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RESEARCH ARTICLE

Teaching fuel cells in the chemistry classroom – A brief survey on the current situation in German schools

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A small questionnaire-based study was carried out in order to get an impression of the current placement of fuel cells in the chemistry classroom in Germany and to develop a research-based, practice-oriented didactical sequence for the teaching of fuel cells. Based on a participative action research-approach, chemistry teachers at schools with a focus on STEM answered a questionnaire. This article gives insight into our approach and results of this preliminary study.

Keywords: survey, STEM, education for sustainable development, fuel cells, preliminary work

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Introduction

In Germany as well as in many other countries, fuel cells as a part of a sustainable energy solution belong to the core teaching contents in the context of Sustainable Development Goals, SDG (Fang, Wan Daud, Halim, & Masdar, 2017; Grandrath & Bohrmann-Linde, 2019). Fuel cells are part of every chemistry curriculum for secondary education. Usually a general comparison between fuel cells and batteries is focused on. In the case of concrete references, hydrogen-based Proton Exchange Membrane Fuel Cells (PEMFC) are to be introduced to the students (Chemistry curriculum for grammar schools in North Rhine-Westphalia, 2013).

The articles in science education journals on fuel cells in teaching present materials and concepts. They focus on the expertise around hydrogen and methanol fuel cells and suggest possible experiments with kits to record characteristic curves, e.g. (Geitmann & Borsum, 2014; Küter, Höller, & Voigt, 2012) or present an educational report on the Power to Gas concept for example (Rubner, Berry, Grofe, & Oetken, 2019). They do not deal empirically with the actual situation of fuel cells. To our knowledge no information has been published about the actual placement and practical realization of fuel cells in German chemistry lessons: In which way do teachers deal with them? Which kinds of fuel cells do they introduce? Which experiments and which didactical settings do they choose?

As one of our workgroup´s projects focusses on the development of school experiments, didactical concepts and learning materials on a variety of fuels cells, we in a first step interrogated chemistry teachers in a small questionnaire-based survey. Based on the information from practitioners and a requirements analysis derived from the gathered answers we then plan to develop our teaching program, following the principle "from well-established contents to innovative ones" such as from galvanic to photogalvanic cells. We finally intend to optimize and evaluate the teaching program in regular interaction with teachers at different stages of their professional career (**Figure 1**).

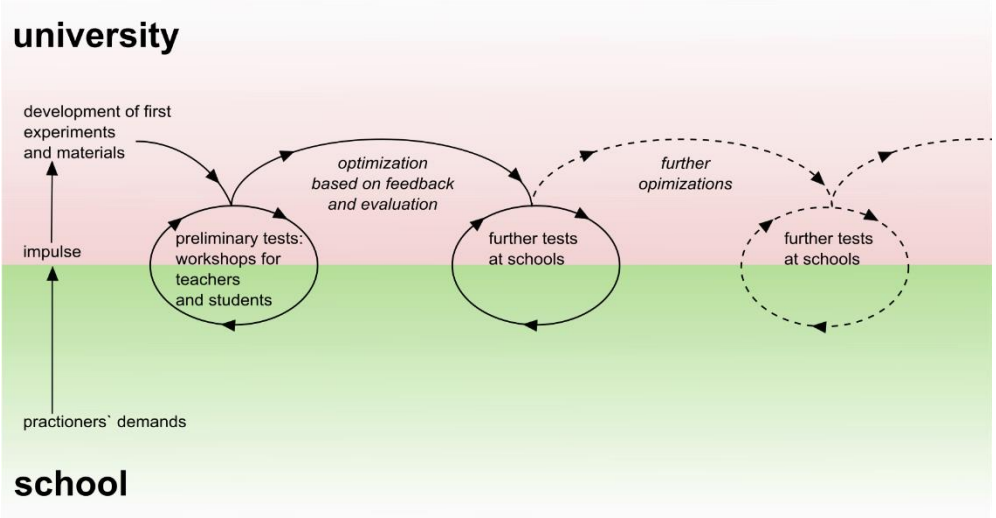

Figure 1. PAR-related steps in the development of didactic concepts and learning materials

Methods

The questionnaire was generated with the intention of gathering general information such as answers to the above-mentioned questions as well as teachers´ opinions and their practical needs concerning the topic. The questionnaire is a mixture of closed and open questions (**Table 1**). It contains a cover note, items for a demoscopic characterisation of the participants, fifteen content questions regarding the subjectively perceived importance of fuel cells and their placement; instructional details; possible demand of teacher training or extracurricular programs for students. In addition, it was asked whether there was a demand of other STEM topic(s) besides fuel cells

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and which kinds of teaching materials (digital, print, videos, procedures etc.) are of interest. At the end of the survey there is space for further remarks.

