New Perspectives in Science Education
International Conference
NEW PERSPECTIVES in SCIENCE EDUCATION

Adapted Primary Literature about CO_2 Reduction Reaction – Chemists' Research Approach to Protect the Climate

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Abstract

European politics and society currently face enormous challenges, such as the energy crisis or the climate change. Research aims to contribute to possible solutions but unfortunately, research results are commonly only published to the scientific community, even though they might help politicians and society making decisions and acting responsibly. One approach to reach a broader audience is Adapted Primary Literature (APL) [1]: literature adapted from research articles and understandable to non-researchers. Herein, we present the conception and evaluation of an APL for high school students originating from a research article that follows the vision of using carbon dioxide as feedstock instead of fossil fuels [2]. This article presents a reaction path from carbon dioxide to carbon monoxide that could be converted into fuels like methane or basic chemicals for products of the chemical industry, such as plastics. The APL has the scientific style of writing and the characteristic sections of research articles: introduction, experimental methods, results, and discussion. High school students' gaps in knowledge about the experimental methods XRD, IR and NMR are closed by additional explanatory texts, whereas experimental details not relevant for high school students (e.g. measuring parameters) are omitted. The main results and the argumentation in the discussion part of the original article are mostly maintained to provide authentic insights into the scientific process of gaining knowledge. The evaluation of the APL revealed that around 20% of a test group of 30 high school students rated the APL as understandable, whereas no one in a control group of nine high school students indicated the translated original research article to be understandable. In addition, one in three of the 30 students showed interest in the APL, but only one in five in working with it in school lessons. Moreover, everybody in a group of ten prospective schoolteachers expressed the intention to use APLs in their future classes. In conclusion, the APL appears to be more understandable than the translated original research article, but there is still room for improvement in terms of understandability and interest.

Keywords: *Adapted Primary Literature, CO_2 reduction*

1. Introduction

Adapted Primary Literature (APL) builds a bridge between research articles and schoolbooks. It is literature which originates from research articles but is specifically adapted to targeted readers. The scientific style of writing and discussing results as well as the structure of the original (introduction, experimental section with methods and results, discussion) are retained. This allows readers to gain authentic insights into recent research and the scientific process of acquiring knowledge and thereby empowers them to make decisions and act consciously based on the latest scientific findings. To fulfil this purpose, a research article was adapted which describes an approach to convert carbon dioxide into fuels and might therefore be a future alternative to the current power production from fossil fuels that causes the climate change by emitting carbon dioxide. The target group were high school students, since they will shape our future. The final APL was evaluated within a survey study with high school students and prospective teachers.

2. Conception

The following sections briefly summarize the original research article and the adaptation process.

2.1 Original article

The original research article [2] presents a possibility to use carbon dioxide as feedstock to produce carbon monoxide that is convertible into fuels like methane or basic chemicals. The following reaction pathway was investigated: In a first step, carbon dioxide is bound under photochemical conditions to a nickel pincer complex as a catalyst. Next, water is split off by adding an acid to form a cationic complex. In the following step, carbon monoxide is released. Finally, the initial nickel pincer complex is recovered by using hydrogen as a reducing agent and forming a hydronium ion. Overall carbon

dioxide and hydrogen react to carbon monoxide and water. This reaction is called reverse water gas shift reaction.

2.2 Adaptation

According to Yarden et al., nine criteria for the selection of a suitable research article have to be considered [1]: the intended application, the curricula contents, the includability in teaching units, the credibility of the references in the article, the knowledge of the high school students, the clarity of the research approach / question, the visualization ability of results, variety of covered research topics and approaches and the motivation and interest of the high school students. We took all the criteria into account and chose an article of the Collaborative Research Centre 1073 (CRC) because the APL was developed within the public outreach project of the CRC and was intended as teaching material that is online accessible to schoolteachers. Moreover, this article deals with a solution approach to climate change which is curriculum content of German high schools [3]. Furthermore, many school students have shown their interest in this topic by demonstrating for climate protection.

In the next step, the knowledge of high school students was identified by studying the school curriculum of the German State of Lower Saxony as an example curriculum [3]. According to it, high school students should have acquired basic knowledge about acids and bases as well as catalysts in grade 11.

