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Connecting Chemical Worlds – Context-based Learning Co-developed

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Abstract: Chemistry as well as chemistry education often raise two different perceptions among non-experts: Chemistry (education) provides spectacular phenomena, experiments and entertainment, but is also perceived as incorporating high levels of risk and many different facts and rules. Students and teachers get more authentic insights and perceptions of the broad spectrum of science tasks, activities and people when working together with scientists, whereas scientists can better understand teachers´ and students´ perspectives with regard to content interests and learning processes at school and beyond.

Keywords: Chemical education · Context-based learning · RIASECN

Introduction

Chemistry as well as chemistry education often raise two different perceptions among non-experts: Chemistry (education) provides spectacular phenomena, experiments, and entertainment, but is also perceived as incorporating high levels of risk and many different facts and rules. The latter is for many connected to school memories of anxiety or boredom. Chemists, of course, do not regard those facets of chemistry as controversial; they know how to connect knowledge and phenomena and how to deal with risks and complex requirements. They see and know the high relevance of chemistry almost everywhere, in life and nature, in society and also in every person's daily life. How could education also make this relevance and enjoyment of seeing and explaining phenomena based on chemical thinking more visible and appealing for more people, students as well as adults?

The grand challenge for chemistry education, however, is not to develop teaching and learning approaches with regard to this overarching goal. Conceptual frameworks such as STS (science – technology – society), CBL (context-based learning), or challenge-oriented learning exist and have broadly been explored in chemistry education research and practice in many countries.[1,2] Structures and approaches to implement context-based learning into regular science or chemistry curricula have also been developed and applied in programs for development and teacher professional development (*e.g.* ref. [3]; see also Table 1 as an example of how to connect contexts and basic concepts).

So, if such frameworks exist, why does chemistry education still comprise rather negative perceptions for many school students and (future) adults instead of curiosity and motivation? Are teaching regulations, such as not enough time, restrictions for change? Does teacher education fail to highlight the relevance of making chemistry education relevant for students? Or is the contextualization of a content still not enough to really connect perspectives within and of chemistry to students' current and future lives?

This article reflects challenges beyond chemical content as a summary of a presentation given at the Swiss Chemical Society meeting 'The Future of Chemical Education, ChemEdu 2023' in Bern in August 2023. Discussion questions from the audience are included at the end, the authors would like to thank all participants for their worthwhile contribution!

Beyond Content – Further Challenges in Focus

A Choice of Content Needs Negotiation of Goals – Why Should Anyone Learn about Chemistry?

A suitable and relevant choice of content is the foundation for any design of teaching and learning. Of course, curricula set a framework for this, but they often still leave room for choice and design. Every school student must learn about acids and bases, to give one example, but the decision on how to teach basic content is often left to a school team or individual teachers. Should students investigate structure–property relations based on inquiry learning schemes? Should they be able to see the use of acids and bases in their own lives, like food and health? Should they become competent in understanding the acidification of oceans and changes in ecosystems and climate? Time for teaching and learning is never enough to cover all aspects that might be interesting for some and relevant for others. A negotiation of goals is necessary to make a fruitful choice for the design of a curriculum, unit or lecture: Which content might stimulate a particular group of students' interests and pre-conceptual knowledge and beliefs best? How is a content related to daily-life experience, societal discussions or future career or engagement opportunities (see also ref. [4])? To which degree is a content necessary for future learning?

The Model of Educational Reconstruction[5] provides a suitable framework for such negotiations and has been applied in many studies and curriculum development approaches. It connects analyses of conceptual developments over time in the history of science up to today's science processes and compares those with equivalent analyses of students' conceptual ideas and further perspectives. This connection forms the foundation for the negotiation of content and the design of learning processes (Fig. 1).

Considering how relevant a content might be, *e.g.* with regard to societal debates, the connectivity between contextual aspects

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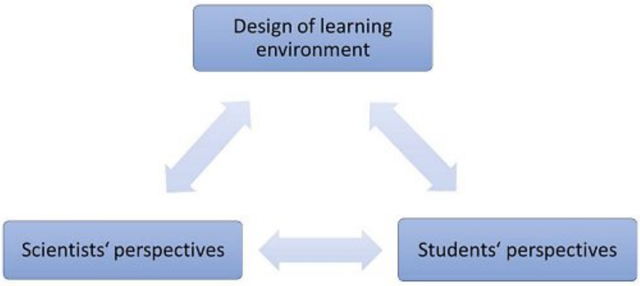

Fig. 1. Basis framework of the Model of Educational Reconstruction.[5]

and conceptual understanding is helpful. Table 1 shows how the role of the oceans in the climate system can be used to develop and apply basic conceptual understanding about chemical equilibrium. A fruitful connection supports the learning *of* chemistry *via* relevant contexts, but also learning *through* chemistry about contexts of relevance for *e.g.* societal debates.