Table 1. Overview of the questionnaires structure.

Demoscopic characterisation
Content questions
1. Do personally you consider fuel cells to be a relevant topic for the future?
2. Do you feel sufficiently informed about current developments in the field of fuel cell technology?
3. In the lessons of which subjects is the fuel cell the subject of discussion at your school?
4. In which class level do you address fuel cells?
5. Which fuel cell types do you talk about in chemistry classes?
6. How do you teach chemistry to develop fuel cells?
7. Are fuel cell experiments carried out in your chemistry class? If yes, please tell us briefly which.
8. Who carries out experiments on fuel cells in your chemistry lessons?
9. Do you have a fuel cell kit at school? Please indicate the number.
10. Do you use the fuel cell kit regularly in chemistry lessons?
11. Is didactically prepared information and experimental material on different types of fuel cells desired? If yes, please indicate your preferences.
12. Would you like to visit an extracurricular program for students to experiment with different types of fuel cells from a STEM perspective? Please briefly explain your reasons.
13. Would you like to participate a teacher training on experiments with different types of fuel cells from a STEM perspective? Please briefly explain your reasons.
14. What other STEM topic do you need suggestions or materials for?
15. *Which format, scope or other characteristics would be desirable from your point of view for accompanying material? For example, file formats, digital/ analogous, animations or other...*
***open questions are written in italics.**
Space for further remarks

The questionnaire was distributed in Germany via three ways: We cooperated with the German STEM-network "MINT-EC", which is a national association of schools with an excellent STEM school profile. A link to the online survey tool was placed at the network´s official school blog with subscribers all over Germany (STEM networks official school blog); the link was also sent to the subscribers of our own student lab´s mailing list and finally an analogous version together with a prepaid reply envelope was mailed to all 93 official STEM grammar schools in the state of North-Rhine Westphalia (NRW). The main focus on teachers from STEM schools served as a further limitation of the sample and NRW was chosen because of its size and for geographic proximity to our university.

The answers were interpreted by summarising, counting frequencies and analysing answers to open questions by category formation and cluster analyses, as this already suffices in our case to gain an insight into current practice.

Results

Characterisation of the sample:

There were 53 participants who took part in the survey, 21 of them via the online tool and 32 via paper mail. There was an almost even distribution between female and male participants (47% female, 51% male). 50 out of 53 teachers teach in NRW, two in Hesse and one in Lower Saxony.

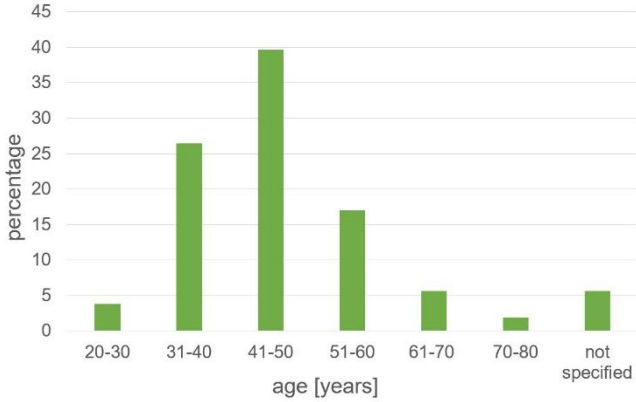

Figure 2. a) Age distribution

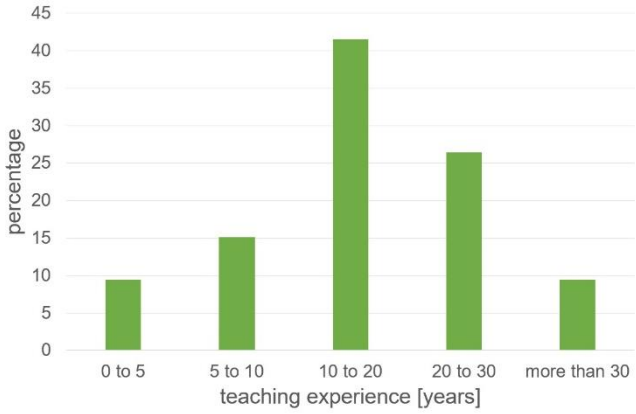

Figure 2. b) Teaching experience distribution

The participants are aged between 27 and 74, their teaching experiences range from one to more than 30 years (ref. **Figures 2a** and **2b**). Since the questionnaire was sent to schools, it can be assumed that even the 74-year-old person is still actively involved in school life and chemistry teaching.

