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Linking the Topics "Climate Change and Nutrition" by Discussing Sustainability in Chemistry Lessons at School

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ABSTRACT: Agricultural production in Europe is intensive, highly specialized, and responsible for some negative environmental impacts related to climate change and loss of biodiversity, raising questions about the sustainability of farming and the wider food system. The integration of legumes into agricultural systems could contribute to the transition to more sustainable food production and consumption. For example, for the production of 100 g of protein in beef, 49.89 kg of CO_2 is emitted, whereas for 100 g of protein in pulses, it is only 0.84 kg. While the general benefits from legume cultivation and consumption are widely known in the scientific community, there is little evidence on how to inform next generations. Therefore, in this paper, the development of materials for discussing sustainability in chemistry lessons at school using a guided inquiry approach is described and discussed. Chickpea and lupin were identified as two contrasting legume species that allowed exploring the role of established and novel crops as an example in Germany. Chemistry experiments related to nutrition were further developed, using canned chickpeas and lupin yoghurt as examples for plant-based food products. All materials were made available using an interaction box to ensure that the students can plan their own learning process individually. After finishing the work with the box, the students can use their results for a discussion.

KEYWORDS: *Climate change, nutrition, sustainability, legumes, school lessons, experiments*

■ INTRODUCTION

Sustainability in the context of climate change is prominent in politics and industry.[1] UNESCO leads and coordinates the "Education 2030 Agenda" to eradicate poverty through the 17 Sustainable Development Goals by 2030. To achieve these goals, a roadmap with action areas has been published.[2] The priority action area 2 - transforming learning environments, names learners explicitly: they should "*become change agents who have the knowledge, means, willingness and courage to take transformative action for sustainable development*".[2] Because "*today's youth will be left to face the consequences of unstainable development*",[2] learners should have sufficient learning opportunities during their school days to enable them to actively participate in society and so to contribute to the development of appropriate frameworks for a sustainable world. In Germany, the "*decade of action*" for Education for Sustainable Development (ESD) was started in 2021 with an online conference.[3] While ESD contributes to all 17 Sustainable Development Goals, it contributes especially to Goal 4 - Quality Education and Goal 13 - Climate Action.[2] In education, awareness of climate change and reducing its impact should be addressed. Therefore, ESD should be part of all educational settings, not only in chemistry. However, many chemical topics are suitable for discussing sustainability, for example the combustion of fossil fuels taking into account the greenhouse effect, renewable energies in combination with new batteries, or the recycling of materials for saving resources or reducing waste; these are often far from what students think about at the age they are in higher secondary levels (age 16–18). Instead, topics that affect the students because they are part of their everyday life, i.e., food, are very suitable. Here, students can exert influence depending on what they eat; the reduction of the CO_2-footprint is especially noticeable for switching from animal-based to plant-based proteins: for 100 g of protein in beef, 49.89 kg of CO_2 is emitted, and for 100 g of protein in pulses, only 0.84 kg are emitted.[4] Ideally, such topics allow including classroom experiments because these are commonly used for knowledge-gathering in chemistry lessons.[5]

In recent literature on chemistry education, the topic "climate change" is addressed: for the connection between climate change and the function of greenhouse gases;[6] by using

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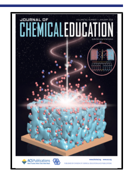

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videos on the chemistry of climate change which improved students' understanding of climate change topics;[7] or by using rich contexts on climate change for introducing the topics of isotopes, acids–bases, gases, and thermochemistry into undergraduate general chemistry courses.[8] For addressing the topic at university and at school, new materials and concepts must be developed; textbooks for chemistry lessons discuss the topic climate change either rarely or peripherally.[9] Therefore, the results of a study of preservice chemistry teachers' understanding of the concepts of climate change are not surprising: the authors showed that their understanding was ambiguous or false.[10] Several curricular innovations address students' knowledge of climate change, for example, by connecting chemistry concepts to real-world significance,[11] by the use of inquiry-based learning which improved students' attitudes and knowledge on climate change,[12] by a project on next generation science standards where preservice science teachers learned chemistry concepts related to climate change,[13] or by improving students' systems thinking and their ability to visualize complex climate change-based scenarios.[14] Because climate science also has ethical, social, and political dimensions, new general education courses address these dimensions by merging STEM with non-STEM subjects.[15] Connections have also been made between chemistry concepts and the principles of climate literacy to make chemistry courses more relevant and ultimately to make citizens more climate literate.[16]

To ensure that courses at the university level include topics on climate change, the instructors must have sufficient knowledge on the topic. A recent study shows that undergraduate chemistry instructors connect mostly the topics of gases, solutions, and reaction chemistry with climate change. Therefore, accessible materials are needed with the goal of including climate change in undergraduate chemistry courses.[17] Such materials are also needed for teaching the topic at school. Therefore, in this article, the development of suitable materials for discussing climate change and sustainability in chemistry lessons using the example of chickpeas and lupines as protein sources for nutrition is described and discussed.

■ BACKGROUND

For planning and conducting chemistry lessons at school, several prerequisites must be taken into account: curriculum, experiments, context, and students' competences and knowledge in combination with appropriate methods. The background specifically used for the development of the materials discussed in this paper is given below.

Curriculum (Including Experiments)

The materials discussed in this paper are developed for students in higher secondary level (age 16–18) at schools in Brandenburg,[5] which is one of the federal states in Germany. Those states are responsible for the curricula at school. Therefore, some differences between the curricula of the federal states can be observed.[18] Fortunately, the topic "proteins" is part of the curriculum of almost all federal states.[19] Within the topic "proteins", several functional groups are thematized, mainly as repetition, but here in the new context of proteins: double bond, hydroxyl, carbonyl, carboxyl, ester, and amine groups. The properties, structure, and function of amino acids and proteins are also part of the curriculum. In this context, the peptide bond is discussed. Experiments named in several curricula include denaturization and the biuret and ninhydrin reaction. As context for these experiments, the detection of proteins in food is listed explicitly. "*The contexts are related to the overarching themes of consumer education and health promotion*" with protein shakes listed as the only suitable context.[5] However, in addition to animal proteins, the importance and benefits of plant proteins should be discussed as well as the relationship to sustainable agriculture. Therefore, in addition to the chemical content, the subject offers many opportunities to integrate other topics, such as nutrition, environmental and climate protection, and sustainability, into the lessons. These contexts are particularly important for the students' development of assessment skills. The context should stimulate students' personal mental activities and should support the development of competences.[19] Therefore, using an actual context should also mean using active teaching methods where students have to use prior knowledge for their problem solving and can develop problem-solving strategies.[20] As a suitable method, the use of interaction boxes will be discussed in this paper.

