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Citizens' views on home experiments in the context of a chemistry citizen science project

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Abstract
Citizen science has gained importance in recent years and revealed great potential, especially regarding science learning and environmental education. However, little is known about ways of supporting individual learning processes within citizen science. With this in mind, a home experiment set, the Nitrogen Box, was developed within a chemistry citizen science project on nitrogen pollution of water bodies. The aim of the box was primarily to deepen the subject matter and to sensitize the citizens to the topic. To gain deeper insights into the usability and added value of home experiments in a citizen science context, semi-structured interviews were conducted with ten citizens. Analysis of these interviews revealed that the nitrogen box contributed to a consolidation and deepening of knowledge of the nitrogen problem in Northwest Germany. Home experiment sets like Nitrogen Box can motivate and enable citizens to engage more deeply with the scientific topic in the future, to reflect on it and discuss it. We discuss how heterogeneity of the target group presents challenges for designing citizen science projects and provide recommendations for the future projects.

Keywords: adult education, citizen science, home experiments, nitrogen pollution, public participation in scientific research

INTRODUCTION AND FRAMEWORK

Citizen science is an approach that involves the public in authentic scientific research through a variety of projects (Dickinson et al., 2012). The way and extent of participation, however, can vary ranging from contributory approaches, where citizens primarily contribute data, to approaches where scientists and citizens work together and public participants are involved in several stages of the research process (Shirk et al., 2012). Early citizen science projects in the 20th century were mainly focused on data collection, especially in the context of ornithological and wildlife studies (Bonney et al., 2009a). In recent years there has been a shift from participants' mere data contribution to acquisition of knowledge and skills (Bela et al., 2016; Conrad & Hilchey, 2011). A relatively newly described potential is the shift from citizen to civic science where stewardship and engagement is put in a new focus and interactive partnerships between different parties are emphasized (Dillon et al., 2016; O'Riordan, 2018). Turrini et al. (2018) describe these different aspects as threefold potential of citizen science with three main goals:

1. **Knowledge generation:** New knowledge in the areas of basic and applied science as well as society-related problems is created, especially regarding the environment and sustainability (Chandler et al., 2017; Dickinson et al., 2010; Turrini et al., 2018).
2. **Learning:** Through participation in citizen science projects, citizens can gain knowledge, skills and acquire scientific and environmental literacy (Bonney et al., 2009b; Phillips et al., 2018; Queiruga-Dios et al., 2020).
3. **Civic participation:** Citizen science can build transformative capacities by enabling citizens to get involved in processes relevant to society (Bela et al., 2016; Dillon et al., 2016; Turrini et al., 2018). Through collaborative learning processes, citizens are empowered to become actively engaged in scientific and environmental issues (Levy et al., 2021).

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Contribution to the literature

- We present the use of home experiments as a novel learning tool in the context of citizen science by means of an implemented example.
- We explore the usability of home experiments in the context of citizen science showing a dependence of the users' perception of the nitrogen box to their existing knowledge and previous attitudes.
- The results show that home experiments are generally positively received by citizens and lead to an increase in learning about the nitrogen issue in Northwest Germany.

