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Future-Orientation in Chemistry Education? Curriculum Analysis and Qualitative Insights into Teacher Students' Attitudes

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Abstract

Schools today face the challenge of preparing learners for a future shaped by rapid changes. [1] Learners must therefore be equipped not only to follow emerging technological advancements, but also to understand, critically evaluate, and actively shape them. [2] To ensure this, references to future are crucial in science education. While Education for Sustainable Development offers large potential for future-oriented approaches, research indicates that its curricular implementation is still insufficient. [3]

To identify references to future-related contents in chemistry class, this study applies a two-step methodological approach: First, all German chemistry curricula were systemically analyzed using Python-based text screening aligned with predefined clusters of terms associated with future and future technologies. Second, given that the implementation of future references in chemistry class is heavily dependent on teachers' attitudes and competencies, a sample of teacher students was interviewed using a semi-structured interview guide. To find linkages to familiar teaching concepts related to temporal perspectives, participants were explicitly asked to reflect on references to past, present, and future in chemistry teaching. All interviews were subsequently transcribed and evaluated using qualitative content analysis. [4] Our results indicate that participants possess substantially more prior knowledge regarding references to past and present than regarding future-related ones. However, participants assign considerable importance to them underscoring their relevance for chemistry education research.

1. Introduction

Preparing students for a society faced by rapid changes is a key challenge of science education. [1] To achieve this, it seems sensible to establish links to future topics in classroom and to develop students' ability to deal with such changes. As an initial step toward identifying potential references to future in formal educational frameworks, curricula were subjected to a structured text screening. The frequency of defined lexical markers (term clusters) allows conclusions to be drawn about the degree of future orientation in the curricula, although the results still need to be reviewed and evaluated individually.

In a second step, it must be taken into account that the implementation of future aspects is not solely determined by curricula, but also by knowledge and skills of chemistry teachers. To assess this component, teacher students were interviewed a semi-structured guide which focuses on future orientation in comparison to past and present orientation. A short summary combines the results of both studies: Future orientation appears notably underrepresented in curricula, whereas teacher students characterize it as motivating, simultaneously emphasizing key challenges of its implementation.

2. Theoretical Background

2.1 Temporal Perspectives in Chemistry Education

The systematic integration of future orientation into teaching and learning processes has been established in educational theory for several decades. In his didactic analysis, Wolfgang Klafki assigns central importance to the future significance of learning content. Within his educational-theoretical framework, curricular content is evaluated, among other criteria, according to its relevance for enabling learners to address present and future aspects. [5]

In addition to the future dimension, other temporal perspectives, particularly references to the past and the present, are likewise well established as structuring elements of classroom practice. In chemistry education, these perspectives are reflected, for example, in history-based problem-oriented approaches [6] as well as in present-oriented concepts. [7] While such approaches primarily emphasize historical developments or contemporary real-life contexts, an explicit future-oriented perspective offers additional potential.

2.2 Potential of Future Orientation for Chemistry Education

The relevance of future-oriented chemistry education can be underlined by the pivotal role of chemistry as a scientific discipline in the development and implementation of sustainable production processes. [8] Chemistry provides essential foundations for innovations in areas such as renewable energy technologies and environmentally benign synthesis pathways. Consequently, it must be recognized that pressing global challenges cannot be adequately addressed without recourse to innovation in chemistry. [9] Innovation research, for example, provides impetus for this: Since 2019, the International Union of Pure and Applied Chemistry (IUPAC) has annually published a “Top Ten Emerging Technologies in Chemistry” list, highlighting developments with large future potential for society and industry. [10]
Against this backdrop, an exclusive focus on past or present in chemistry education appears insufficient. Rather, emerging technologies should be addressed and systematically examined and critically evaluated with regard to their economic, ecological, and social implications. [8] Such an approach is closely aligned with the framework of Education for Sustainable Development (ESD). In official orientation frameworks for the implementation of ESD, future-oriented competencies and exemplary teaching contexts are explicitly identified as central components. [11] The focus on future orientation therefore holds considerable potential for fostering engaging, innovative, and socially responsive chemistry instruction [8].