Context

"*Global climate change is one of the most pressing environmental issues facing the world today*".[6] Therefore, topics belonging to climate change should be part of the chemistry curriculum at school or at university, because "*particularly today's youth will face choices in the future about energy use and policies to reduce greenhouse gas emissions in an effort to reduce or manage the anthropogenic impact on climate*".[6] For chemistry education, five areas of interest for students' understanding of climate change are listed: electromagnetic radiation, greenhouse effect (how greenhouse gases work), ozone, environmental issues, and proposed solutions to mitigate the effects of climate change.[6] Climate changes that can be observed already have an effect on the environment: the shrinking of glaciers and ice, the shift of plant and animal geographic ranges, and the earlier bloom of plants and trees. For the future, more heat waves can be expected.[21] As a result of these environmental effects, climate change also has an impact on nutrition. On the one hand, the production of food from animal sources generates a lot of greenhouse gas emissions; on the other hand, the soils are becoming increasingly drier due to climate change. The shift from animal- to plant-based proteins would reduce the emission of greenhouse gases. Therefore, climate change, agriculture, and nutrition are interconnected.[22] The effects of climate change on agriculture will have implications for food security and, therefore, for nutrition. Climate-smart approaches are therefore needed to maximize nutrition in the face of climate change.[22] For linking the chemical content "proteins" with climate change, nutrition is an ideal context not only because of the impact of food production on the emission of CO_2 but also because of students' interest in both topics and as a result their emotional involvement. Therefore, using a suitable context supports the acquisition of new knowledge and the application of available knowledge as for example shown by using rich contexts on the topic "climate change".[8]

Examples for plant-based proteins that can contribute to a climate friendly nutrition are, for example, chickpeas or lupins. Therefore, it is not surprising that International Pulses Day on 10 February highlights the importance of pulses for our nutrition, but also for sustainability and to raise public awareness.[23] Grain legumes, chickpeas, and lupins do not require additional nitrogen fertilization and at the same time

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improve soil fertility and water retention and support humus formation.[24] Fertilizers contribute to climate change through emissions during the production of fertilizers (depending on the source of energy), the transport, and application of fertilizers to the soil. In a study of case studies across Europe, cropping systems with legumes reduced nitrogen fertilizer use by 24% and 38% and nitrous oxide emissions from soils by 18% and 33% in arable systems with grain legumes and forage systems with forage legumes, respectively, compared to systems without legumes.[25] Both chickpeas and lupins have health benefits as they are nutrient-rich and contain many proteins, vitamins, fiber, and unsaturated fatty acids.[26] Grain legumes are the main source of plant-based protein.[24] Other components such as starch are also very relevant for food and nonfood products, especially from field peas.

Legumes have been consumed for many centuries. However, their cultivation is in competition with other crops such as cereals, maize, or rapeseed.[27] The current area under legume cultivation in Germany is 5.4%[28] with 14.5% devoted to grain legumes on a worldwide basis.[20] By 2030 the policy aim is to increase the area to 10% in Germany and similar aims exist for Europe.[20] To achieve this, both the supply from agriculture and demand from buyers must be increased. Increased cultivation of legumes in Germany is possible only if solution-oriented research in the breeding and processing industries meets the interest of consumers.[29] Legumes are named as a "*cornerstone to more sustainable agri-food systems and diets in Europe*".[30] Although legumes are excellent sources of proteins and reduce the need for synthetic N fertilization, legume promotion campaigns will be needed to ensure that customers will include more legumes in their diets.[30] In the US, legume intake remains low and is also below US dietary guidelines.[31] In Australia, legumes were first mentioned in the Australian Dietary Guidelines in 1992, as part of the vegetable food group.[32] Crop management such as crop rotations with and without legumes affect the performance of crops in cropping systems.[33] Climate change factors such as increasing drought impacts the yield of grain legumes such as soybeans.[34] Additional irrigation can increase the protein content and total protein yield[35] important for food processing, e.g., tofu. Apart from protein, grain legumes provide various nutritional components such as carbohydrates, sugars, vitamins, more than 15 essential mineral elements, and mono and poly unsaturated fatty acids.[36] These are affected by environmental conditions, and the impacts of climate change require more research.

The white lupine (for an example, see Figure 1) was mentioned by Hippocrates of Kos (400 to 356 BC) as a human food. The white lupine was in the 19th century cultivated for green manure. To be suitable for human consumption, the content of alkaloids in lupins must be reduced. The first alkaloid-poor lupins were bred by von Sengbusch in 1927. These are called sweet lupins.[37] The variety of alkaloid-poor lupins remains an ongoing task, as the alkaloid content is inherited predominantly.[38]

The world's largest area for lupin production is in Australia. Within the EU, Germany has the largest area under cultivation; they are mainly cultivated in Brandenburg, Mecklenburg-Western Pomerania, Saxony, and Saxony-Anhalt, on sandy soils with a low pH value.[38] Most of the lupins are sold in Germany as animal feed.[39] Due to the demand for regional, sustainable, and plant-based foods, the demand for lupin products is also increasing for our diet. Lupins serve, for example, as a meat

Figure 1. White lupins as an example of sweet lupins (private; author M.S.).

protein substitute or for use in baked goods and confectionery. Lupin coffee or milk alternatives such as lupin drink or lughurt (yoghurt made from sweet lupins) are also produced.[40] In the US, canned chickpea, chickpea chips or puffs, lupin flour, and protein pasta with lupin flour are available in supermarkets, for example.

Chickpeas are among the oldest cultivated plants (for an example, see Figure 2). Their use began around 8000 B.C. in the near east and southwest Asia. They served, among other things, to prevent skin diseases and for drainage. In Europe, they were roasted in the 18th century as a substitute for coffee.[41] Attempts to cultivate chickpeas in Germany at commercial scale started recently.[42] The sandy soils, for example, in Brandenburg, could be suitable for cultivation, since the chickpea tolerates dry conditions. A high amount of rainfall is troublesome due to the occurrence of fungal diseases.[43] A major problem in growing chickpeas is weed management. However, chickpeas have increased protein and iron content as well as vitamins B1, B6, E, and C, and are mainly used for human nutrition. In India, Mexico, Turkey, and North Africa, for example, they are an important basic food. In North Africa, they form the basis for hummus and falafel, two dishes that are also well-known in Germany.[44]

Sustainability includes not only the shift from animal to plant proteins aiming to reduce greenhouse gases but also research on sustainable cropping systems. Research on legumes is fundamental and supports broad implementation in agricultural practice. It was shown that legumes in different regions of Europe were able to reduce nitrous oxide emissions by an average of 18% and 33% respectively in arable and forage crop rotations, compared to systems without legumes.[25] The use of mineral nitrogen fertilizer could be reduced by 24% and 38%, respectively.[25] When farmers were able to develop adapted crop sequences with market access and adequate prices, this led to a win−win situation, i.e., positive environmental and economic performance.[45] Legumes in crop rotations increase the yields of subsequent crops and partly stabilize the performance.[33] However, the yield stability of grain legumes is significantly lower than that of winter cereals.[46] Current research aims at adaptation to climate change through drought-adapted crops such as chickpeas, diversification through mixed cropping systems,[47] and

Figure 2. Chickpeas (private; author M.S.).