Citizen science projects can address a wide variety of topics such as archaeology (Smith, 2014), astronomy (Price & Lee, 2013) and health (Wiggins & Wilbanks, 2019). However, the majority of projects still focus environmental and ecological issues and have been analyzed extensively in Turrini et al. (2018), for example. By addressing these issues, there is a great potential for the promotion of scientific literacy, especially through the connection of societal issues and environmental education (Affeldt et al., 2017; Queiruga-Dios et al., 2020). Apart from the acquisition of project-related content knowledge, several other possible learning outcomes resulting from the participation in citizen science have been reported (Phillips et al., 2018). These include for instance an increased interest in environmental topics (Hiller & Kitsantas, 2014; Silva et al., 2016), higher self-efficacy concerning environmental action (Hiller & Kitsantas, 2014; Kelemen-Finan et al., 2018), increased motivation to participate in environmental action (Silva et al., 2016), acquisition of procedural and methodological scientific research skills (Ruiz-Mallén et al., 2016) or even measurable change in individual behavior (Vetenskap & Allmänhet, 2021). Nevertheless, the desired success is not always achieved in terms of learning objectives, so that a significant change is not always measurable (Brossard et al., 2005). This raises the question of how citizens can be additionally supported in their learning processes. Often, citizen science participants are trained at the beginning of a project to ensure data quality (Crall et al., 2011, 2013; Ratnieks et al., 2016; van der Velde et al., 2017), which has its justification since the quality and handling of data are crucial for the success of citizen science projects (Bowser et al., 2020). Besides instruction on scientific methods and monitoring skills, other goals of training, workshops and educational material are content specific knowledge and environmental action. Examination of an intensive one-day training revealed improvements in content specific science literacy and knowledge and increased willingness to participate in environmental activities (Cronje et al., 2011). Since educational goals are moving more and more into focus, several project-related learning opportunities and activities have been reported. For example, through the design and performance of experiments citizens are supposed to gain deeper project-related scientific insights (Kruse et al., 2020). Herodotou et al. (2018) designed citizen science tools to support inquiry learning through digital platforms and offered a set of guidelines to support learning in citizen science projects: For example, tools should enable users to conduct their own investigations. Furthermore, the scientific inquiry process should be scaffolded to facilitate participation through different tools and mechanisms. The focus should not be on data contribution only, instead, the core principles 'learning by doing' and 'being part of a community' should be communicated. Learning something new is one of the major motivations for citizen science participants (West et al., 2021) and these principles are regarded as an important basis in the design process of educational citizen science projects even though more research is needed concerning the design and use of tools (Herodotou et al., 2018).

One tool that is mostly known in formal educational contexts so far, is the conduction of home experiments, also known as kitchen chemistry (Yip et al., 2012). Gendjova (2007) investigated the effects of home experiments in 7th grade chemistry teaching and observed positive effects on content knowledge, attitudes and desire for additional activities through the performance of home experiments in addition to traditional classroom experiments. Especially the connection of chemistry with real life and accessible materials were identified as essential conditions to increase pupils' interest and performance. De Vries et al. (2006) conducted home experiments not only as a supplement but even instead of school experiments in upper school classes. Here, too, an increased enthusiasm of the pupils for the topic was observed and they were encouraged to work and research more independently. Distance learning and experimenting at home have inevitably gained importance in the recent years due to the COVID-19 pandemic and the subsequent campus and school closures. (Domenici, 2020; Kennepohl, 2021; Schultz et al., 2020). It can be challenging to design suitable home experiments with easily accessible and safe materials, which means that experiments sometimes have to be adapted and simplified for home use. Furthermore, obstacles in the learning process can be met less easily from a distance than during a face-to-face interaction, so the quality and scope of accompanying materials must also be assured (Sari et al., 2020). Therefore, when developing the experiments, attention must be paid to who the target group is, what purpose the experiments are to fulfil and what goals are to be