As suggested by Yarden et al. [1], the article was adapted section by section in the following order: results, experimental methods, introduction, discussion, title, and summary. In the results section, only the central reaction pathways were described, alternative ways were left out. Additionally, they were simplified visualized, e.g. the pincer complex structure was abbreviated (s. Fig. 1).

The methods for investigating the reaction pathway, namely x-ray crystallography, nuclear magnetic resonance spectroscopy and infrared spectroscopy, are not part of the German school curriculums [3], which is why the experimental section of the APL, unlike the original article, contained explanatory texts and visualizations of these methods which can similarly be found in schoolbooks [4] (s. Fig. 1). In return, the exact measurement parameters listed in the original article were omitted.

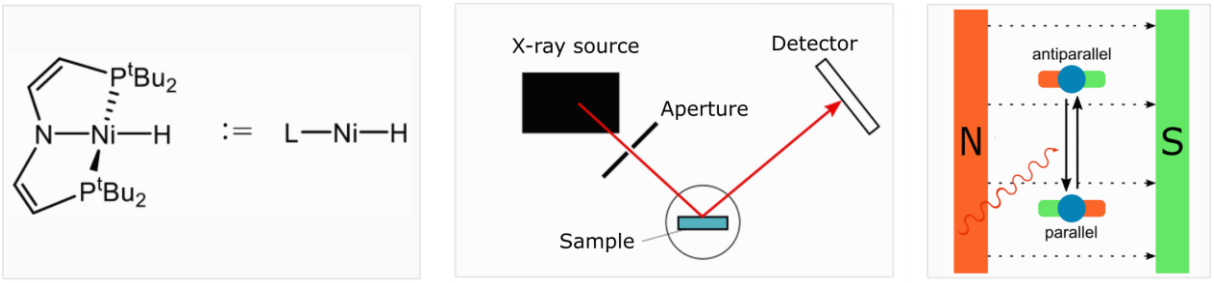

Fig.1. Visualizations used in APL: Abbreviated nickel pincer complex (left), simplified setup of x-ray diffractometer (centred) and schematic picture of basic principle of nuclear magnetic resonance spectroscopy (right).

In the introduction section, the social relevance of the research topic was expressed more clearly in the APL than in the original article. The focus was on the socially relevant climate change and the solution approach of the researchers in order to increase the interest of those students in the APL who participate in the Fridays-For-Future demonstrations and therefore probably seek for climate protection approaches. In addition, the introduction was extended by basic knowledge about complexes and coordination compounds because those chemical topics are not included in the German school curriculums [3]. In contrast, the discussion section was shortened because only the results mentioned in the APL were discussed. The argumentation style of the original article was maintained.

The original title “Photochemically Driven Reverse Water-Gas Shift at Ambient Conditions mediated by a Nickel Pincer Complex“ contained scientific terms students are not familiar with. For this reason, it was replaced by the title “The photochemically driven reverse water gas shift - an attractive approach for a climate-friendly production of synthesis gas?“. Furthermore, a question was added to arouse interest. In the summary of the APL, the content of the APL was reproduced in one to two sentences per section.

3. Evaluation

A survey study with high school students and prospective teachers was performed, to assess their interest in working with APLs in school lessons and evaluate the understandability of the designed APL. The following questions were raised:

- Do high school students understand the text of the designed APL?
- Are high school students interested in the designed APL? Would they like to work with APLs in school lessons?
- What opportunities and risks of integrating APLs in school lessons do prospective teachers consider? Do they intend to integrate them into their future chemistry classes?
- Do the results of the survey with high school students change the opportunities and risks prospective teachers consider? Do they change prospective teachers' intention to integrate APLs into their future chemistry classes?

3.1 Survey with high school students

The survey was performed with 39 German high school students (grade 11) which were divided into two groups: a test group consisting of 30 students and a control group of 9 students.

3.1.1 Methodology

To test whether the APL is understandable to the students, a pre-/post-test design was chosen. Both tests consisted of the same two multiple-choice questions about the approach of using CO_2 as feedstock instead of fossil fuels. The questions for the test and control group were not identical, because the content of the introduction text is slightly different:

Question 1 for the test group: Which statements are correct?