Figure 3. Interaction box on chickpeas and lupines (private; author J.H.).

exploring new opportunities for regional utilization of legumes in the food sector.

An important context for chemistry lessons at school on this topic is the diet of young people. Vegetarian (without meat and fish) or vegan (only plant-based food) diets are a trend, also among young people.[48] The results of the VeChi Youth Study showed that 37.2% of children and adolescents (age 6–18 years) ate vegetarian food and 28.2% vegan.[49] A vegan diet is positive for preventing several diseases, especially cardiometabolic diseases, but risks certain mental health problems due to the potential for micro and macronutrient deficits.[50] Research on the costs of different diets showed that the relative affordability was largest for vegetarian and vegan diets that focused on legumes and whole grains.[48] However, "*a vegetarian diet in childhood and adolescence requires good information and supervision by a paediatrician, if necessary, in cooperation with an appropriately trained dietary specialist*".[51] Therefore, different diets should also be part of chemistry lessons at school, especially while discussing the topic of nutrition because chemistry lessons at school contribute to the acquisition of "*scientific competence, which provides orientation in the natural sciences and technology-influenced living environment*".[5] The use and application of those competences on every day topics can be trained effectively during chemistry lessons.

Methods

Concepts on the use of suitable context for chemistry lessons have been developed and published, for example, the concept "Chemistry in context" (ChiK), which addresses the relevance of chemistry for our daily life,[52] and can be seen as further

Table 1. Experiments in the Interaction Box

Experiment	Description
Biuret experiment (detection of proteins)	Denaturization of proteins; complex between copper ions and the protein bonds which results in a purple color.
Denaturization of proteins by heating or bases	Denaturization of the protein (the primary structure remains intact). Alkaline hydrolysis takes place by the addition of caustic soda, which produces detectable ammonia.
Ninhydrin experiment (proof of amino acids)	Denaturization of the proteins followed by the reaction of the free amino groups at the N-terminal end of the polypeptide chain with the ninhydrin reagent to form a blue-violet dye.
Azo dyes with amino acids	The presence of the amino acids histidine and tyrosine can be tested. If histidine and tyrosine are present in a sample, orange and red azo dyes are formed.

development in the concepts of ChemCon[53] or Salters.[54] The use of suitable context can address the problem of students not seeing the relevance of chemistry.[55] If the content is contextualized, then inquiry-based learning would be a good method. Inquiry-based learning is positive for students' learning.[56] For the materials discussed in this paper, guided inquiry has been chosen. Here, although the problem is given by the teacher, the students can execute further steps of the process, for example, the formulation of hypotheses.[57] By doing so, cooperative learning can take place, and the students can develop their skills and abilities.[57] The students participate in chemistry classes as researchers.[58] To make the materials available to the students, all materials (see Appendix 1) were collected in interaction boxes.[59,60] In an interaction box, all materials (including chemicals and glassware, etc.) are made available to the students. For each purpose (information, repetition, experiments, etc.), the materials are printed on differently colored paper (for example, white for information or blue for repetition). The students can then organize their use of the box individually; however, small groups are preferable (3−4 students). Therefore, the box (see Figure 3) includes an overview on all materials and possible questions or hypotheses to ensure that the students can work with the box even if they are not able to formulate their own questions or hypotheses. Depending on the students' competences, the teacher can decide whether to include the complete experimental instructions or to include only the chemicals and glass equipment to ensure that the students can plan their experiments independently. The interaction box can be expanded, for example, with cooking recipes for cooking with lupines and chickpeas or with current information from media such as television, magazines, or newspapers. The recipes can be designed for example as gap-filling exercises.[23] For the use of media information, a game or a crossword can also be designed for applying this information. After finishing the work with the box, the students can use their results for a discussion. Therefore, the materials for preparing this discussion are also included in the box. In Appendix 4, Internet sources for research and information on protein requirements and protein content in various foods are available (in German and in English). The students can then determine their own protein requirements using various foods as examples. To make a good diet, the differences between animal- and plant-based proteins, including suitable Internet sources, are also listed in Appendix 4. The students can then discuss that not only the amount of proteins but also the source of proteins is important.

■ DEVELOPMENT OF THE MATERIALS

For the development of the materials (for all materials, see Appendix 1), several prerequisites have been considered. They should be suitable for the following:

- inquiry-based learning;
- heterogeneous learning groups;
- planning and conducting of experiments on the topic "nutrition";
- discussing sustainability;
- including topics from everyday life.

To ensure this, the materials were designed in a way that the teacher could use them in various educational settings, varying the openness of the teaching method depending on the learning group. Because the materials include different types of materials and are organized as interaction boxes, both teachers and students can use the materials individually. The students can plan their course of action while working with the interaction box independently as intended by the method.[59,60]

The interaction box consists of the following materials (see Appendix 1): manual for using the box, list of chemicals and glass equipment, info-text on international celebration days, learning games for repeating prior knowledge on acids and proteins, experiments, jigsaw and WebQuest regarding sustainability, climate change and nutrition, questions and hypotheses, and ideas for presenting the results. Because the development of the experiments was the most time-intensive, it is described in detail below.

