercises, but it can be exploited as an information source as well also shown in the following case studies. The explanations provided for the experiments are kept to a minimum and commensurate with the level of students (beginner, intermediate, and advanced) and focus on the macroscopic and symbolic representational models.³²

The Database at Work

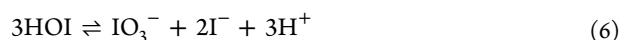
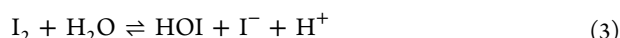
Let us suppose that an instructor is interested in using the commonly available antiseptic povidone–iodine as a source of iodine in an experiment with other household items. S/he can enter either ‘iodine’, ‘Betadine’ or ‘poly(1-vinyl-2-pyrrolidone)’ in the search bar of the **Materials** subdatabase. The result of the “iodine” query yields *Betadine* (solution) and three pertinent experiments (*Reaction of starch and Betadine*; *Reaction of vitamin C and Betadine*; and *Reaction of Lyxio and Betadine*, Figure 3).

Case Study 1: The Properties of Povidone–Iodine

Let us see first the characteristics of this drug. Povidone–iodine [PVP-I, poly(1-vinyl-2-pyrrolidone)–iodine], in many countries known as Betadine, is an antiseptic (solution, cream, or spray) used for skin disinfection and minor wounds. The solution actually is a dilute iodine solution, with iodine being present largely as triiodide ion (I_3^-) although the exact composition is subject to a rather complex set of equilibria (eqs 1–6):



$R_x = \text{poly}(1\text{-vinyl-2-pyrrolidone})$



The proposed structure of povidone–iodine complex is shown in Figure 4.⁷² The free molecular iodine concentration (I_2) is only 4.5×10^{-6} mol/L (1.1 ppm) in 20% solution, the maximum ($\sim 10^{-4}$ mol/L, 25.4 ppm) is reached in 0.1% solution.⁷³ As in many chemical demonstration experiments iodine is used in solution, we supposed that this complex can substitute iodine in several situations that are beyond the traditional use of the povidone–iodine complex.^{74–76}

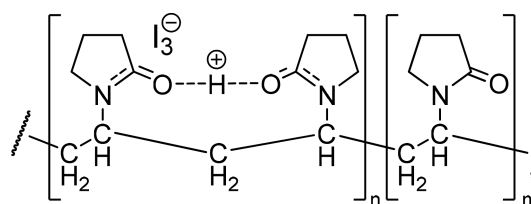


Figure 4. Partial structure of povidone–iodine complex.

Case study 2: Color Reaction of Starch and Povidone–Iodine

The well-known color reaction of starch and iodine^{77,78} can be carried out with povidone–iodine as well, as demonstrated in the experiment *Reaction of starch and Betadine*. The intensity of the characteristic blue color clearly shows the concentration difference between Lugol’s iodine solution⁷⁹ and povidone–iodine that is even more spectacular when the two solutions are diluted (Figure 5; the most commonly used aqueous Lugol’s solution consists of 5% (m/v) iodine and 10% (m/v) potassium iodide).

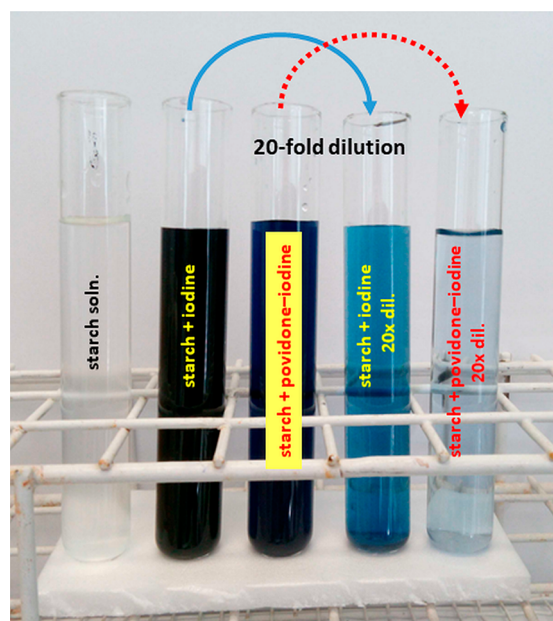


Figure 5. Color reaction of starch and iodine (Lugol’s solution) vs starch and povidone–iodine in concentrated and diluted solutions, respectively.