1. Active research is being carried out into the conversion of CO_2 into fuels / energy sources such as methanol.
2. CO_2 is a low-energy substance and therefore cannot react at all.
3. The aim of some scientists is to produce fuels/energy sources such as methanol in a climate-friendly way.
4. I don't know.

Question 2 for the test group: Which statements are correct?

1. CO is currently produced industrially mainly from methane with the emission of CO_2.
2. CO is currently produced industrially from CO_2 in the air.
3. Methanol is currently produced in a climate-damaging way.
4. I do not know.

Question 1 for the control group: Which statements are correct?

1. Active research is being carried out into the use of CO_2 as a renewable raw material.
2. CO_2 is a low-energy substance and therefore cannot react at all.
3. The aim of some scientists is to produce fuels / energy sources such as methanol in a climate-friendly way. To do this, they convert CO_2 into CO, which, when mixed with H_2, forms a synthesis gas for methanol.
4. I don't know.

Question 2 for the control group: Which statements are correct?

1. CO_2 and H_2 usually react with molecular catalysts to formic acid and not CO.
2. The scientists in the article are researching how CO and not formic acid can be produced from CO_2.
3. The scientists in the article are researching ways to produce CO from the formic acid formed.
4. I do not know.

The post-test additionally contained a self-assessment part to study, on the one hand, the understandability with a different method and, on the other hand, the readability of the APL as well as students' interest in the APL. Readability here terms the writing style (the complexity of the used vocabulary and syntax) and was measured to be able to discuss whether a low understanding is caused by a complicated written text.
Each construct was measured by two items with a four-point Likert scale (s. Tab. 1). The item quality was not tested in a pre-study, but the items for measuring students' interest were adapted from the PISA study 2015 [5].

Construct	Number of items	Items (translated into English)
Understandability of APL	2	The content of the text was difficult to understand. The text was hard to grasp.
Readability of APL	2	The text was easy to read. The language of the text was easy.
Interest in APL	2	The text was interesting. I enjoyed reading the text.
Interest in working with APL in school lessons	1	Test group: I would like to work more with such texts (adapted primary literature) in school lessons. Control group: I would like to work more with such texts (translated research articles) in school lessons.

Tab.1. Number of items and items used for each construct.

The survey took place at the end of a teaching unit about fossil fuels. Students had pointed out negative impacts of the German oil consumption on the environment, society and economy and discussed approaches to reduce the oil consumption, before they then faced the challenge of finding out a recent approach of chemists by reading the introduction text of a research article. The APL was handed out to the test group and the original research article to the control group. To avoid language effects, the original research article had been translated into German. Students obtained the information that two versions of the article are provided: an original research article written by scientists to communicate new findings to other scientists which was only translated into German and an article which was translated and adapted to make it more understandable than the original article. However, they did not know which version each individual student received.

3.1.2 Results

The percentage of correct answers to the multiple-choice question 1 in the test group increased from pre- and post-test (s. Fig. 2). The percentage of the first correct answer to question 2 also increased from pre- to post-test, but the percentage of the second one decreased. In the control group, the percentage of respondents who gave the right answers to question 1 decreased from pre- to post-test, whereas it increased for question 2 (s. Fig. 3). Three control group students returned the blank post-test.

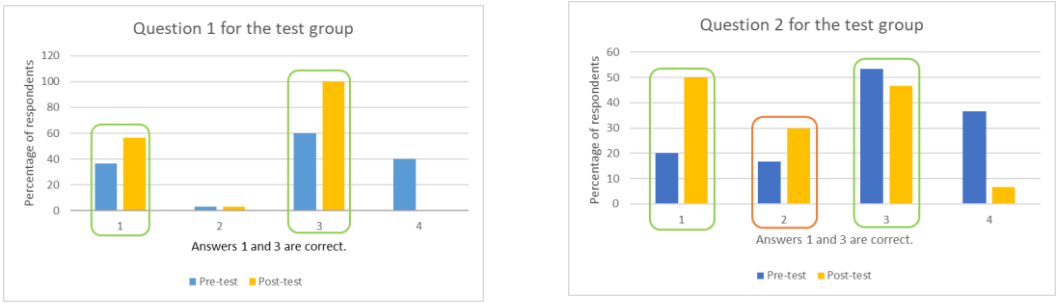

Fig.2. Percentage of respondents within the test group who gave the answers 1, 2, 3 and 4 to question 1 (left) and 2 (right).