Experiments on Chickpeas and Lupines

Experiments for use in chemistry education at school should be suitable for the learning topic, should allow openness while experimenting, and should be chosen according to the following principles: low-cost, low-risk, and low-tech.[61] By using plant-based products instead of animal-based products, the impact of the experiments can also be reduced, which contributes to an environmentally sustainable lab activity. The experiments should be adapted to the level of knowledge and age of the pupils.[23] For supporting the development of competences following the concept of "nature of science",[62] students should formulate hypotheses before they conduct the experiments and discuss these hypotheses while evaluating the experiments. Several experiments on the subject of "amino acids and proteins" were tested and developed in the laboratory (for details, see Appendix 2). For the experiments, samples of four grain legumes were provided by the Leibniz Centre for Agricultural Landscape Research (ZALF): white lupin variety "All White," narrow-leaved lupin variety "Probor", and the chickpea varieties "Nero" (Desi type) and "Orion" (Kabuli type). The company Prolupin GmbH provided the lupin protein isolate, which is used, e.g., in lughurt (a yoghurt with proteins from lupin). The experiments were also tested with supermarket products (hummus, canned chickpeas, canned sweet lupin, yoghurt, lupin drink, and lughurt) in order to take into account the relevance of the students' everyday life and to ensure that the experiments can be used for chemistry lessons if there are neither grains nor protein isolates available. In total, nine experiments have been

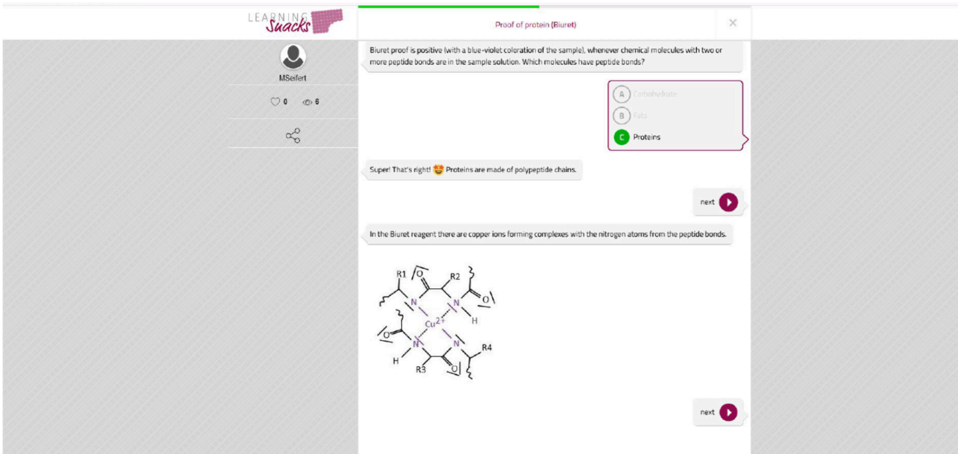

Figure 4. Screenshot of the support for experiment "detection of proteins (Biuret)".

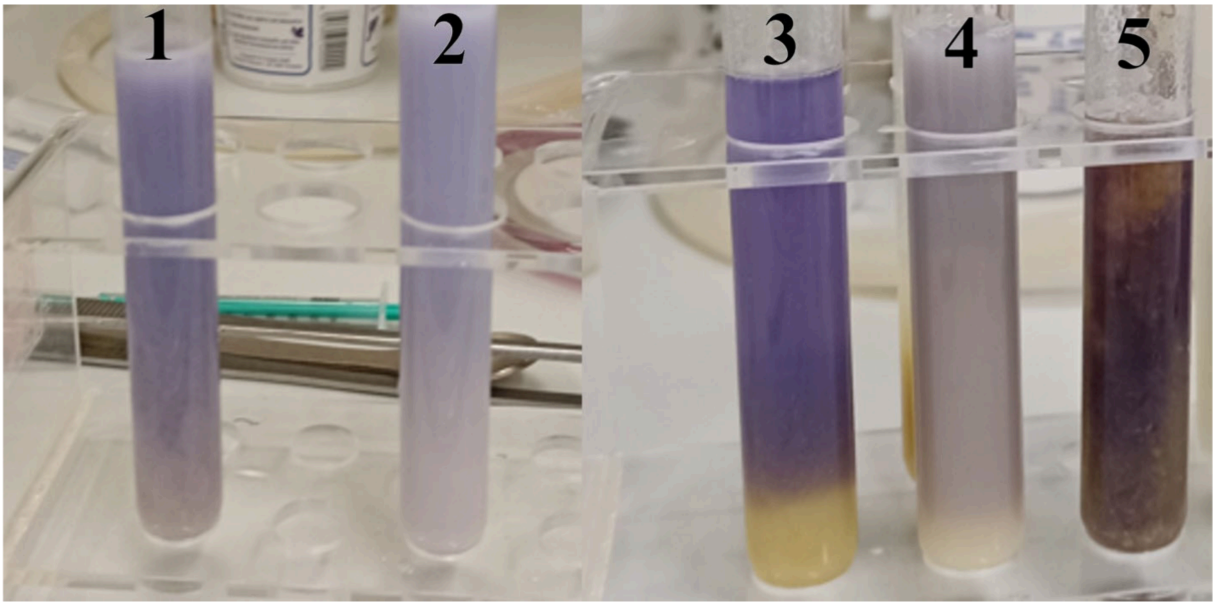

Figure 5. Results of the experiment (Biuret) (private; author M.S.). 1: hummus, 2: Natur Lughurt, 3: Canned chickpeas, 4: LUVE Natur Drink, 5: Canned sweet lupin.

conducted. However, only four are suitable for chemistry lessons at school (see Table 1). The other experiments either had too few visual effects or needed high concentrations of acid, which is problematic (or not allowed) for lessons at secondary schools. For details, see Appendix 2.

For all experiments, worksheets have been developed. To support students in discussing the results of the experiments, interactive support, which is available via QR codes, was created online on the Learning Snacks learning platform (see Figure 4). If the pupils do not have (or are not allowed to use) devices for accessing the QR codes, the support can also be made available via a school computer or printed on paper by the teacher.

The experiment "detection of proteins (Biuret)" achieved clear test results both with the samples provided by the ZALF (can be replaced by all other chickpea and lupin grains) and with the supermarket products. Depending on the amount of protein in the food, the color depth varied (see Figure 5); the more protein there was, the more intense the color. In order to compare the intensity of reactions with the amount of protein, pupils can be provided with (or brought by the pupils) various vegetable and animal foods, which are then tested experimentally. Before experimenting, the students are asked to formulate their own, verifiable question, such as "Does the intensity of the violet color of the test solution depend on the protein content of the food sample?". The daily life of the students is taken into account by these individually formulated questions, which should be motivating. Methodical variance can also be provided by changing between partner and group work.