To address the research question concerning the extent to which chemistry education in Germany incorporates a future-oriented perspective, a two-stage methodological design was employed.

In the first step, a systematic **curriculum analysis** was conducted. Based on predefined clusters of terms associated with temporal orientation, the chemistry curricula of all German federal states as well as the National Educational Standards (NES) were examined for explicit references to future-oriented content and competencies.
In the second step, an **interview study with teacher students** was conducted in order to obtain insights into the perceived and enacted relevance of future perspectives in instructional practice. The data were gained with particular attention to the relative prominence of future-oriented aspects in comparison to references to past and present perspectives.

3. Curriculum Analysis

3.1 Methodology

For the analysis of chemistry curricula, all curriculum documents from the 16 German federal states and the NES (secondary levels I and II) were compiled. Subsequently, thematic term clusters were defined to enable a structured and targeted document search. These clusters comprised terms related to future technologies, innovation, and contemporary research. Table 1 presents a selection of the defined term clusters together with their associated terms.

Table 1. Selection of term clusters (translated into English).

Cluster Name	Terms
Emerging Technology (ET)	emerging technology
Technology (T)	technology
Future Orientation (FO)	“future”, future issues, future issue, future-oriented, future orientation, future perspective, future topics, promising for the future, forthcoming
Innovative Research (IR)	research, innovative, modern, “new”

To conduct an automated search across all curricula, Python scripts were developed with the assistance of generative AI (ChatGPT 4o, OpenAI). The scripts incorporated the libraries PyMuPDF for document extraction, re for term searching, pandas for tabular data processing, and openpyxl for the export to xls format. Subsequently, term frequencies were quantified and the results were subjected to a detailed examination. Owing to its focus on manifest content (i.e., specifically the occurrence of particular terms), the curriculum analysis can provide only preliminary indications regarding the future orientation of the individual curricula. A more comprehensive examination of the full set of competencies would be required to determine whether references to future perspective extend beyond the explicit lexical level.

3.2 Results

Table 2 summarizes the term frequencies found in the curricula by the Python analysis.

Table 2. Quantified Results of Curriculum Analysis.

Curricula									
Federal State	**ET**	**T**	**FO**	**IR**	**Federal State**	**ET**	**T**	**FO**	**IR**
BW	0	0	5	14	NW	0	3	5	14
BY	0	16	3	9	RP	0	30	23	83
BB/BE	0	2	7	8	SL	0	0	0	4
HB	0	11	4	5	SN	0	2	2	10
HH	3	10	2	16	ST	0	3	1	4
HE	0	6	6	15	SH	0	7	4	25
MV	0	4	9	10	TH	0	3	0	3
NI	0	1	2	2	**Σ**	**3**	**98**	**73**	**222**
National Educational Standards									
Secondary Level	**ET**	**T**	**FO**	**IR**					
I	0	5	0	3					
II	0	3	2	4					
Σ	**0**	**8**	**2**	**7**					

The results indicate that the term “emerging technology,” which constitutes the corresponding term cluster, is mentioned only three times across all analyzed curricula and the NES (secondary level I/II). In the Hamburg core curriculum, emerging technologies are primarily referenced as possible contextual frameworks for topics such as plastics, mobility, and energy, and are characterized as CO_2-neutral or CO_2-reducing. They are thus situated within the framework of education for sustainable development. In contrast, the term “technology” is mentioned 98 times in total, with the majority in the curricula of Rhineland-Palatinate. There are references to specific fields of technology such as nanotechnology and biotechnology (Bavaria), as well as general references to expertise in technology assessment.

The term clusters “future orientation” and “innovative research” yield a substantially high number of references, especially in the curricula. A substantial proportion of the findings in the term cluster “innovative research” relate to the term “research,” which may or may not indicate a focus on the future. As with the term cluster “technology,” the large number of findings in the Rhineland-Palatinate curriculum is striking here.