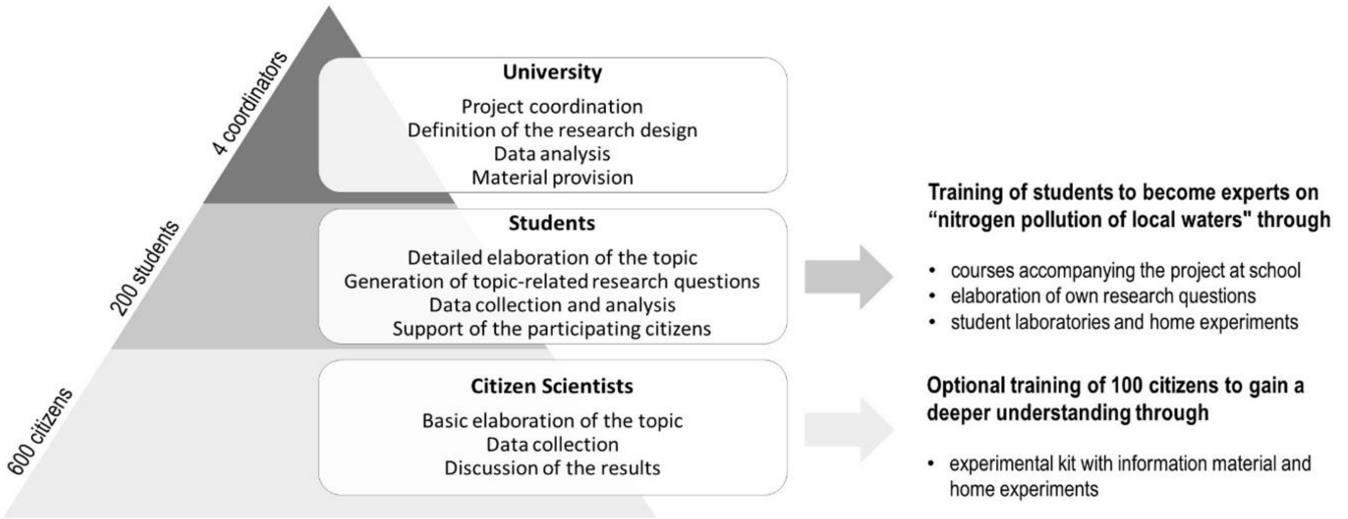

Figure 1. Project structure and key actors

Figure 2. The nitrogen box

achieved with the experiments (Lyall & Patti, 2010). Since, in contrast to the school and university context, the prior knowledge and experience of citizens is often unknown and the age structure is also extremely diverse, providing experiments and materials in the citizen science context can be particularly challenging.

The Citizen Science Project

Against this background, the use of home experiments was integrated and evaluated within a citizen science project that was carried out in the north-west of Germany. In the project 'Pupils and citizens conduct research together with scientists on the nitrogen pollution of local waters'. Nitrate levels of local water bodies were regularly measured over a period of one and a half years (Brockhage et al., 2021). The topic around nitrate was chosen because the release of reactive nitrogen has been a major global issue for years. Human-induced processes, especially in the context of industry, energy and food production, have increased the release of reactive nitrogen, which has long-term negative effects on the environment (Galloway et al., 2003). In Germany, particularly in Lower Saxony, this problem has already manifested in the loss of biodiversity and decrease of groundwater quality (Kastens & Newig, 2007; Salomon et al., 2016). Previous approaches to tackling this complex problem have shown little success, partly due to the conflicting interests of different stakeholders (Kirschke et al., 2019).

Approximately 200 pupils were trained as experts by the universities of Oldenburg and Osnabrück with the help of seminars and school labs (**Figure 1**). They served as contact persons, so-called research sponsors, for about 600 citizens and supported them with measurements and questions. The participating citizens received a short brochure to acquire a fundamental understanding of the topic. However, the focus of the study presented here is on about 100 citizens who received optional training with the so-called nitrogen box.

The nitrogen box contained an experimental kit with information material and home experiments. The goal was to enable citizens to critically reflect not only on governmental decisions and media presentation but also on their own behavior and attitudes.

In creating the nitrogen box (**Figure 2**), care was taken to consider the issue of nitrate in the wider context of the nitrogen cycle, considering other reactive nitrogen compounds such as ammonium and nitrogen oxides. An accompanying brochure then discussed human influences on the nitrogen cycle and the resulting consequences. In addition, it provided an overview of

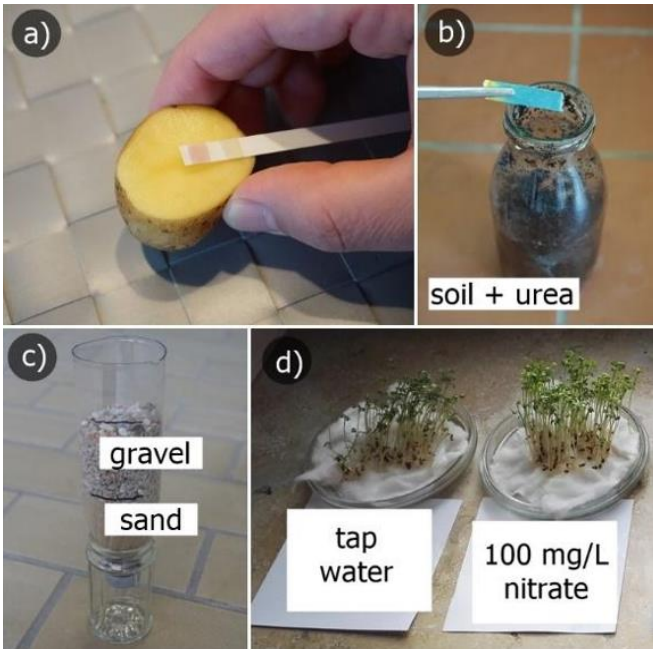

Figure 3. Selection of some experiments from the nitrogen box: a) testing the nitrate concentration of a potato, b) urea decomposition in the soil with formation of ammonia, c) examining the adsorption of ammonium and nitrate ions in the soil with a gravel-sand filter, and d) influence of nitrate on cress growth