Case study 3: Reaction of Povidone–Iodine and Drugs Containing *N*-Acetyl-L-cysteine

Thiols can be oxidized with mild oxidants (e.g., iodine) into disulfides.⁸⁰ This reaction can be elegantly exemplified by using drugs containing *N*-acetyl-L-cysteine and the iodine-containing povidone–iodine to afford a cystine derivative (Figure 6).

In this example a drug containing *N*-acetyl-L-cysteine (Lyxio) was chosen [experiment *Reaction of Lyxio and Betadine*; additional drugs with this substance as an active pharmaceutical ingredient (API) are listed in Supporting Information 1, Table 4]. The reaction of Lyxio with povidone–iodine, however, is perplexing: both substances, when dissolved, are yellow in color and the transformation does not produce a color change. The reason for this

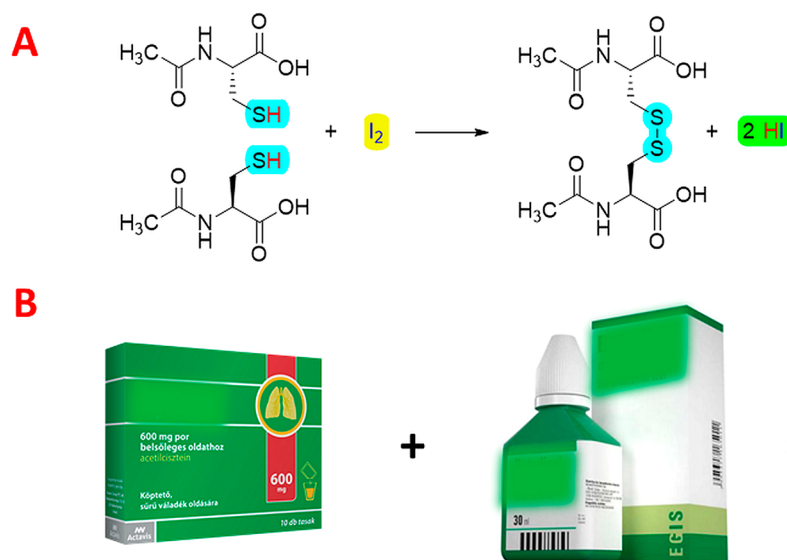


Figure 6. (A) Reaction of *N*-acetyl-L-cysteine and iodine; (B) reaction of the drugs Lyxio and Betadine.

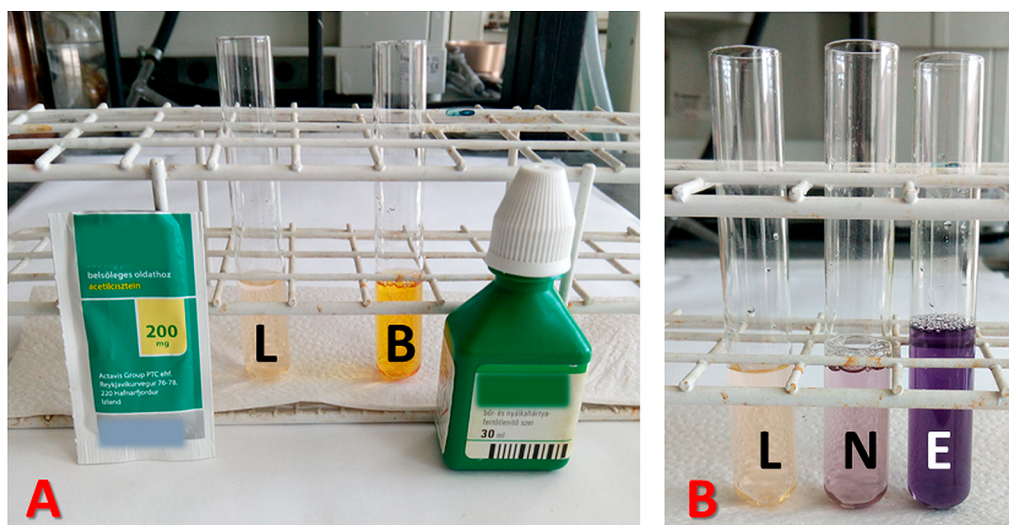


Figure 7. Titration reaction of Lyxio and Betadine in the presence of starch indicator. (Panel A) Lyxio (L) and Betadine (B) solutions prior to titration. Solution L also contains colorless starch solution as well. (Panel B) Original Lyxio solution (L), the Lyxio solution with starch indicator near the end point (N) and at the end point (E).