Nevertheless, it remains questionable to what extent these references are translated into explicitly formulated competencies. Frequently cited examples include the use of hydrogen as an energy storage medium, batteries, fuel cells, and accumulators. A structured contextualization of future orientation, linking perspectives from the history of science with contemporary developments, can be found in the curriculum (secondary level II) of Baden-Württemberg.

At the same time, the implementation of future-oriented teaching appears to depend considerably on the initiative of individual teachers. This is reflected, for example, in the curriculum of Rheinland-Palatinate (secondary level II), which explicitly allows for the inclusion of content (“additional innovative materials”) that was not considered relevant at the time the curriculum was developed.

In conclusion, despite its programmatic significance, future orientation occupies a comparatively subordinate position within the curricula. Furthermore, the degree of future orientation across the individual curricula varies greatly. The lacking explicit use of the term “emerging technology” (only three occurrences in all curricula) indicates that the practical realization of future-oriented content largely depends on the individual commitment of teachers.

4. Interview Study with Teacher Students

4.1 Methodology

In the interview study, a sample of teacher students (Master of Education studies at the University of Göttingen, *N* = 10) was interviewed using a semi-structured interview.

To give participants a starting point of discussion, an illustration with prototypical statements of three teachers was created shown in figure 1. From left to right, the three teachers represent a past perspective, a present perspective and a future perspective.

Fig. 1. Illustration of three teachers referring to past, present and future perspective.

In addition, an interview guide was created offering various questions about the illustration and the temporal perspectives that can be discerned in it. Figure 2 summarizes the interview guide. First, participants were asked to describe their initial impressions after reading the statements (I). The subsequent questions (II) were intended to prepare participants for the discussion of temporal references in chemistry lessons, thereby enabling them to address the research questions in (III). These questions focus on the relevance of temporal perspectives and on how participants perceived their weighting in chemistry lessons. In addition, participants were invited to reflect on how they would weigh the temporal perspectives in future lessons and to indicate which perspective they consider most important.

I: **Introduction**: What was your first impression when reading the statements of the three teachers?

II: Perception and Interpretation

- In your opinion, what distinguishes the three teachers in their teaching styles?
- If you consider the three teaching approaches as three different perspectives or views on chemistry, how would you describe these perspectives? (Do the teachers set different priorities, and where do these priorities lie?)
- Which temporal references or orientations could play a role in the three approaches? (Where is the focus in terms of time?)

III: Reflection on Temporal Perspectives

- In your opinion, which role does the...

  blue person (past perspective), orange person (present perspective), pink person (future perspective)

  ...play in chemistry teaching? Or rather, which significance does this approach have for chemistry teaching?
- To which extent are the different approaches included in the chemistry lessons you have experienced so far?
- How do you think the different approaches are weighted in chemistry teaching?
- How would you weight the different perspectives in your own future lessons, and how does this differ from your previous experiences with chemistry lessons?
- When you think about what you have learned about chemistry teaching during your teacher training, which temporal references do you think are most important?

Fig. 2. Summary of the questions included in the interview guide.

All interviews were recorded, anonymized and transcribed with the participants' consent.
In the aftermath, the interviews were evaluated by qualitative content analysis [4] using MAXQDA.

4.2 Results

During the evaluation of the participants' interviews, a category system was created including eight main-categories:

- Temporal perspectives in chemistry class
- Relevance of past perspective
- Relevance of present perspective
- Relevance of future perspective
- Reflection of personal experiences at school
- Reflection of experiences in internships at school

- Temporal perspectives in university teacher education
- Educational aspects on the integration of temporal perspectives in chemistry class

When evaluating the interviews, the individual references to the main category "Temporal references in chemistry lessons" revealed that the participants all recognized the reference of the illustration to temporal perspectives.
In the following section, the further categories are discussed in detail.

4.2.1 Relevance of Past, Present and Future Perspective

Table 3. Results for sub-categories concerning the relevance of past, present and future perspective. The numbers represent the frequency of each subcategory, with the number of interviews in which the subcategory appears shown in parentheses.