current national laws and guidelines as well as information on reactive and preventive measures for water conservation. Finally, the brochure focused on the influence of the individual and the possibilities for each citizen to lower their nitrogen footprint. A full German version of the brochure is freely available online in Lüsse et al. (2022b). For all these areas, it included thematically appropriate experiments, which were described in detail in a second experiment booklet. A digital German version of this experiment booklet can be accessed in Lüsse et al. (2022c). This booklet provided a total of fifteen simple experiments, some of which were adapted for home use from existing experiments in the literature and some of which were developed by the authors themselves:

1. Testing water samples for ammonium ions
2. Testing water samples for nitrate ions
3. Examining the root nodules of legumes
4. Urea decomposition in soil
5. Nitrogen oxides in waste gases
6. Adsorption of ammonium and nitrate ions in soil
7. The effect of urea on soil
8. Investigating the nitrate levels of fruit and vegetables
9. Nitrate and nitrite in spinach
10. Nitrate levels in pickled meat
11. Color development in pickled meat
12. The effects of different nitrogen inputs on plant growth using cress as an example
13. Determining the nitrogen content in soil
14. Soil nitrogen mineralization
15. Nitrate removal by means of ion exchange

Some experiments were quite straightforward, such as testing fruit and vegetables for nitrate by simply holding the reaction zone of a test stick against freshly cut vegetables (e.g., potato, courgetti, etc.) and reading off the approximate value. Other experiments required a little more effort, e.g., investigating the percolation of ammonium and nitrate in the soil using a simple, homemade gravel-sand filter. Also included were a few long-term experiments where results were only visible after a few days, including a qualitative look at urea decomposition in the soil and an investigation of the effects of fertilizers on plant growth using cress as an example (**Figure 3**).

All the experiments could be easily carried out from home using the chemicals and materials provided as well as typical household items such as glasses and spoons. The experiment booklet included a full list of required equipment as well as safety instructions for handling chemicals and general tips.

We used interviews to get insights on citizens' access to and attitudes towards the issue of nitrate pollution. In addition, the focus was on the question of why the citizens decided to use the nitrogen box and how they assess their own behavior regarding the nitrogen problem. Finally, we investigated how the use of the box influenced the citizens in order to derive the potential and the added value of home experiments in the context of citizen science.

METHOD AND PARTICIPANT SAMPLE

The first version of the nitrogen box was given to 13 schools participating in the project and used there in the context of lessons and seminar work. Feedback from teachers and pupils was gathered to design a second, optimized version of the box for citizens. Of the approximately 600 citizens who had already participated in nitrate monitoring, about 100 citizens were given the opportunity to receive the nitrogen box. All 600 citizens were contacted by email and informed about this offer. 97 citizens took this offer and received the box via mail in August and September 2020.

In February and March 2021, the semi-structured interview guide was tested in a pilot study with a teacher participating in the project, who used the box together with her students. Subsequently, the interview guide was optimized and focused on the following main aspects, whereas each aspect contained several key questions to provide answers to the research aims:

1. perception and access to the topic,
2. quality and content of the nitrogen box, and

Table 1. Participant sample

Characteristic		Frequency
Gender	Female	2
	Male	8
Age	30-39 years	1
	40-49 years	2
	50-59 years	4
	60-69 years	3
University degree	Yes	8
	No	2

3. effects due to the use of the nitrogen box.

E-mails were sent to all participating citizens to recruit volunteers to take part in the interviews, after which ten participants signed up (**Table 1**).