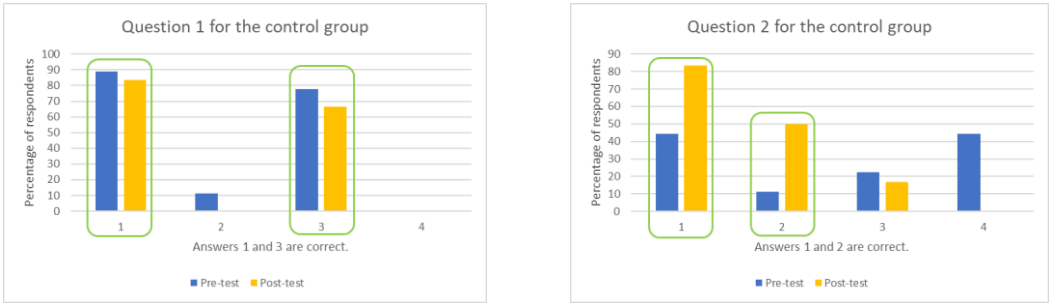

Fig.3. Percentage of respondents within the test group who gave the answers 1, 2, 3 and 4 to question 1 (left) and 2 (right).

More than 20% of the test group had the impression that the APL is understandable, whereas none of the control group assessed the original article to be understandable (s. Fig. 4). More than 80% of the

control group stated that the original research article was not understandable. In comparison, only 50% of the test group indicated the APL as not understandable. Similar results were obtained for the readability. For both constructs, however, the differences measured between the mean values of the test and control groups are not significant.

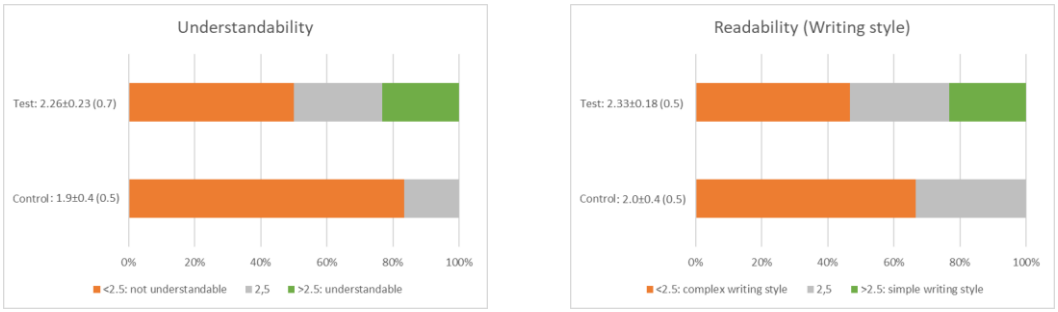

Fig.4. Results of survey concerning understandability (left) and readability (right) of the APL and the original article resulting from the test group (upper bar) and control group (lower bar), respectively; values given are mean values, 95% confidence intervals and standard deviations in brackets. Due to the Likert scale, values range from 1 to 4 (very low to very high understandability/readability).

Only one third of the test group expressed no interest in the APL, one third showed interest. Moreover, almost two thirds of the control group were interested in the translated research article, but only 20% of the test group and around 30% of the control group seemed to be interested in working with the APL and the original research article in school lessons, respectively (s. Fig. 5).