In Germany teachers usually teach two different subjects. Besides chemistry most participating teachers teach biology (38%), followed by mathematics (26%) and physics (15%), very few teach a language or a social science.

Current situation at schools

Every participant declared fuel cells as being important, but only 35% of them feel sufficiently informed about current developments. Fuel cells are mainly taught in chemistry lessons, but also in the related natural sciences (**Table 2**).

Table 2. Fuel Cells as teaching contents in the natural sciences

	Chemistry	*Physics*	*STEM*	*Biology*	*Geography*
f	53	25	4	1	1
%	100	48	8	2	2

STEM lessons are interdisciplinary facultative subjects where topics off the regular science curricula can be dealt with (North Rhine-Westphalian Institute for School Development).

All of the participating teachers situate fuel cells in upper secondary education classes, half of them also in lower secondary education classes. Regarding the different types of fuel cells only very few are addressed at schools (**Table 3**). When it is the case, the focus is usually on hydrogen-driven fuel cells.

Table 3. Types of fuel cells discussed at school

	Hydrogen fuel cell	Methanol fuel cell	Ethanol fuel cell	Solid oxide fuel cell	Alkaline fuel cell	Glucose fuel cell	Methane fuel cell
f	53	9	2	1	1	1	1
%	100	17	4	2	2	2	2

The reason for this is most likely the fact that hydrogen fuel cells are explicitly mentioned in the chemistry curricula for advanced courses preparing for the final exams (Chemistry curriculum for grammar schools in North Rhine-Westphalia, 2013). About 66% of the respondents answered that they teach fuel cells theoretically and about 64% practically, depending on the respective situation and available time. 89% of those who integrate experiments use a commercially available PEMFC fuel cell kit, only 8% of them use a low cost-setup or alternative approach via an electrolysis of slightly acidified water using platinum electrodes, combined with operating the cell after the generation of the gases. In most cases the experiments are realized as student-experiments, in fewer cases as demonstrations. 66% of the respondent's state that they have fuel cell kits available at their schools, though there is a great difference in the number of available kits (**Table 4**).

Table 4. Number of available fuel cell kits

Number of fuel cell kits	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**12**
f	12	8	3	3	3	2	2	1
%	36	22	9	9	9	6	6	3

Most teachers only have a small number of kits. 71% of them use their fuel cell kit regularly.

Communicated demands

86% of the teachers stated that there is a demand for didactic teaching materials and concepts. The respondents had the opportunity to express optional wishes regarding this question. They most frequently asked for experimental procedures, additional material on hydrogen fuel cells and information on other types of fuel cells.

Furthermore, 83% of the respondents indicated that they would like to visit an extracurricular lab unit on the subject of fuel cells with their students. The most frequent reason given was that it would enable them to carry out more complex experiments than in a typical school laboratory, that the staff was trained and that the subject of fuel cells itself was an important topic for the future. As reasons against a visit teachers stated that the (organizational) effort involved was too high and that there was not enough time available for chemistry lessons in general.

In addition, it was asked whether further teacher training on the subject of fuel cells was of interest. Almost 85% of the teachers welcomed a teacher training. The decision was usually based on the desire to optimize their experimental expertise, to learn about current developments and to obtain impulses and materials for use in schools. Also the classification of fuel cells as an important future topic in the realm of a transformation of the energy economy was increasingly cited.

Three fourths of the teachers (74%) indicated other STEM topics for which they needed materials (see **Table 5**). Concerning the demands of new teaching and learning materials the majority of respondents prefer digital materials (24), ideally editable versions. Worksheets for students (11) as well as experimental manuals on low cost-setups (4) were also requested. In addition, animations (31) and videos (7) are listed.

Ten participants used the opportunity to write free comments. They reflected that fuel cells should actually be compulsorily anchored in curricula and that they very much welcome the opportunity to convey their needs as practitioners to us. Some excerpts are as follows:

- "Fuel cells should actually be anchored more in curricula and curricula."
- "An interesting topic that is often neglected."
- "I like this kind of survey because the teachers at the base are asked about their needs."