The interviews themselves took place in digital form due to the COVID-19 pandemic. They were recorded and varied in length between about 15 and 45 minutes. For the analysis, the interviews were transcribed, and categories were inductively formed according to the qualitative content analysis approach by Mayring (2015). The concept of inductive category development was chosen because no other studies have been published on this research to date whose theoretical foundations could have been referred to in the selection of categories. Since inductive category development is a summative approach, the material was systematically reduced step by step. For this purpose, the statements of the citizens were paraphrased and summarized, so that finally a category system could be formed. As a final step, this summary category system was checked back against the source material. The categories were discussed in detail within the working group for validation, looking at anchor examples as identifiers of the main categories. An overview of the categories relevant to the research questions can be found in the supplementary material.

RESULTS

What Access Do Citizens Have to the Issue of Nitrogen?

While three of the citizens interviewed were new to the topic of nitrogen for the first time at the beginning of the project, most of the interviewees had previous experience with the topic in various ways years before, be it through private interest or job-related involvement. The private interest is mainly due to the proximity of the participants to an area strongly characterized by agriculture:

> "Just from the fact that we are located in a stronghold of factory farming. Many of our friends and acquaintances are farmers, so we certainly have serious discussions about these things there" (male citizen, 51 years).

The professional references mentioned by three of the interviewees are diverse and range from the perspective of the water protection authority to construction perspectives from civil engineering to the perspective of a person involved in agriculture.

Regarding the citizens' access to the topic of nitrogen, they were first asked about content-related associations in relation to the topic. The environmental impact associated with reactive nitrogen was mentioned most frequently. Other associations were fertilization, industry and traffic, consumer behavior and nutrition, health aspects, political dealings, factory farming, distrust of the media, but also the necessity of nitrogen as a plant nutrient. In addition to the diversity of content associations, a wide variety of fundamental attitudes to the topic of nitrogen could also be observed. One citizen emphasizes the importance of nitrogen as a nutrient:

> "Nitrogen is an important plant nutrient. Without nitrogen we wouldn't have enough to eat" (male citizen, 64 years).

For others, the topic is accompanied by a certain concern and insecurity and thus a negative reference:

> "It's the impact on our food, on our lives, our health, which are rather negative in that form" (male citizen, 43 years).

Why Do Citizens Choose to Use the Nitrogen Box?

When the box was advertised, it was already explained to the citizens by e-mail that the box offers material to deal with the topic in depth and experimentally. At the same time, it was pointed out that the offer is primarily an offer for adults and, due to the complexity of the topic, is only suitable to a limited extent for children, depending on their age and support possibilities. The reasons given by the citizens why they decided to use the nitrogen box in addition to participating in the nitrate monitoring are manifold. Some citizens were simply curious and approached the box very openly and without expectations. One aspect that was emphasized by six of the interviewed citizens was the possibility to become active themselves and to be able to take and control measurements in this way. Fun and interest in experimenting also played a role:

> "And in general, I always find it exciting to do experiments myself and to take part in them" (male citizen, 51 years).

Another aspect was education, not only for oneself but for others. Two of the interviewees ordered the box so that they could work through it together with their children in order to

> "perhaps also give the next generation a little more to hand than we got back then" (male citizen, 51 years).

Others wanted to know how the topic was didactically taught and to what extent the materials could be used in their own teaching or to introduce the topic to other people. However, two citizens also emphasized that they wanted to personally educate themselves in this way and delve deeper into the subject matter. Lastly, four participants liked the project, wanted to support science and in this way

> "[…] make a small contribution to research" (female citizen, 51 years).

Overall, the intensity of use of the box by the citizens surveyed varied greatly. While one citizen conducted almost all experiments, other citizens had not yet conducted any experiments themselves at the time of the interview. However, a large part of the respondents had conducted at least four experiments (six citizens) and all interviewed citizens had engaged with the material. Lack of time was mentioned as the main reason for not experimenting more (seven citizens) and especially for long-term experiments or experiments that required some preparatory work, the effort was considered too high for some citizens. The interviewees said that such experiments could be more interesting for children and young people than for adults. For most adults, the experiments that are more interesting are those in which a result is obtained quickly and easily.

How Do Citizens Evaluate Their Own Behavior Regarding the Nitrogen Problem?