Activities Form Interests – What Do Scientists really Do?

Content and contexts can raise curiosity and situational interest. However, a sustainable development of individual interests needs more than initial curiosity.[6] Students engage in different activities such as sports, music or science over the time of their early childhood and school experience. Which activities do they meet within science? The main focus of school science still seems to be the learning of science concepts, inquiry-based approaches are also well known and somewhat implemented in science learning.[7] However, real science offers further perspectives for learning science content through an even broader field of activities. Based on analyses of science experts' tasks, and on models of the so-called 'nature of science',[8,9] we have adapted a model which is used in career orientation: Our adaptation of Holland's well-known RIASEC model provides a framework (Fig. 2) for the design and analyses of activities for school students in science or chemistry. Activities could range and point out hands-on experiments based on existing descriptions (realistic), a development of new approaches for projects and investigations (investigative), visual designs of molecules or data findings (aesthetic), projects with younger groups of students (social) or with peers (networking), developing ideas for products (enterprising) or working with data (conventional – leading, perhaps, towards a future data science thinking category?). The broader the spectrum of activities related to science in learning contexts and in (future) professional or societal engagement contexts can be, the more likely it is that students with different interests and abilities relate their own perspectives to science and become interested in science learning. They will not all become chemists in the future, but they might develop more positive relations to chemistry and apply better knowledge in many different professional careers, such as politics or economy among others.

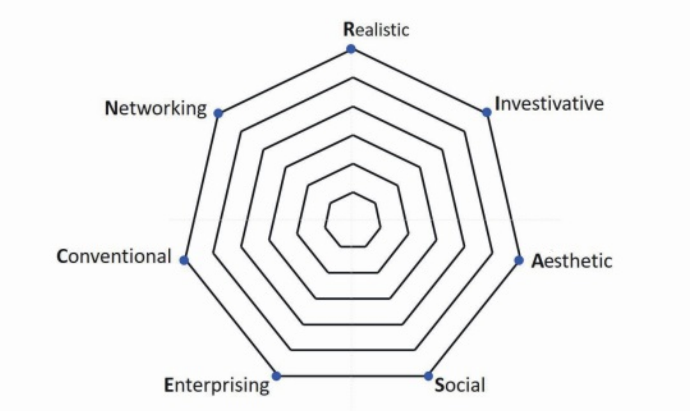

Fig. 2. Adapted RIASECN framework.[6]

Studies on students' interest based on this model have shown that students being engaged in science, *e.g.* participants in Science Olympiads, show especially high interests in activities related to investigations, social engagement and networking.[10] Studies analyzing interactions of interest and understanding have pointed out that interests again in those dimensions are positively related to learning outcomes,[11] potentially due to the high cognitive activities needed for planning an investigation, for explaining something to others ('learning through teaching') or for discussing findings with peers. These results are promising and also point out the necessity to enlarge the spectrum of suitable learning activities far beyond rule learning of content knowledge.

Identity and Sense of Belonging – Would I Like to Be one of them?

Choosing a study program or a personal career path incorporates again more than enjoying an activity or being interested in a content. It often incorporates beliefs about people, prestige and others of the field in vision, and a negotiation with one's own perceptions of how one would like to be and of how peers and other related persons might like this field (so called self to prototype matching). Stereotypes therefore play an important role for an identity development and a choice of study or career (see *e.g.* for girls in competitions[12]), leading to a higher or lower perception of a sense of belonging. Explicit reflections on stereotypes and potential role models should therefore also be included in science learning, as already offered in enrichment activities and out-of-school learning. They can again be related to studies on motives: Van Vorst and Aydogmus[13] have identified three profiles of students pointing out different motives for choice in context-based learning: While for many students' personal relevance is most important, others are motivated by curiosity and their own interests as well as by surprising information. Assuming that the latter are also characteristics of professional scientists these might be a good starting point for further reflections on identities and stereotypes of scientists. An on-going project in our Kiel Science Network (https://www.kielscn.de/) investigates profiles of students

Table 1. Connectivity of contextual questions and conceptual understanding.