Past Perspective		Present Perspective		Future Perspective	
Sub-Category		**Sub-Category**		**Sub-Category**	
General relevance of past perspective	11(7)	General relevance to everyday life	6(4)	Relevance of new technologies	2(2)
Understanding scientific methods	6(5)	Contribution to maturity: consent	2(2)	Chemistry as a tool for shaping the future	10(8)
Learning supportiveness of historical perspectives	6(6)	Contribution to maturity: limitations	2(2)	Future perspective and vocational orientation	7(5)
Historical understanding as the foundation for future competencies	3(3)	Relevance to everyday life for motivation	11(8)	General relevance of future perspective	4(4)
Reconstruction of misconceptions	3(3)	Relevance to everyday life for understanding	3(3)	Fostering critical thinking	1(1)
Limited students' motivation due to historical references	2(2)	Applicability in everyday life	4(3)	Role of extracurricular activities/locations	2(2)
Thematic dependence of historical references	4(4)	Thematic dependence on everyday references	4(4)	Motivation to change	4(3)
		Application in higher grades	1(1)	Development of ideas for future	1(1)
				Suitability for higher grades	5(2)
				In-depth knowledge necessary	2(2)
				Curricular limitations	2(2)

Statements that can be assigned to the main category "relevance of past perspective" are represented across all interviews. The overarching significance of integrating past perspective for chemistry education is explicitly emphasized eleven times by seven participants. In addition, participants establish conceptual connections between Nature of Science (NOS) and past perspective, particularly with regard to the development of scientific models and the emergence of students' misconceptions. Six participants characterize historical references as supportive of learning processes, whereas two participants associate the past perspective with decreased student motivation.
In contrast, the present perspective is predominantly described as highly motivating, especially when linked to students' everyday experiences and real-life contexts. For both past and present perspectives, participants stress that their pedagogical applicability is contingent upon the specific chemistry topic addressed.
Regarding the future perspective, eight participants attribute substantial scientific relevance to chemistry in shaping future developments. Simultaneously, they argue that future-oriented approaches are more appropriate for higher grade levels, partly due to necessary in-depth knowledge. Five participants further highlight the aspect of incorporating future perspectives to support vocational orientation within chemistry education.

Overall, the findings indicate that all three temporal perspectives – past, present and future – are regarded as educationally important. However, their implementation is described as context-dependent and subject to specific constraints, such as the perceived suitability of future-oriented approaches for higher grade levels.

4.2.2 Reflection of Personal School Experiences and Experiences in School Internships

Table 4. Results for sub-categories concerning the reflection of personal school experiences and experiences in school internships.

Reflection of personal school experiences		Reflection of experiences in school internships	
Sub-Category		**Sub-Category**	
Dominance of past perspective	11(7)	Dominance of present perspective	4(4)
Dominance of present perspective	4(3)	Dominance of present and past perspective	2(2)
Lack of past perspective	3(2)	Past perspective less dominant than in personal school experience	1(1)
Lack of present perspective	6(5)	Lack of future perspective	5(5)
Lack of future perspective	9(7)	Present and future perspective as a part of evaluative competence	1(1)
Future perspective mentioned in high-level courses	1(1)	Choice of temporal perspective dependent on teacher	2(2)
Coverage of all temporal perspectives	1(1)	Temporal perspectives generally missing	2(2)
Temporal perspectives missing at all	3(3)		

These main categories include references to participants' experiences during their own school years as well as during school internships.
With regard to their personal school experiences, it is particularly notable the past perspective is described as dominant in seven interviews, whereas in two interviews its absence is stated. The present perspective appears to have been perceived more heterogeneously: Three participants characterize it as dominant, while five report it is entirely lacking. The majority of participants states the future perspective as underrepresented during their schooling, and three participants even indicate a total absence of any explicit temporal perspectives.
In relation to school internships, no clear predominance of the past perspective can be identified. Instead, four participants emphasize that the present perspective was most frequently observable in instructional practice. One participant explicitly remarked that, from his perspective, historical references had been more prominent during his own school years than during his internship experiences. The findings concerning the future perspective in school internship corresponds to those reported for participants' personal school experience: Future-oriented aspects are characterized as underrepresented.