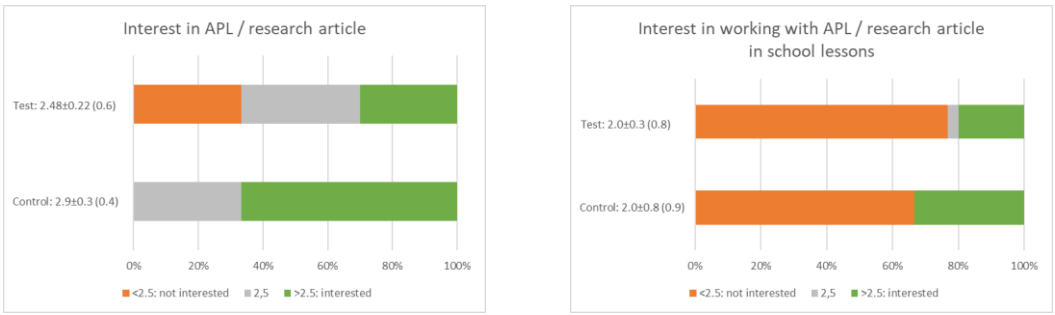

Fig.5. Results of survey concerning interest in APL / original article (left) and interest in working with APL / original article in school lessons (right) resulting from the test group (upper bars) and the control group (lower bars); values given are mean values, 95% confidence intervals and standard deviations in brackets. Due to the Likert scale, values range from 1 to 4 (very low to very high interest).

3.1.3 Discussion

The results of the multiple-choice pre- and post-tests are not conclusive. In both the test and the control group one of the two questions suggests that students understood the text, while the other leaves room for discussion: The reason why the percentage of respondents in the test group who gave the second correct answer to question 2 decreased might be related to the wrong answer “CO is currently produced industrially from CO_2 in the air.” Students probably thought that this answer is right because the article reports about CO produced from CO_2, but not on an industrial scale. Maybe they simply missed the word “industrially” when reading the answer option. The unclear control group results are likely caused by only six of nine control group students returning a completed post-test, which may be a sign that those students felt not capable of answering because they did not understand the text.

The results of the self-assessment part of the survey indicate that the APL was more understandable to the high school students who participated in the study than the translated research article, even though the difference in the measured mean values is less than 0.5 and not significant. If the difference is rather small, many more participants would likely have been required for a significant result.

As the results for the understandability and the readability of the APL were similar, the reason why students rated the text to be “not understandable” did probably not predominantly result from a complicated written text.

3.2 Survey with prospective teachers

Another part of the survey was conducted with prospective teachers which were preferred over established teachers, because they might be more open to new concepts, as they do not yet have tried and proven concepts for teaching the curriculum content, but rather need to test concepts and figure out which one works best for them. The chosen prospective teachers were nine university students in the first or second year of the Master of Education program and one student at the very end of the Chemistry Education Bachelor program. All ten students participated in a Chemistry Didactics seminar, six students in person and four virtually. Six students were female and the rest male. Their second subjects besides Chemistry were Mathematics, Biology, French, Philosophy and Sports.

3.2.1 Methodology

The survey was included in one session of a Chemistry Didactics seminar. Firstly, students were encouraged to think about opportunities and risks of the integration of APLs into school lessons and to express their thoughts with notes pinned on the board or with the online tool “shared notes”, immediately after the concept of APLs had been presented to them and the designed APL had been handed out to them. Furthermore, they were invited to make a mark between the two options “I will, or I will not integrate APLs in my future Chemistry lessons”. Secondly, the results of the survey study with high school students had been shown before students then got the chance to change their notes and the position of their marks.

3.2.2 Results from participation in person

Among others, university students considered the opportunity to integrate current research into school, to make additional learning offers for high-performing school students and to motivate them by authentic science (s. Fig. 6). However, they worried that APLs might not be understood by school students, especially not by low-performing students. Apart from that, they took into account that teachers have to respect the curriculum and need to spend extra time incorporating APLs into lessons. After the survey about high school students’ understanding of APLs and interest in them had been shown, university students added notes about the risk of the APL being too long and the APL topic not being interesting to a learning group.
Most of the students placed their marks closer to the statement “I will integrate APLs into my future Chemistry lessons” but moved them a bit closer to the middle position between the two contrary statements, when they had seen the results of the survey with high school students (s. Fig. 7).