phenomenon is the presence of a yellow food colorant (Sunset Yellow FCF, FD&C Yellow No. 6 in the US and E110 in Europe) in the drug Lyxio and the intrinsic yellow color of dilute iodine solutions. The problem, however, can be simply solved: the addition of starch solution indicates the excess iodine; thus, the Lyxio solution can be easily titrated drop by drop in the presence of starch indicator (Figure 7). This experiment nicely illustrates simultaneous redox and functional group transformations, both being rather problematic teaching exercises.³²

Case Study 4: Turpentine and Povidone–Iodine Fail to React

It is interesting to examine whether the violent reaction of turpentine⁸¹ (containing primarily the monoterpenes α - and β -pinene, with lesser amounts of carene, camphene, dipentene, and terpinolene) and iodine is working with povidone–iodine or not. The result is that this reaction fails with turpentine and Betadine. The reason is 2-fold: (a) the two reactants are in

different phases (turpentine poorly dissolves in water while povidone–iodine is essentially an aqueous solution) and (b) the concentration of free, molecular iodine is very low in povidone–iodine (see above). This fact highlights the importance of careful experiment design. For curious students it can be recounted that the original turpentine–iodine reaction was in use for the disinfection of life-threatening wounds of large-bodied animals (horses, cattle).⁸² Such an intervention today is certainly out of the question considering the current safety standards!

Case Study 5: Drain Cleaning Preparations at Work

By querying the **Experiments** subdatabase one may look for an experiment containing the concept ‘Heat phenomena of chemical and physical processes’ and ‘heat of hydration’ or ‘heat of dissolution’ that will lead to the experiment *Operation of drain cleaning materials* (Figure 8).

Drain cleaners are designed to unclog the drains and traps of sinks, bathtubs, showers, kitchen drains, septic tanks, cesspools,

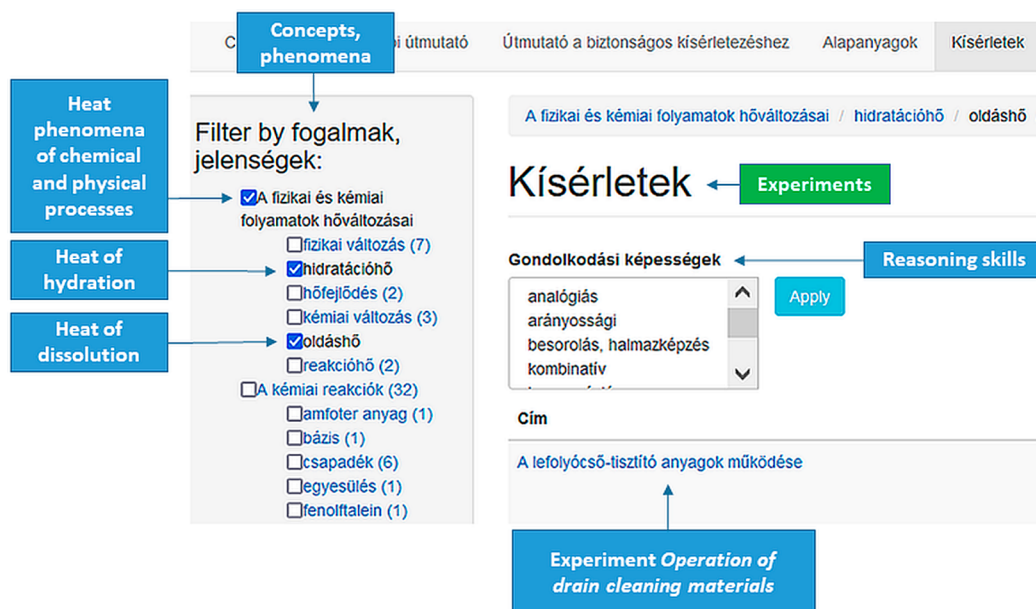


Figure 8. An example of an Experiments subdatabase query for 'heat of hydration'.