4.2.3 Temporal Perspectives in University Teacher Education and Educational Aspects on the Integration of Temporal Perspectives

Table 5. Results for sub-categories concerning temporal perspectives in university teacher education and educational aspects on the integration of temporal perspectives.

Temporal perspectives in university teacher education		Educational aspects on the integration of temporal perspectives	
Sub-Category		**Sub-Category**	
Dominance of past perspective	7 (3)	Topic-dependent choice of perspective	3 (3)
Past perspective considered	2 (2)	Past perspective as an introduction	3 (2)
Lack of past perspective	2 (1)	Focus on the past perspective	2 (1)
Dominance of present perspective	5 (3)	Past perspective as secondary	2 (2)
Present perspective considered	3 (3)	Use the past perspective depending on the topic	2 (2)
Dominance of past and present perspective	9 (7)	The past perspective can promote misconceptions	1 (1)
Lack of present and future perspective	1 (1)	Focus on present and past	4 (3)
Future perspectives considered via sustainability	4 (4)	Give strongest weight to the present	7 (5)
Future perspective considered by individual modules	11 (8)	Present perspective to foster learner autonomy	1 (1)
Future perspective mentioned as positive aspect	1 (1)	Do not force real-life relevance	1 (1)
Temporal perspectives generally missing	2 (1)	Present perspective because it is required	1 (1)
Own choice of temporal perspectives dependent of teacher studies	1 (1)	Future perspective as secondary	6 (4)
		Future perspective applicable depending on age	5 (3)
		Stay up to date through the future perspective	1 (1)
		Willingness to consider the future perspective	12 (8)
		Difficulties in distinguishing between present and future	3 (2)
		Link the future perspective to the present	2 (2)
		Clearly distinguish temporal perspectives from one another	1 (1)
		Confident handling of present and past	2 (2)

	perspectives	
	Uncertainty regarding the future perspective	8 (3)
	Balanced weighting	4 (4)
	Strong contrast to previous experience	1 (1)

Concerning temporal perspectives within university-based teacher education, eight participants associate a future orientation primarily with the integration of individual modules into the overall curriculum. For instance, participants report linkings from current chemical research – particularly those addressed in the context of their final theses – to future-oriented considerations in the context of sustainability. Overall, the results indicate that future dimensions are only marginally embedded within subject-specific teacher education. Instead, seven participants describe past and present perspective as more salient, a tendency that may be attributed to established instructional methods like historically-problem-oriented teaching.
With respect to the pedagogical integration of integrating temporal perspectives, eight participants express their willingness to incorporate future perspectives into chemistry lessons. Simultaneously, three participants articulate uncertainty regarding its practical implementation. Among all temporal perspectives considered, four participants characterize the future perspective as supplementary rather than integral to the curriculum contingent upon students' grade level and the specific instructional topic.

6. Conclusion

In summary, this study suggests that although future orientation is present in some curricula, it is nevertheless underrepresented. References to the concept of future technologies are particularly lacking. Concurrently, the interview data reveal a pronounced emphasis on past- and present-oriented perspectives. The present perspective is predominantly regarded as supportive of learning processes, whereas the past perspective is frequently associated with motivational benefits.
Participants' recollections of past perspective primarily stem from their own school experiences, a pattern that may be attributed to the traditionally strong emphasis on historically oriented instructional approaches in Germany. [12] In contrast, the present perspective was perceived as particularly dominant during school-based internships, which may be interpreted as indicative of a shift from a predominantly past-oriented framework toward a stronger focus on contemporary contexts (i.e., real-life contexts). One possible explanation for this development is the increasing pressure of time constraints, which may lead educators to reduce the consideration of historical development.
Despite indications of a relative decline in explicitly past-oriented approaches, such perspectives continue to play a substantial role in university teacher education. At the same time, the present perspective is likewise described as salient within this context. Notably, many participants express a willingness to incorporate a future-oriented perspective. Therefore, vocational orientation is identified as one potential reference point. However, participants also identify potential challenges, e.g. uncertainty regarding effective implementation strategies and the appropriate weighting of the future perspective in relation to past and present perspective.

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