The experiment "denaturization by heating and bases" achieved good results for the experiments with plant proteins. The color changes of the universal indicator paper were clearly visible. Before experimenting, the students can formulate a hypothesis, by applying their knowledge on acids and bases, about what to expect if ammonia is released. The experiment "detection of amino acids (ninhydrin)" is also suitable due to the short duration of the experiment and the clear blue-violet coloring that can be observed. However, vinyl gloves should be worn during the experiment as the ninhydrin solution reacts on

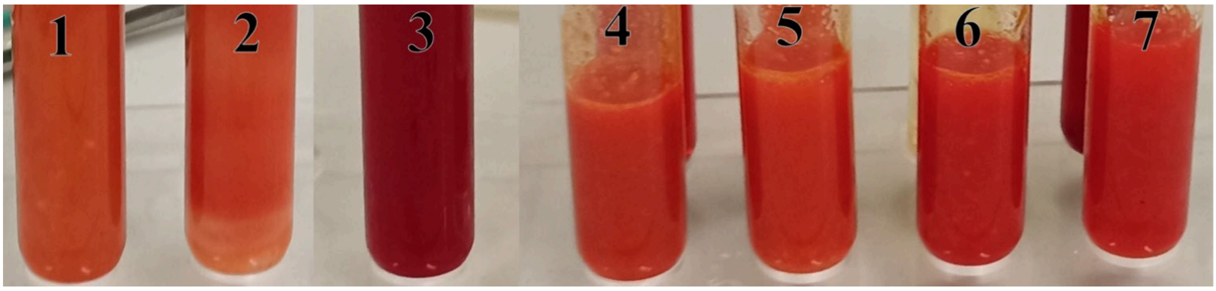

Figure 6. Results of the experiment "azo dyes based on aromatic amino acids" (private; author M.S.). 1: Hummus, 2: LUVE Natur Lughurt, 3: isolated lupine protein, 4: chickpea variety "Orion", 5: chickpea variety "Nero", 6: white lupin, 7: blue lupin

contact with the skin and leaves a temporary stain. The individual steps of the experiment are independently created by the students, supported by the materials, to support the development of research competences as intended by the concept of "nature of science".[62] The vegetable foods used showed a different intensity of color, which is not due to the protein content; for example, lughurt gave a more intense color impression than the lupine drink used, although it contains more protein. Other ingredients in the food are probably responsible for this. Depending on the research question, the teacher should decide whether to discuss these results with the students and choose the foods used accordingly. If the food sample contains proteins with aromatic amino acids, then azo dyes can be synthesized. Depending on the food sample, the color is more or less intense (see Figure 6). During the experiment, different observations can be made. Therefore, a photo protocol of the experiment can be recommended. Depending on the aromatic amino acids, different colors are obtained. Therefore, additionally, a task on different azo dyes is included in the material. As a support, a Learning Snack scaffold is available.

EVALUATION OF THE MATERIALS

All materials have been evaluated by students (preservice chemistry teachers) ($N = 15$) of the master course "chemistry lessons for heterogeneous learning groups"[63] in summer term 2024. All students have taught at school either during internships in their studies or as a substitute teacher due to the great shortage of teachers in Germany. The course has a clear focus on planning chemistry lessons and developing suitable materials. During the course, the students repeatedly have evaluated materials, either by using their own criteria or commenting on given items. Due to this focus in the course and their own teaching experience, the students have the required competencies for evaluating materials and concepts for chemistry education at school. During the term, the students receive each week a task that they solved at home, either alone or in small groups. In one week, instead of this task, the students were asked to evaluate the materials presented here (Appendix 1). The students received all materials (online via the Moodle course) and a questionnaire with a 4-item Likert scale (forced choice option[64]) and open questions (printed on paper) (Appendix 3). The evaluation sheet consists of the following categories: materials, international celebration days, repetition, questions and hypotheses, experiments, jigsaw, and WebQuest. The evaluation was anonymous and voluntary; 15 students (of 16 students enrolled in the course) participated actively in the evaluation and returned the completed evaluation sheet. The students were informed on the use of the data. As a thank-you for their work, they received all materials in German. Table 2 gives a summary for the students' rating (for all results, see Appendix 3). For the lowest and highest arithmetic mean, a description of the respective item is added in parentheses.

Table 2. Summary of the Results of Students' Rating of the Materials

Materials	Range of students' rating (four item Likert scale); arithmetic means (description of the item)
Students' understanding of all materials	3.46 (WebQuest) − 3.93 (chemicals and glass equipment)
Use of international celebrations day as a context	3.27 (suitable as introduction) − 3.73 (poster as presentation type)
Repetition of the topics "proteins and amino acids"	3.50 (games suitable for self-regulated learning) − 3.87 (most important content on the topic)
Questions and hypotheses	3.40 (impulses for own questions) − 3.87 (clearly formulated questions)
Experiments	3.60 (use of stepped supporting tools[65] in own lessons) − 3.87 (instructions clearly understandable)
Jigsaw teaching technique	3.27 (suitable for heterogeneous learning groups) − 3.87 (fits the topic)
WebQuest	3.00 (securing results/flyer close to everyday life) − 3.73 (innovative topic fits real-life topic)

The results of the students' rating of all items show that the arithmetic means range between agree and strongly agree (arithmetic means 3.00−3.93). The biggest differences in the evaluation occurred in the rating of the "WebQuest" material. Here, for two items, the arithmetic mean is only 3.00 (just in the range of agree), which can be explained by personal preferences of the students. Overall, this method is not very common in chemistry lessons, which can also be one explanation for the differentiated rating. The best ratings were given for the material "experiments". Here, no student disagreed. All students would use the experimental instructions and the accompanying support (designed with the tool learningsnacks[66]) in their own chemistry lessons. Not all students used the opportunity "What else I would like to say regarding...". Summarizing, tips for other designs were given, and the games were rated as suitable as well as not suitable for heterogeneous groups; here, it can be assumed that students' personal experiences with heterogeneous groups influence their rating. Some texts were rated as too big, and for the WebQuest a different form of presentation than flyer was recommended (five times) because it was rated as old-fashioned. However, considering all ratings and the open answers, the materials and methods were rated as suitable for chemistry lessons on the topic.

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J. Chem. Educ. 2025, 102, 84−93

■ LIMITATIONS

For the materials described and discussed in this paper, a few limitations must be taken into account. All materials were developed by one person (the first author) but were discussed repeatedly with the corresponding author. The experiments were developed also only by the first author. Here also practical issues have been discussed repeatedly with the corresponding author. A lot of time and effort were also invested in the development of the experiments, resulting in four experiments that are suitable for the topic and for use at school. All materials were then evaluated once by 15 preservice chemistry teachers because there were no more students available. Unfortunately, it was not possible to use the materials in a school with the target group, which is the main limitation of the work discussed in this paper.

■ CONCLUSIONS AND OUTLOOK

The novel teaching materials and experiments on chickpea and lupin were rated as being suitable for dealing in detail with the subject of plant proteins in the classroom in higher secondary school (age 16–18). Contexts such as "climate change", "sustainability", and "nutrition" could also be explored using the results of the experiments. The materials can be expanded individually depending on the curriculum. Due to their subject matter, the materials can be used very well for connecting subjects (for example, chemistry with biology, economy, geography, or politics). The materials in the interaction box can be used in several instructional settings, as discussed before.