Contextual questions	Conceptual understanding
Where has the CO_2 disappeared?	Solubility of gases, incomplete reactions
Which conditions do oceans provide?	Impact of temperature and pressure, LeChatelier's law, reversibility of reactions, chemical equilibrium
How is CO_2 distributed in ocean systems?	Open and close systems, comparison of reality and experimental systems
Which role do oceans have, how might climate change affect ocean systems?	Application of chemistry for systems thinking

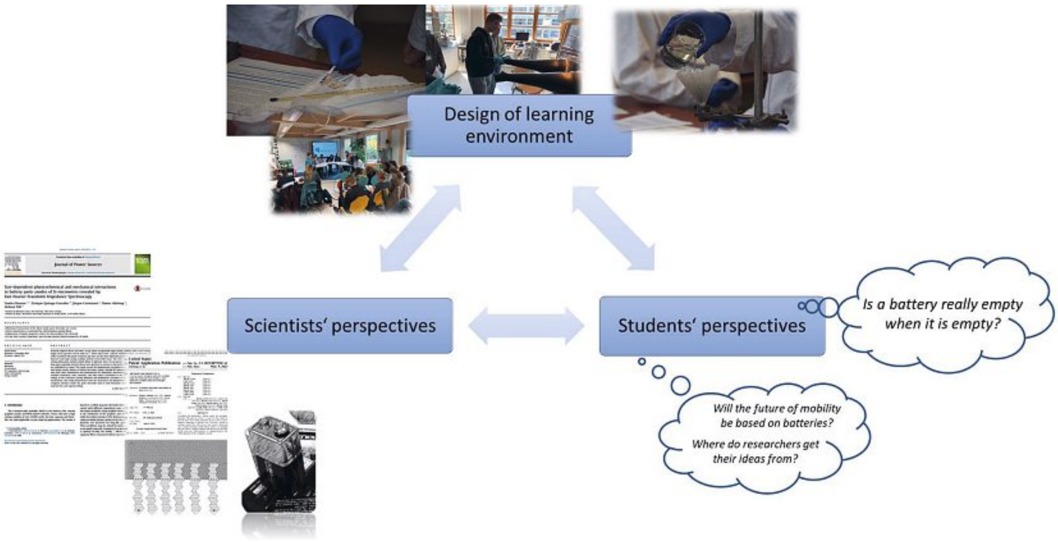

Fig. 3. Educational reconstruction of battery research as a topic for teaching and learning.

with regard to science communication and the appeal of different visual representations of science and scientists.

Learning from and with each other: Towards more Co-development of Context-based Learning

To better understand and highlight the real relevance of contexts and activities for learners on the one hand side, and of scientists' motives and identities on the other, cooperation among different stakeholders and co-developments are regarded as fruitful in science education and science communication. In our projects we have adapted different formats of co-development, all incorporating a close cooperation among scientists and science educators as well as practitioners, such as teachers or students. Some programs additionally involve design expertise, *e.g.* in the *KielSCN*. Thereby, the Model of Educational Reconstruction has been transformed into a cooperation model in those projects, with a changing focus for the science education researchers, moving from analyzing and developing content and learning environments only towards involving and connecting experts in addition. The following examples show this framework in action.

Future Mobility through Battery Developments?

Research on batteries and other energy storage devices are of high relevance for our current society, due to the trend towards electric cars and mobility. It is also a good example to show how science and society interact, and how conceptual understanding has developed over time. Historical findings indicate that first batteries like the 'Bagdad Battery" might have been developed and used long before any conceptual understanding of the underlying processes existed. That development, on the other hand, was driven by personal or societal demands as well, see *e.g.* the goal of coating vases and swords with metals thereby making them more stable for everyday life, but also by curiosity and phenomena. What fosters research on batteries today, what are the main challenges and achievements in our century? Battery researchers themselves can provide the most authentic insights in the current research, so one goal of our STEM Academy (*MINT-Akademie Schleswig-Holstein*) is to develop teaching materials and experiments based on current research questions for schools, connecting teachers and high school students with researchers (Fig. 3). In addition to traditional school subjects a course for project-based learning ('Profilseminar') has been implemented at upper secondary schools in Schleswig-Holstein. The STEM Academy developed a course structure that enables direct interaction and exchange among researchers and teachers in the phase of preparation and additionally of researchers and students during the course. This way, the students have always access to an expert and can ask questions. The approach combines context-based learning with inquiry approaches and offers activities for students along all RIASECN elements. Authentic insights into different environments, such as research labs, companies and also student learning labs are provided, as well as discussions on career perspectives by potential role models. Students' perspectives have been collected and integrated at the beginning of the course and can now be provided to future teachers joining the program.

