IUPAC Top Ten Emerging Technologies in Chemistry Education

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Abstract

According to the concept of education for sustainable development (ESD), science education is aimed at enabling students to act and think sustainably, which is a key competence for future in in the context of global challenges.[1] In this context, UNESCO officially proclaimed the "Decade of Action" for progress in achieving the Sustainable Development Goals (SDGs) from 2020 to 2030.[2] The meaning of future topics and sustainability for didactics was already underlined in critical-constructivist didactics by Wolfgang Klafki: Educational content has to bear a meaning in future life of students.[3][4] In this article, future topics are at first defined by their focus on technologies which contribute to the solution of key human challenges like environmental pollution, nutrition, mobility and healthcare. Therefore, the question arises whether future technologies are addressed in chemistry education. To investigate this question, trend reviews of chemistry education were analyzed regarding the "Top Ten Emerging Technologies in Chemistry", which are annually published and contain future technologies in chemistry chosen by selected experts.[5] The research clarifies that chemistry education does not sufficiently focus on technologies contributing to deal with future challenges, which is surprising because of students' increasing interest in sustainability. As a conclusion, explanations for these deficits (missing experimental approaches/teacher training) and propositions for further research are formulated.

Keywords: *future technologies, chemistry education, education for sustainable development*

1. Introduction

At the end of the 1990s, researchers from German societies of science and chemistry education, e. g. GDCh and GDCP, formulated central aims of science education: Science education plays an important role for students' general knowledge, development of personality, the possibility to understand and evaluate technical development.[6] The last aspect has become more and more important in the context of technical innovations in the last decades.

The aims of science education formulated in the 1990s are still valid in 21th century: Nevertheless, today's research focuses on the aspect of sustainable development. In science education, the branch concerning with sustainable development is called "education for sustainable development" (ESD).

The concept of ESD was mainly promoted by the United Nations (UN), such as they aimed to integrate sustainability into education.

UN's efforts in ESD, starting with the 1977 conference of Tsibli (Georgia), culminated in the "Decade of ESD", proclaimed for the period from 2005 to 2014, and the commitment of the Sustainable Development Goals (SDGs) in the programme "ESD for 2020".[1][2]

Central aims of ESD are to "prepare the younger generation to become responsible citizens in the future […] able to participate in a democratic society and to help in shaping future society in a sustainable fashion".[1, p.59]

The central role of ESD in chemistry education has already been underlined by Burmeister, Rauch and Eilks (2011).[1] They propose a multidimensional approach including technical approaches (e. g. concerning the principles of Green Chemistry) and societal approaches connected to chemistry. Furthermore, German chemistry curricula for higher classes underline that chemistry classes deal with economic, ecological and political phenomena enabling students to reflect their own actions under the criterion of sustainability.[8]

Nevertheless, it has to be put into question whether technologies, which can greatly contribute to sustainability, are sufficiently reflected in chemistry education.

2. Technologies in Chemistry Education: State of Research

In the context of central aims of chemistry classes, formulated by GDCh and GDCP researchers, and the main aspects of ESD; it becomes obvious that technologies should play a central role in chemistry education. As technologies should, in the understanding of ESD, be used to cope with future challenges, it makes sense to state "technologies" more precisely as "future technologies".
Current research often refers to "emerging technologies".[9] Emerging technologies can be defined by five criteria:

- radical novelty,
- fast growth,
- coherence,
- prominent impact
- uncertainty/ambiguity.[9]

In this definition, the role of emerging technologies for future is especially underlined.
For educational purposes, the meaning of future topics was already emphasized by Wolfgang Klafki: in his critical-constructivist didactics.[3] His didactical analysis consists of several steps: After ensuring that the educational content exemplifies a general sense for the students and is already available in students' previous knowledge, teachers should reflect on whether the educational content has a future meaning for the students.[3]
Both aspects, future meaning and sustainability, can be connected using the concept of "emerging technologies". Separate from aspects connected to ESD, a deeper understanding of technological development is necessary for participating in a society which is more and more influenced by technologies in everyday life – a claim already formulated by Wolfgang Klafki as "significance for children's future".[3, p.24]. Furthermore, emerging technologies provide opportunities to integrate recent scientific discoveries into chemistry education. In this paper, "future technologies" in chemistry education are hence defined as technologies contributing to key human challenges like climate change, environmental pollution, nutrition, mobility and healthcare.