The materials focus on plant-based proteins for nutrition using the examples of chickpeas and lupins. By focusing on this topic in chemistry lessons, the students can discuss the shift from plant-based proteins to animal-based proteins and the consequences not only for their own diet but also for the environment, here especially the positive influence on climate change by reducing the amount of CO_2 emissions by replacing animal-based proteins with plant-based proteins. When these proteins are used, the experiments themselves also contribute to a reduction of CO_2 emissions. The amount of protein in various foods can be examined, as the color intensity changes according to the amount (for example in the Biuret experiment). The results can then again form the basis for discussions, for example, for the question "which food or what amount of food is needed for a healthy diet?". In dry regions, the cultivation of chickpeas and lupins is advantageous because these crops require less rain. Strategies for dealing with climate change in agriculture can therefore also be discussed.

The materials are also suitable for use in heterogeneous learning groups because a variety of materials and learning games are available, which allows the students to manage their own learning process. They can also decide individually which games they want to use for repeating content on proteins and amino acids. For this, not only the content but also the type of game varies. For example, there are matching games and crosswords.

The interaction box can be expanded with cooking recipes for cooking with lupines and chicken peas or with current information from media, for example, TV, magazines, or newspapers. The recipes can be designed, for example, as gap-filling exercises.[14] For the use of the media information, a game or a crossword can also be designed for applying this information. After finishing the work in the box, the students can use their results for a discussion. If teachers want to use the materials, local references (for example, regional cultivation and research or food brands) should be replaced by local references in their own region or country. A description of how to make lupine milk from lupine seed is available in Appendix 2 if lupine milk or yogurt is not available in a local supermarket. Another possibility is using other vegan protein products, for example, yoghurt made from field beans (included in the interaction box; see Figure 3). For chemistry lessons in languages other than English, the materials should be translated. Teachers who want to use the German materials should contact the corresponding author.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.4c00131.

Appendix 1: The content of the interaction box (PDF, DOCX)

Appendix 2: Details on the experiments (PDF, DOCX)

Appendix 3: The evaluation of the materials (questionnaire and results) (PDF, DOCX)

Appendix 4: Information on proteins: requirements, content in various foods, and differences between animal vs plant-based proteins (PDF, DOCX)

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Notes

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REFERENCES

(1) Scott, A. BASF targets sustainable products. *C&EN* **2023**, *101*, 11.
(2) UNESCO: Education for Sustainable Development – A roadmap, 2020. Available online at https://unesdoc.unesco.org/ark:/48223/pf0000374802.locale=en (accessed August 2024).
(3) UNESCO - Deutsche UNESCO-Kommission: UNESCO-Programm "BNE 2030", 2021. Available online at https://www.unesco.de/bildung/bildung-fuer-nachhaltige-entwicklung/unesco-programm-bne-2030 (accessed August 2024).
(4) https://ourworldindata.org/grapher/ghg-per-protein-poore (accessed August 2024).
(5) Senatsverwaltung für Bildung, Jugend und Familie Berlin and Ministerium für Bildung, Jugend und Sport des Landes Brandenburg: Rahmenlehrplan für die gymnasiale Oberstufe Teil C [curriculum for chemistry at higher secondary level] Available online at https://bildungsserver.berlin-brandenburg.de/fileadmin/bbb/unterricht/rahmenlehrplaene/gymnasiale_oberstufe/curricula/2022/Teil_C_RLP_GOST_2022_Chemie.pdf (accessed August 2024).
(6) Versprille, A.; Zabih, A.; Holme, T. A.; McKenzie, L.; Mahaffy, P.; Martin, B.; Towns, M. Assessing student knowledge of chemistry and climate science concepts associated with climate change: resources to inform teaching and learning. *J. Chem. Educ.* **2017**, *94* (4), 407–417.
(7) Finkenstaedt-Quinn, S. A.; Hudson-Smith, N. V.; Styles, M. J.; Maudal, M. K.; Juelfs, A. R.; Haynes, C. L. Expanding the educational toolset for chemistry outreach: providing a chemical view of climate change through hands-on activities and demonstrations supplemented with TED-Ed videos. *J. Chem. Educ.* **2018**, *95* (6), 985–990.
(8) Mahaffy, P. G.; Holme, T. A.; Martin-Visscher, L.; Martin, B. E.; Versprille, A.; Kirchhoff, M.; McKenzie, L.; Towns, M. Beyond "inert" ideas to teaching general chemistry from rich contexts: visuazlizing the chemistry of climate change (VC3). *J. Chem. Educ.* **2017**, *94* (8), 1027–1035.
(9) Wilson, P.; Duarte, N.; Harris, T.; Sayers, T.; Weinrich, M. Analysis of climate change in general chemistry textbooks. *J. Chem. Educ.* **2024**, *101* (4), 1435–1441.
(10) Wan, Y.; Ding, X.; Yu, H. Pre-service chemistry teachers' understanding of knowledge related to climate change. *Chem. Educ. Res. Pract.* **2023**, *24*, 1219–1228.
(11) Kim, J. Exploring climate change through experiential learning activities for nonscience majors. *J. Chem. Educ.* **2024**, *101*, 4037.
(12) Igboanugo, B. I.; Naiho, O. I. Effectiveness of inquiry-based chemistry learning on students' attitudes and knowledge of climate change mitigation behaviors. *J. Chem. Educ.* **2024**, *101*, 3318.
(13) Wang, X.; Liu, Y. Engaging K–8 preservice science teachers through an NGSS-Based climate change project. *J. Chem. Educ.* **2022**, *99* (3), 1287–1295.
(14) Liang, Y.; Xiao, Z.; Wang, S.; Li, Y.; Li, H. An interdisciplinary practical project for preservice science teachers: Visualizing climate change based on systems thinking. *J. Chem. Educ.* **2024**, *101* (7), 2682–2692.
(15) Clark, T. M.; Clark, C. T.; Jeong, S.; Cervenec, J. Using content area reading to support an interdisciplinary storyline involving climate science. *J. Chem. Educ.* **2024**, *101*, 3823.
(16) Aubrecht, K. B. Teaching relevant climate change topics in undergraduate chemistry courses: Motivations, student misconceptions, and resources. *Curr. Opin. Green and Sustain. Chem.* **2018**, *13* (13), 44–49.
(17) Wilson, P.; Sayers, T.; Weinrich, M. Survey of United States undergraduate chemistry Instructors' perspectives on teaching climate change. *J. Chem. Educ.* **2024**, *101* (7), 2630–2643.
(18) Hermanns, J.; Keller, D. School-related content knowledge in organic chemistry - How different school curricula should be considered for the development of tasks. *Progress in Science Education* **2019**, *2* (1), 17–27.
(19) Parchmann, I.; Grasel, C.; Baer, A.; Nentwig, P.; Demuth, R.; Ralle, B. "Chemie im Kontext": a symbiotic implementation of a context-based teaching and learning approach. *Int. J. Sci. Educ.* **2006**, *28* (9), 1041–1062.
(20) Schumacher, R.; Stern, E. Promoting the construction of intelligent knowledge with the help of various methods of cognitively activating instruction. *Front. Educ.* **2023**, *7*, 979430.
(21) Earth Science Communications Team at NASA's Jet Propulsion Laboratory | California Institute of Technology. Available online at https://climate.nasa.gov/effects/ (accessed August 2024).
(22) Fanzo, J.; Davis, C.; McLaren, R.; Choufani, J. The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security* **2018**, *18*, 12–19.
(23) Seifert, M. Entwicklung von Unterrichtsmaterialien zum Thema pflanzliche Eiweißquellen am Beispiel von Lupinen und Kichererbsen [development of materials for chemistry lessons on the topic plant proteins on the example of lupins and chickpeas]. Bachelor thesis, Universität Potsdam, Germany, 2023.
(24) Watson, C.; Reckling, M.; Preissel, S.; Bachinger, J.; Bergkvist, G.; Kuhlman, T.; Lindström, K.; Nemecek, T.; Topp, C.; Vanhatalo, A.; Zander, Z.; Murphy-Bokern, D.; Stoddard, F. Grain legume production and use in European agricultural systems. *Adv. Agron.* **2017**, *144* (1), 235–303.
(25) Reckling, M.; Bergkvist, G.; Watson, C. A.; Stoddard, F. L.; Zander, P. M.; Walker, R.; Pristeri, A.; Toncea, I.; Bachinger, J. Trade-offs between economic and environmental impacts of introducing legumes into cropping systems. *Frontiers in Plant Science* **2016**, *7*, 669.
(26) Groeneveld, M.; Müller, C. Hülsenfrüchte: Gesund essen. Was macht Hülsenfrüchte so wertvoll? [Pulses: Eating healthily. What makes pulses so valuable?] Bundeszentrum für Ernährung. Available online at https://www.bzfe.de/lebensmittel/vom-acker-bis-zum-teller/huelsenfruechte/huelsenfruechte-gesund-essen/ (accessed August 2024).
(27) Erbersdobler, H. F.; Barth, C. A.; Jahreis, G. Legumes in human nutrition: nutrient content and protein quality of pulses. *Ernährungs Umschau* **2017**, *64* (9), 134–139.
(28) Statistisches Bundesamt (Destatis). Land- und Forstwirtschaft, Fischerei, Landwirtschaftliche Bodennutzung. Anbau auf dem Ackerland [Agriculture and forestry, fishing, agricultural land use. Cultivation on arable land]; 2030312228004; 2022. Available online at https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Publikationen/Bodennutzung/anbau-ackerland-vorbericht-2030312228004.html (accessed August 2024).
(29) Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V. (Hrsg.) ZALF-Wissenschaftler in die Steuerungsgruppe des "Fachforums Leguminosen" der Deutschen Forschungsallianz berufen [ZALF scientist appointed to the steering group of the "Legume Expert Forum" of the German Research Alliance] https://www.zalf.de/de/aktuelles/Seiten/PB2/Fachforum-Leguminosen.aspx (accessed August 2024).
(30) Ferreira, H.; Pinto, E.; Vasconcelos, M. W. Legumes as a cornerstone of the transition toward more sustainable agri-food systems and diets in Europe. *Front. Sustain. Food Syst.* **2021**, *5*, 694121.
(31) Semba, R. D.; Rahman, N.; Du, S.; Ramsing, R.; Sullivan, V.; Nussbaumer, E.; Love, D.; Bloem, M. W. Patterns of legume purchases and consumption in the United States. *Front. Nutr.* **2021**, *8*, 732237.
(32) Hughes, J.; Pearson, E.; Grafenauer, S. Legumes – A comprehensive exploration of global-food-based dietary guidelines and consumption. *Nutrients* **2022**, *14*, 3080.
(33) Reckling, M.; Albertsson, J.; Vermue, A.; Carlsson, G.; Watson, C. A.; Justes, E.; Bergkvist, G.; Jensen, E. S.; Topp, C. F. E. Diversification improves the performance of cereals in European cropping systems. *Agronomy for Sustainable Development* **2022**, *42*, 118.
(34) Elsalahy, H. H.; Reckling, M. Soybean resilience to drought is supported by partial recovery of photosynthetic traits. *Frontiers in Plant Science* **2022**, *13*, 971893 DOI: 10.3389/fpls.2022.971893.