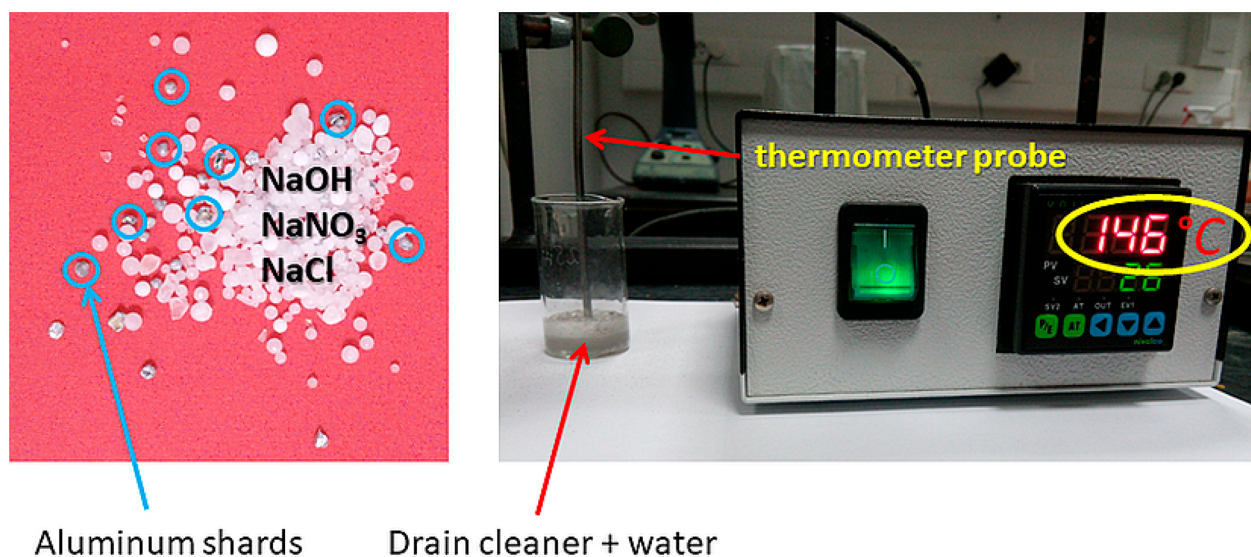
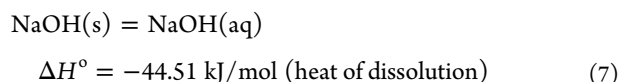


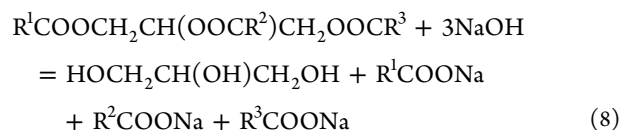
Figure 9. A drain cleaner at work.

etc., when these become plugged with hair, grease, food residues, soap deposits, or the gelatinous masses that can result from the action of microorganisms.⁸³ Drain cleaners fall roughly into three categories: (a) caustic agents with basic and (b) rarely acidic components and (c) green (enzymatic and bacterial) cleansers (Supporting Information 4, Table 5) which can be either powdered (concentrated) or liquid (solutions). The powdered alkaline drain cleaner used in our experiment contains 40–60% sodium hydroxide, 8–15% sodium nitrate, and 1–3% aluminum shards (the cleanser Drano Crystals Clog Remover is very similar in composition, cf. Supporting Information 4). The way this cleanser works is rather complex:

(1) The dissolution of sodium hydroxide produces a large amount of heat (eq 7):



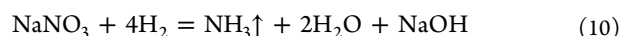
(2) The ensuing hot alkaline solution catalyzes the hydrolytic decomposition of lipids into water-soluble fatty acid salts and glycerol (eq 8):



(3) Aluminum reacts with sodium hydroxide and generates hydrogen gas (eq 9):



(4) Sodium nitrate reacts with excess hydrogen to afford less dangerous gaseous ammonia (eq 10):



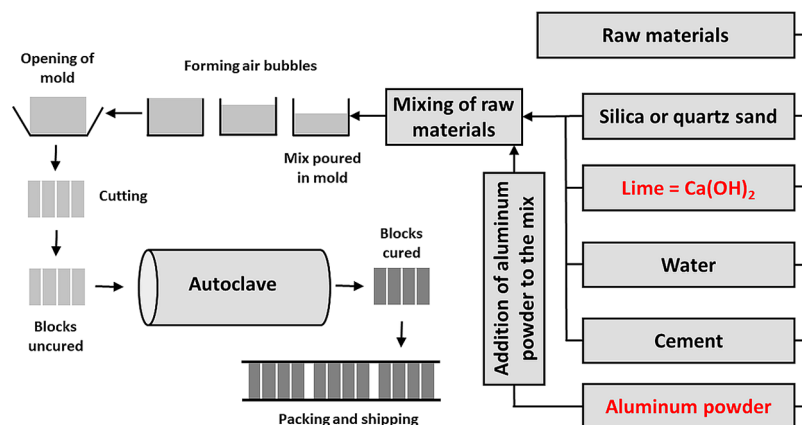


Figure 10. Manufacturing process of autoclaved aerated concrete. Adapted with permission from ref 86. Copyright 2014 Engineering and Technology Publishing.