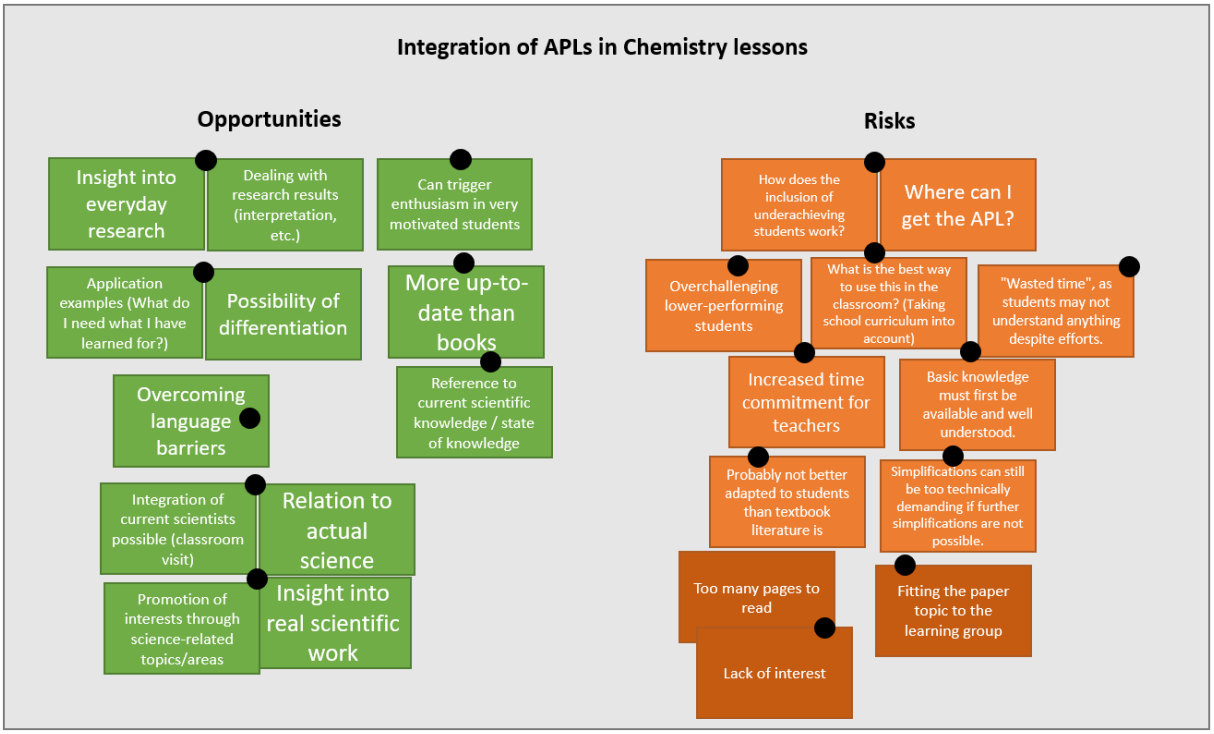

Fig.6. Translated noted opportunities and risks of integrating APLs in school lessons six prospective teachers considered: The light green and light orange notes had been pinned on the board before the results of the survey with high school students were shown, while the dark orange notes were added after that.

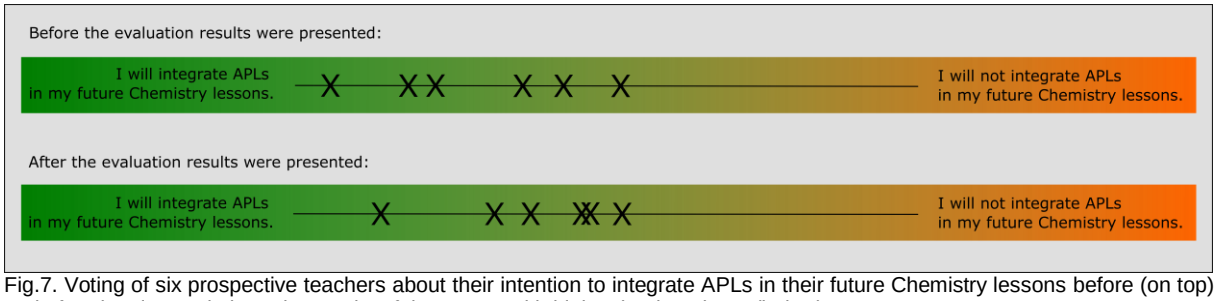

Fig.7. Voting of six prospective teachers about their intention to integrate APLs in their future Chemistry lessons before (on top) and after they learned about the results of the survey with high school students (below).