(35) Karges, K.; Bellingrath-Kimura, S. D.; Watson, C. A.; Stoddard, F. L.; Halwani, M.; Reckling, M. Agro-economic prospects for expanding soybean production beyond its current northerly limit in Europe. *Eur. J. Agron.* **2022**, *133*, 126415.

(36) Wang, N.; Hatcher, D. W.; Toews, R.; Gawalko, E. J. Influence of cooking and dehulling on nutritional composition of several varieties of lentils (Lens culinaris). *LWT − Food Science and Technology* **2009**, *42* (4), 842−848.

(37) Hanelt, P. *Die Lupinen. Zur Botanik und Geschichte landwirtschaftlich wichtiger Lupinenarten [The lupins. On the botany and history of agriculturally important lupin species]*; Ziemsen: Wittenberg, Germany, 1960.

(38) Wehling, P.; Böhme, A. Standortanforderungen und Anbau von Lupinen [Site requirements and cultivation of lupins]. In *Lupinen. Anbau und Verwertung*; Gesellschaft zur Förderung der Lupine (G.F.L.), 2016, 7−19.

(39) Notz, I.; Reckling, M. Why farmers grow lupin. Insights from a survey of German farmers. *Legumes Translated Practice Note* **2022**, *70*, 1−5.

(40) Priepke, A.; Gefrom, A. Verwertungsmöglichkeiten der Lupine [Utilization options for lupins]. In *Lupinen. Anbau und Verwertung*; Gesellschaft zur Förderung der Lupine (G.F.L.), 2016, 42−55.

(41) van der Maesen, L. J. G.; Cicer, L. *A monograph of the genus, with special reference to the chickpea (cicer arietinum), its ecology and cultiviation*; PhD thesis, Landbouwhogeschool te Wageningen, The Netherlands, 1972.

(42) Hof-Kautz, C. *Körnerleguminosen im Ökolandbau. Die Sorten 2022 [Grain legumes in organic farming. The varieties 2022].* Ministerium für Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen, 2022. Available online at https://www.oekolandbau.nrw.de/fachinfo/pflanzenbau/ackerbau/koernerleguminosen-im-oekolandbau-die-sorten-2022 (accessed August 2024).