3. Methods

To investigate whether chemistry education already focuses on future technologies, two trend reviews are analysed.
These trend reviews are annually published in the journal "Nachrichten aus der Chemie" and summarize recent developments in chemistry education research. They are divided into two parts, one dealing with experimental and conceptual topics, one dealing with empirical educational research. To record as many research papers as possible, articles in english (J.Chem.Ed., W.J.Chem.Ed.) and german (CiuZ, CHEMKON, MNU, NiU) journals are included in the annual research.
Possible emerging technologies in chemistry education can be found in the "IUPAC Top Ten Emerging Technologies in Chemistry": In this publication, selected experts annually summarize the technological development in chemistry research compiling a Top Ten List. Table 1 shows the "Top Ten Emerging Technologies" of 2021 and 2022.[10][11]

Table 1: IUPAC Top Ten Emerging Technologies in Chemistry 2021 and 2022.[10][11]

IUPAC Top Ten Emerging Technologies in Chemistry 2021	IUPAC Top Ten Emerging Technologies in Chemistry 2022
1 Blockchain technology	1 Sodium-ion batteries
2 Semi-synthetic life	2 Nanozymes
3 Superwettability	3 Aerogels
4 Artificial humic matter	4 Film-based fluorescent sensors
5 Chemical synthesis of RNA and DNA	5 Nanoparticle megalibraries
6 Sonochemical coatings	6 Fibre batteries
7 Chemoluminiscence for biological use	7 Liquid solar fuel
8 Sustainable production of ammonia	8 Textile displays
9 Targeted protein degradation	9 Rational vaccines with SNA
10 Single-cell metabolomics	10 VR-enabled interactive modelling

The titles and abstracts of all analysed articles in the trend reviews [12] and [13] were searched for keywords referring to the “IUPAC Top Ten Emerging Technologies” of the same year. As the trend reviews incorporate German and English articles, keywords in German and English were used. Furthermore, all keywords were formulated as universal as possible in order to get many results in the first step. After searching for the keywords shown in Table 2 and 3, all papers found as results were read with regard to whether IUPAC Top Ten Technologies are really considered (step 2).

4. Results

Table 2 shows the keywords and results for 2021.

Table 2: Results for 2021.

Technology Nr.	Keywords	No. Results	No. Matchings
1	blockchain	0	0
2	Genetik, genetics, semi-synthetic life	0	0
3	Benetzbarkeit, wettability	0	0
4	Humin, humic	0	0
5	RNA/DNA	2	0
6	Beschichtung, coating	1	0
7	Lumineszenz, luminescence	5	0
8	Ammoniak, ammonia	2	0
9	Protein, protein	5	0
10	Metabolomik, metabolomics	0	0

Table 3 shows the keywords and results for 2022.

Table 3: Results for 2022.

Technology Nr.	Keywords	No. Results	No. Matchings
1	Natrium, sodium, Batterie, battery	7	0
2	Nanozyme, nanozyme	0	0
3	Aerogel, aerogel	1	1
4	Fluoreszenz, fluorescence	4	1
5	Nano/Bibliothek, nano/library	0	0
6	Faserbatterie, fibre battery	0	0
7	E-Fuel, flüssiger Kraftstoff, Biokraftstoff, (bio-)fuel, liquid solar fuel	4	1
8	textiles Display, textile display	0	0
9	Impfung, vaccine	0	0
10	virtual reality, VR	0	0

Discussion

The results in Table 2 and 3 reveal that IUPAC Top Ten Emerging Technologies are rarely considered in chemistry education. In 2022, Meurisch et al. present a paper dealing with carbon aerogels, their structure and properties.[14] Fluorescence spectroscopy is used by Shen et al. as a method for identifying impurities in water.[15] The synthesis of biofuels for chemistry class using biowaste is presented by Wilke.[16]

5. Conclusion

As humanity is challenged with several problems like climate change, environmental pollution, nutrition, mobility and healthcare, sustainability and – in educational research – the concept of ESD have gained in importance. Furthermore, a focus on technologies in chemistry class has been underlined since the 1990s. In the context of ESD, it makes sense to define “technologies” as “future technologies”. Hence, this study analysed whether chemistry education research sufficiently focuses on future technologies. As current research often refers to the term “emerging technologies” focusing on fast-growing, new, prominent, but still uncertain technologies, the “IUPAC Top Ten Emerging Technologies” of 2021 and 2022 were used as examples. As an introspective into current chemistry education research, trend reviews of 2021 and 2022 were consulted.
The findings of this study reveal that chemistry education has to put more emphasis on emerging technologies. Consequently, emerging technologies with regard to conceptualisation are underlined as a research desideratum for chemistry education. Missing experimental approaches, large technical difficulties and lacks in teacher trainings can be mentioned as possible reasons. Nevertheless, emerging technologies have great potential for chemistry class and cross-curricular teaching, as several key human problems have to be solved interdisciplinary.
Table 4 shows possible topics and links of selected emerging technologies for chemistry education.

Table 4: Possible topics and links of IUPAC Top Ten Technologies for chemistry education.

IUPAC Top Ten Technology	possible topics and links
Superwettability	properties of surfaces, bionics
Artificial humic matter	sustainable agriculture
Sonochemical coatings	properties of surfaces, healthcare, energy
Sustainable production of ammonia	sustainability, green chemistry
Sodium-ion batteries	energy storage, mobility
Aerogels	energy saving
Fibre Batteries	energy storage
Liquid solar fuel	energy storage, mobility

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