3.2.3 Results from virtual participation

Virtual participants of the seminar pointed out the opportunity that students can acquire skills they need for scientific work and studying at a university and that APLs can represent the scientific process of gaining knowledge. In addition to the concerns already mentioned by students attending in person (APLs being too complex for students and too time consuming for teachers), virtual participants identified the risk of the original article being adapted so much to school students that the scientific structure is lost. Just like the in-person participants, virtual participants were in favour of APL integration into Chemistry lessons. The presentation of the survey study with high school students did not result in participants changing their notes or voting. Here is the complete list of notes and voting of the virtual participants (translated into German):

Opportunities:

- Opportunity to introduce school students to scientific literature
- general skills in relation to scientific work are trained (reading and understanding scientific texts, application and use of technical language, ...)
- Preparation for university
  - ➔ early familiarization with such texts
  - ➔ can facilitate the transition from school to university
- compressed presentation of information
- represents the process of research

Risks:

- Complexity
- English as a foreign language (?)
- High time commitment for teachers
- Risk of changing scientific texts too much so that the actual structure of scientific research is lost (negative impact on later professional life or university studies)

I will integrate APLs in my future Chemistry lesson (0% to 100% meaning “strongly disagree” to “strongly agree”)

- 80% (certainly well suited for school courses at a high level)
- 70 %
- high school class 70%; other classes 50%
- high school class 70%, other classes 30%

3.2.4 Discussion

Prospective teachers considered great opportunities, but also understandable risks. Their concern that even adapted research articles might be too complex for some students was supported by the survey study with high school students. We assume two reasons for their slightly decreased interest in integrating APLs in school lessons after the results of the survey study with high school students had been shown: Half of the surveyed high school students stated the APL to be not understandable and only 20% would like to work with APLs in school lessons. In agreement with this assumption, the prospective teachers expressed the risk that school students have no interest in APLs after seeing the survey with high school students. However, prospective teachers found as many opportunities as risks and the voting showed that they were overall more inclined to integrate APLs into their future teaching than not to do so. Finally, it should be noted here that the study with the prospective teachers

including the voting was not secret and was performed as part of a Chemistry Didactic seminar, which may have affected the study results.

4. Conclusions

An APL originating from a research article dealing with a solution approach for the climate change was developed and evaluated in a survey study. The results give rise to the assumption that the APL is more understandable to high school students than the original research article which was only translated into German. Thus, the purpose of making a research article understandable for high school students seems achieved. However, half of the high school students surveyed stated the APL as not understandable, which shows that the APL needs to be revised to further enhance the understandability. Moreover, the study revealed that the APL could be made more interesting for high school students. Prospective schoolteachers were also surveyed, and they all expressed their intention to integrate APL into their future classes, even though they considered as many risks as opportunities in doing so and even though the survey results about school students' interest had a slight negative impact on their intention and considerations.

Acknowledgement

We would like to thank the German Research Foundation for funding the Public Outreach Project within the framework of the Collaborative Research Center 1073.

References

[1] Yarden, A., Norris, S. P., & Phillips, L. M. (2016). Adapted Primary Literature. Springer.
[2] Schneck, F., Schendzielorz, F., Hatami, N., Finger, M., Würtele, C., & Schneider, S. (2018). Photochemically Driven Reverse Water-Gas Shift at Ambient Conditions mediated by a Nickel Pincer Complex. Angewandte Chemie International Edition, 57(44), 14482-14487.
[3] Niedersächsisches Kultusministerium (2022). Kerncurriculum für das Gymnasium – gymnasiale Oberstufe die Gesamtschule – gymnasiale Oberstufe das Berufliche Gymnasium das Abendgymnasium das Kolleg: Chemie.
[4] Bee, U., Blauth, O., Gietz, P., Irmer, E., Kirberger, C., Maier, H., Nelle, P., Töhl-Borsdorf, J., Wiese, K. & Zippel, T. (2018). Elemente Chemie Oberstufe. Ernst Klett Verlag
[5] Mang, J., Ustjanzew, N., Leßke, I., Schiepe-Tiska, A., & Reiss, K. (2019). PISA 2015 skalenhandbuch: Dokumentation der Erhebungsinstrumente. Waxmann Verlag.