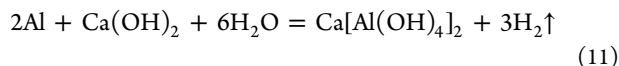
(5) Sodium nitrate also helps proliferate *Nitrosomonas* bacteria which more easily use nitrates than elementary oxygen.

The above combined effects help to unclog drains.

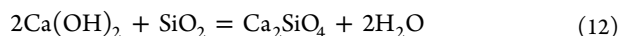
In the above experiment described in the database (*Operation of drain cleaning materials*, Figure 8) a drain cleaning preparation containing aluminum is added to water, and excessive gas formation and heat evolution are being observed (Figure 9). **Wear safety goggles and rubber gloves when carrying out this experiment as it involves significant heat generation, beware of the resulting hot alkaline solution!**

Case study 6: The Manufacturing of Autoclaved Aerated Concrete

The above example of a drain cleaning preparation experiment can be exploited in providing additional information on similar reactions that are employed in the construction industry. The manufacturing of autoclaved aerated concrete (AAC, e.g., Ytong, Aircrete, Thermalite, Hebel Block, Starken) relies on essentially the same reaction as that of aluminum with sodium hydroxide in drain cleaners. In this latter case lime (calcium hydroxide) is used as a base (eq 11):



The reaction of aluminum produces hydrogen gas (eq 11) that will cause foaming in the concrete as it forms and increases the volume of gas concrete up to 60%. This foaming results in pores in the set concrete that provides structural benefits. At the end of the foaming process, the hydrogen escapes into the atmosphere and is replaced by air, this process is facilitated by hot steam in strong, pressurized, steam-heated vessels (autoclaves). Furthermore, during this steam pressure hardening process, when the temperature reaches 190 °C and the pressure reaches 8 to 12 bar (800 to 1,200 kPa), quartz sand reacts with excess calcium hydroxide to form calcium orthosilicate hydrates (eq 12, simplified version),^{84,85} which gives AAC its high strength and other unique properties (AAC simultaneously provides structure, insulation, and fire- and mold-resistance).



Depending on its density, up to 80% of the volume of an AAC block is air. AAC's low density also accounts for its low

structural compression strength, it can carry loads of up to 8 MPa, about 50% of the compressive strength of regular concrete (Figure 10).⁸⁶

DISCUSSION AND IMPLICATIONS

The purpose of this database is not just to convey and digitize existing data and sources but also to provide new opportunities and a fresh look at how available common chemicals and chemistry demonstration experiments can be interlinked and implemented in different activities. The database can be exploited in a multifaceted way for reaching various pedagogic targets: it helps knowledge acquisition, development of thinking, and the design of experiments for students and by teachers as well. Likewise, it can be employed in inquiry- and problem-based learning for exposing a phenomenon or problem and for information retrieval as well, demonstrated in the above exemplary case studies. The database was conceived with regard to recent international approaches, for example, the applications-led curriculum development to make sense of the world around the learners in the context of their age and wider culture^{35,87} and the Next Generation Science Standards (NGSS) of the USA with disciplinary core ideas, crosscutting concepts, and science/engineering practices.⁸⁸ The actual content of such an integrated database is certainly culture- and country-specific but it has a general relevance in chemistry education. The unique structure and the interlinking of the two subdatabases and its concept are universal and can be used in different environments as well. Although the use of everyday chemicals (typically mixtures) has certain limitations, their application is justified under given conditions to illustrate important chemical principles and to explain and relate the chemistry of everyday chemicals.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.1c00540>.

Tables showing the substance groups of the experiments subdatabase; concepts and phenomena of the experiments subdatabase; list of required equipment of the experiments subdatabase; selected list of the names of drugs containing *N*-acetyl-L-cysteine (PDF, DOCX)

User guide to the chemicals and experiments database (PDF, DOCX)

Image of a pdf report generated for an experiment in the experiments subdatabase (PDF)

Table showing the composition of some drain cleaning preparations (USA/Canada/UK market) (XLSX)

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Author Contributions

Author contributions have been assigned according to the Contributor Roles Taxonomy (CRediT) system⁸⁹ as follows: conceptualization, data curation, formal analysis (L.K.); funding acquisition (E.K.); investigation, methodology (L.K.); project administration (L.K.; E.K.); resources (E.K.); software (G.B.); supervision (L.K.; E.K.); validation (L.K.; E.K.; G.B.); visualization (L.K.; G.B.); writing—original draft (L.K.); writing—review and editing (L.K.; E.K.).

Notes

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