Table 5. Topics on which teachers wish to have further materials

STEM topic	*f*	*%*
(bio) polymers	8	21
dyes	7	18
future batteries	5	13
aromatics compounds	2	4
sustainability	1	3
corrosion protection	1	3
nano-tubes	1	3
food technology	1	3
carbon fibre	1	3
photosynthesis as part of electrochemistry	1	3
analytical methods	1	3
automotive engineering	1	3
binding agents	1	3
carbon cycle	1	3
complex compounds	1	3
electrochemistry	1	3
CRISPER/CAS9	1	3

Discussion and Outlook

We are well aware that compared to the number of chemistry teachers in Germany, only a few teachers answered the questionnaire. This restriction was necessary for organizational reasons. Additionally, the survey was carried out in the proximity of our university, in order to further involve teachers in cooperation without having them to travel long distances. Even if the sample was small, impulses can be derived from the survey: fuel cells are still an issue of great interest, but there is also a demand of didactic support in the shape of student laboratory units and teaching materials that can be used directly in class as well as teacher training. It also becomes clear that materials on other STEM topics are asked for and that there is a growing interest and demand for digital, multimedia materials. In addition to the continuation of the didactic exploration and developments in the field of fuel cells at university, cooperation between university and practitioners from schools should be further developed. We use this survey as a first positive impulse in the sense of participatory action research, as teachers consulted have expressed suggestions for cooperation on their own initiative.

So far we have simplified well-known school experiments on fuel cells such as alkaline fuel cells and direct alcohol fuel cells and developed novel experiments on biological fuel cells based on yeast and sugar in addition (Grandrath & Bohrmann-Linde, 2019). Our aim is to provide teachers /learners with experiments that are easy to carry out, that enable clear observations and which are based on lowcost materials from everyday life. There have already been developed freely available learning videos (Website of the work group chemistry education Wuppertal). Further materials, such as interactive eBooks, videos and worksheets, are currently evolved for our experiments taking up the impulses from the survey. Our further work will focus on the field trial of the materials. They will be tested in extracurricular lab units for students and teacher trainings as well as in regular school lessons by local teachers themselves. The teachers will take part in the future optimization process. This contributes to optimization in a variety of ways, as indicated by the dotted lines in **Figure 1**. The tests will first run within NRW and then throughout Germany. Finally, the material will also be prepared for a bilingual setting as well as for an international audience. The current version of the materials is always inserted on the homepage of the working group for free download.

References

Chemistry curriculum for grammar schools in North Rhine-Westphalia. (2013). *Kernlehrplan für die Sekundarstufe II Gymnasium / Gesamtschule in Nordrhein-Westfalen: Chemie*. Ministerium für Schule und Weiterbildung.

Fang, T. P., Wan Daud, W. R., Halim, L., & Masdar, M. S. (2017). How Ready is Renewable Energy? A Review on Renewable Energy and Fuel Cell Teaching in Schools. *World Engineering Education Forum*, *7*., 236–244.

Geitmann, S., & Borsum, D. (2014). *Unterrichtsmaterial über Batterien und Brennstoffzellen: Bat terien und elektrische Antriebe - Wasserstoff und Brennstoffzellen* (1. Aufl., Lehrerausg). Oberkrämer: Hydrogeit Verlag.

Grandrath, R., & Bohrmann-Linde, C. (2019). Teaching Sustainability in the Chemistry Classroom: Exploring Fuel Cells in Simple Hands-on Experiments with Hydrogen, Sugar and Alcohol. *World journal of chemical education*, *7*(2), 172–178.

Küter, U., Höller, S., & Voigt, C. (2012). *Brennstoffzellen im Unterricht: Grundlagen - Experimente - Arbeitsblätter* (3. Aufl.). Oberkrämer, Ortsteil Schwante: Hydrogeit Verlag.

North Rhine-Westphalian Institute for School Development. https://www.schulentwicklung.nrw.de/lehrplaene/upload/klp_SI/GE/wp-nw/SiLP_GE_WP_NW_2016_03_18.pdf: last accessed on 05.03.2019.

Rubner, I., Berry, A. J., Grofe, T., & Oetken, M. (2019). Educational Modules on the Power-to-Gas Concept Demonstrate a Path to Renewable Energy Futures. *Journal of Chemical Education*, *96*(2), 248–255. https://doi.org/10.1021/acs.jchemed.7b00865

STEM networks official school blog. https://www.mint-ec.de/aktuelles/blog-facebook: last accessed on 28.02.2019.

Website of the work group chemistry education Wuppertal. https://chemiedidaktik.uni-wuppertal.de/index.php?id=4859&L=0. Last accessed on 15.08.2019.