First experiences have shown that students look for their own research question and interest by checking the news, doing internet research, interviews or talking to other role models. Most current high-school projects are based on the development and replacement of Li-ion batteries by sodium batteries or other alternative energy storage devices. The main focus of these projects is of course the perception of why sodium batteries are a good alternative to current battery devices, but additionally, trying to implement the material research and development by incorporating high amounts of sodium ions into materials. Like the real battery researchers in industry, the high-school students developed alternative and sustainable materials, always bearing in mind the economic and financial aspects of these batteries. This very interdisciplinary approach fosters not only interest, but also knowledge of chemistry (as well as the chemistry of materials), physics, and also other broader perspectives relating to society and environment. The students engaged and discussed challenges and opportunities and relate directly to these school topics, trying to enhance this interest also in extracurricular activities. Hence, by investigating actual battery materials, researchers and high-school students analyze their functionalities and challenges. Starting from this gained knowledge, they try to adopt and optimize these materials by using basic school concepts like structure–property relations to increase the battery capacity. For researchers, their daily work includes working with experimental results and their interpretation. Most likely, they have to repeat their experiments, or do other most complimentary characterization techniques in order to investigate and understand their own experimental results. At first glance, it is mostly not clear what the results mean and how to continue their research leaving the researchers with open questions. This experience was often not included in students' perception of research and researchers, having to deal with it every day. Having an independent project in school like in the 'Profilseminar' introduces high-school students in many ways to authentic research. First feedback indicates: "[…] research is working with experimental results and coping with failure during these experiments…" (a student's answer in the evaluation, grade 12). Others pointed out that authentic research includes structuring the daily work in order to be more efficient, relating this also personally for their own schoolwork. Overall, those first experiences have shown high motivation for insights into authentic research settings. Visits to research environments or by researchers coming to school indicate results of broader perspectives on science research by students, compared to programs without such interaction. An evaluation instrument for investigating students' self-efficacy perception for different areas of competencies has been developed and will be applied for pre-post-tests in the future.

Sustainable Food Production – Chemical Lenses on Ingredients and Processes

Co-development experiences among (future) teachers, scientists and entrepreneurs can also be implemented into university study programs. We have developed a joint Master course 'From research into education' for student teachers and 'sustainable food production' for nutritional- and food scientist students where we connect content learning with science education and science communication knowledge and let the university students co-develop learning environments for school students. Colleagues from the food science department at Kiel University have given lectures on basics and research projects in sustainable food technologies; colleagues from IPN and *KielSCN* have held seminars on the elements of the Model of Educational Reconstruction, on audience profiles in science communication, and on modes and formats of science communication and learning. The students were then divided into groups and worked on projects related to current food issues, such as alternative protein sources for meat analogues or plant milk. Other projects included local research on mussels as bio-economic food factories and protein modification for technological purposes, such as oleogelators. Outcomes of this group work ranged from hands-on experiments for school students to game-based learning activities; the best have been implemented in the student laboratory *Kieler Forschungswerkstatt* (https://www.forschungs-werkstatt.de/alle-angebote/foodlabor/) or have been used to provide loanable or online support and information. The newest products, such as games or digital tools, will be applied as preparation and reflection sources for schools before and after a visit to the food:lab. The cooperation among the different study programs was perceived very positively in general, but also showed the need for clear structures and a clarification of the specific roles that science students and student teachers can provide best. A further challenge are the different examination regulations and thus the different demands on students from the various faculties.

Reflection and Outlook

First experiences with both projects were highly motivating but also included challenges. Dealing with open-ended tasks was one of them, both for teachers and for students. While questions that cannot be answered yet are driving forces and high motivation for researchers, they often incorporate uncertainty and anxiety for teachers and students. The discussion at the Swiss Chemical Society conference raised the issue of assessment, which has also been pointed out by the students as a hurdle for creativity and project-based learning. Focusing the assessment on aspects of science processes and the nature of science might allow a reflection of a project independent of the findings or success. This would allow creative approaches and (productive) failures without the risk of poor assessment results.

Another issue discussed and also required by teachers were good practice examples as the identification of suitable project tasks and research questions for students is a well-known hurdle for student inquiry work. Grounding the choice of projects in students' interests would not be enough as suitable projects must also allow the students to apply and test different problem-solving strategies. Our on-going work will implement a framework of problem-solving approaches in examples of student projects to better support teachers and students in the future.

In summary, co-development approaches do provide better insights for all participating groups: Students and teachers gain more authentic insights and perceptions of the broad spectrum of science tasks, activities and people, whereas scientists can better understand teachers' and students' perspectives with regard to content interests and learning processes at school and beyond. To support self-efficacy and competence developments, ranges of activities should be provided as well as scaffolds for problem-solving in open-ended projects. Involving role models explaining one's own research experiences, career choices and positive effects of interdisciplinary teams are promising in this regard. Assessment tasks should be further developed to allow creative approaches as well as feedback on skills and learning progressions especially related to the nature of science and scientific processes. Future partnerships among research and practice and among different disciplines can provide good practice examples and enrich traditional chemistry learning by motivating and relevant programs on chemistry in our society and daily lives.

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