(43) Klaiss, M.; Wendling, M. Körnerleguminosen: Ergebnisse der Kampagne 2021 [Grain legumes: results of the campaign 2021]. Bioaktuell.ch., 2021. Available online at https://orgprints.org/id/eprint/44749/1/klaiss-wendling-2022-bioaktuellch-Koernerleguminosen_%20Ergebnisse-der-Kampagne2021.pdf (accessed August 2024).

(44) Bayerische Landesanstalt für Landwirtschaft (Hrsg.) Kichererbse. Anbau und Verwertung [Chipea: cultivation and use]. Available online at https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/059723_kichererbse.pdf (accessed August 2024).

(45) Notz, I.; Topp, C. F. E.; Schuler, J.; Alves, S.; Gallardo, L. A.; Dauber, J.; Haase, T.; Hargreaves, P. R.; Hennessy, M.; Iantcheva, A.; Jeanneret, P.; Kay, S.; Recknagel, J.; Rittler, L.; Vasiljević, M.; Watson, C. A.; Reckling, M. Transition to legume-supported farming in Europe through redesigning cropping systems. *Agronomy for Sustainable Development* **2023**, *43*, 12.

(46) Reckling, M.; Döring, T. F.; Bergkvist, G.; Stoddard, F. L.; Watson, C. A.; Seddig, S.; Chmielewski, F.-M.; Bachinger, J. Grain legume yields are as stable as other spring crops in long-term experiments across northern Europe. *Agronomy for Sustainable Development* **2018**, *38*, 63.

(47) Lamichhane, J. R.; Alletto, L.; Cong, W.-F.; Dayoub, E.; Maury, P.; Plaza-Bonilla, D.; Reckling, M.; Saia, S.; Soltani, E.; Tison, G.; Debaeke, P. Relay cropping for sustainable intensification of agriculture across temperate regions: Crop management challenges and future research priorities. *Field Crops Research* **2023**, *291*, 108795.

(48) Springmann, M.; Clark, M. A.; Rayner, M.; Scarborough, P.; Webb, P. The global and regional costs of healthy and sustainable dietary patterns: A modelling study. *Lancet Planet. Health* **2021**, *5*, e797−e807.

(49) Alexy, U.; Fischer, M.; Weder, S.; Längler, A.; Michalsen, A.; Keller, M. Food group intake of children and adolescents (6−18 years) on a vegetarian, vegan or omnivore diet: results of the VeChi Youth Study. *Br. J. Nutr.* **2022**, *128*, 851−862.

(50) Bali, A.; Naik, R. The Impact of a Vegan Diet on Many Aspects of Health: The Overlooked Side of Veganism. *Cureus* **2023**, *15* (2), No. e35148.

(51) Rudloff, S.; Bührer, C.; Jochum, F.; Kauth, T.; Kersting, M.; Körner, A.; Koletzko, B.; Mihatsch, W.; Prell, C.; Reinehr, T.; Zimmer, K.-P. Vegetarian diets in childhood and adolescence. Position paper of the nutrition committee, German Society for Paediatric and Adolescent Medicine (DGKJ). *Molecular and Cellular Pediatrics* **2019**, *6*, 4.

(52) Nentwig, P. M.; Demuth, R.; Parchmann, I.; Gräsel, C.; Ralle, B. *Chemie im Kontext*: Situating learning in relevant contexts while systematically developing basic chemical concepts. *J. Chem. Educ.* **2007**, *84* (9), 1439−1444.

(53) American Chemical Society. *ChemCom: Chemistry in the Community*, 2nd ed.; Kendal/Hunt: Dubuque, IA, 1993.

(54) Salters Advanced Chemistry Project. *Chemical Storylines; Chemical Ideas; Activities and Assessment Pack*; Heinemann Education: Oxford, UK, 1994.

(55) Osborne, J.; Simon, S.; Collins, S. Attitudes towards science: a review of the literature and its implications. *Int. J. Sci. Educ.* **2003**, *25* (9), 1049−1079.

(56) Jegstad, K. M. Inquiry-based chemistry education: a systematic review. *Studies in Science Education.* **2024**, *60*, 251.

(57) Orosz, G.; Németh, V.; Kovács, L.; Somogyi, Z.; Korom, E. Guided inquiry-based learning in secondary-school chemistry classes: a case study. *Chem. Educ. Res. Pract.* **2023**, *24*, 50−70.

(58) Ferreira, M. D.; Sentanin, F. C.; Parra, K. N.; Bonini, V. M. N.; de Castro, M.; Kasseboehmer, A. C. Implementation of inquiry-based science in the classroom and its repercussion on the motivation to learn chemistry. *J. Chem. Educ.* **2022**, *99* (2), 578−591.

(59) Hermanns, J. Eine Interaktionsbox zum Thema "Thermodynamik" [An interaction box on the topic "thermodynamics"]. *PdN-Ch.* **2010**, *59* (1), 6−11.

(60) Hermanns, J. Lebensmittelkonservierung früher und heute - eine Interaktionsbox zum Thema "Konservierungsstoffe" [Food preservation in the past and today - an interaction box on the topic of "preservatives"]. *PdN-Ch.* **2014**, *63* (1), 32−36.

(61) Banerji, A.; Schönbein, A.-K.; Wolff, J. OLED Reloaded: Die Synthese des Halbleiterpolymers MEH-PPV als Schulversuch [The synthesis of the semiconductor polymer MEH-PPV as a school experiment]. *CHEMKON* **2017**, *24* (4), 251−256.

(62) McComas, W. F., Ed. *The nature of science in science education: rationales and strategies.* Kluwer Academic Publishers: Dordrecht, The Netherlands, 1998.

(63) Hermanns, J. Lehr-Lern-Formate für heterogene Lerngruppen im Chemieunterricht am Beispiel einer Lehrveranstaltung für Master-Lehramtsstudierende. In Niesta-Kayser, D., Giera, W.-K., Schmalenbach, C., Eds.; *Gleichberechtigte Teilhabe durch kooperative Lehr-Lernprozesse in heterogenen Lerngruppen*; Waxmann: Münster, 2024, 215−227.

(64) Allen, E.; Seaman, C. Likert scales and date analyses. *Quality Progress* **2007**, *7*, 64−65.

(65) Hermanns, J.; Schmidt, B. Developing and applying stepped supporting tools in organic chemistry to promote students' self-regulated learning. *J. Chem. Educ.* **2019**, *96* (1), 47−52.

(66) https://www.learningsnacks.de (accessed August 2024).

https://doi.org/10.1021/acs.jchemed.4c00131
J. Chem. Educ. 2025, 102, 84−93