The assessment of one's own behavior was considered important especially in order to create a basis for the evaluation of possible impacts through the use of the nitrogen box. Four aspects were derived from the citizens' answers, whereby some participants' answers could be assigned to more than one category:

1. Responsibility is not up to the individual (one citizen)
2. Aware of potential for improvement (five citizens)
3. Conscious living and consumer behavior already existent (six citizens)
4. Own assessment difficult (two citizens)

Many citizens are aware of the potential for improvement in their personal behavior. It was emphasized several times that there is actually always something that can be improved. However, habit and convenience often play a role here, especially when it comes to food or car use:

> "Yes, ambivalent. As I said, so it's in the head. I am actually convinced that one should do much more. Nevertheless, I don't cycle to work, which would actually be possible, but instead get into the car for reasons of comfort. So then there is this dichotomy. I am aware that one should do more and I also find it admirable when people tell me that they do great things and pull it off. Personally, I'm not so strict about it sometimes, unfortunately" (male citizen, 42 years).

At the same time, many citizens could already name aspects in which they reflect their behavior as conscious and responsible. Four focal points were identified:

1. **Building and household:** One interviewee wants to ensure water conservation through concepts on private property.
2. **Discussion and self-reflection:** Regular reflection and discussion of one's own consumption behavior in one's own family takes place in the case of one interviewee.
3. **Means of transport:** Three interviewees mentioned using the car as rarely as possible.
4. **Nutrition:** Conscious handling of food and conscious nutrition, especially by reducing the consumption of meat, is addressed by four of the participants.

Two of the participants found it difficult to make their own assessment

> "[…] because I don't know if it is particularly pronounced in me or if it is just normal for me. I can't say that" (female citizen, 33 years).

What Impact Does the Use of the Nitrogen Box Have on Citizens?

With regard to the question of what the citizens took away or learned from using the box, it was possible to identify some methodological, experimental skills as well as, above all, content-related aspects from the answers. In terms of methodological and experimental skills, some activities and experiments have remained in the minds of the citizens. Regarding the experiment in which fruit and vegetables were tested for their nitrate content, one citizen emphasized:

> "It was new to me that [...] the nitrate value of green vegetables [...] is very high" (female citizen, 33 years),

whereby the experimental elaboration played a role

> "to be able to test something like that initially [...]. Otherwise, you don't have any other possibilities to find out something like that" (female citizen, 33 years).

Another citizen, for example, very much enjoyed the study of the effect of fertilizers on plant growth:

Table 2. Identified categories regarding learned content through the use of the nitrogen box

Aspects learned through the use of the box	Example
Influence of soil composition (one citizen)	"This booklet has made it clear to me that the composition of the soil, such as solid rock and sand, plays a major role. And that has now become clearer to me why we have such high [nitrate] values there" (male citizen, 67 years).
Awareness of one's own responsibility (one citizen)	"That one should not only think in terms of agriculture, that private individuals are also involved. And yes, everyone's behavior contributes to it" (female citizen, 51 years).
General refreshment & expansion of knowledge (three citizens)	"On the one hand, it has refreshed my knowledge, but on the other hand, it has also significantly expanded it" (male citizen, 64 years). "I have already learned something in that sense, also the big picture, the connections. What you already knew about individual things has now been put together to form a bigger picture" (male citizen, 43 years).
Awareness of complexity of topic (four citizens)	"So much plays into it, even all these experiments, you saw that. Everywhere you can and have to pay attention to it. It's a very complex issue" (female citizen, 51 years).
Regional information & references (two citizens)	"Things are also discussed, for example, concrete examples. For example, what has been done in [name of the village]. So really concrete measures [...]. Of course, I was not so aware of such things. That was then added on top of everything else" (male citizen, 51 years).

> "I prepared fertilizer solutions and you could see how it worked in detail. I found that very interesting" (female citizen, 51 years).

In addition to the concrete experiment-related aspects, the citizens stated that they had learned the certain aspects by using the box, which we show in **Table 2**.

Four citizens already had a lot of prior knowledge through their studies and profession, so according to them this previous knowledge was not really expanded by the box.

In addition to the learning effects, the focus was on the question of the extent to which the use of the box had an impact on the behavior and attitudes of the citizens. The aforementioned awareness of the complexity of the issue and of one's own responsibility also play a role here. Some citizens could not observe any concrete changes in themselves, but existing attitudes were strengthened (four citizens). The nitrogen box was considered helpful in this regard:

> "Now, through these experiments and the background knowledge from the accompanying booklet, I think you also have relatively good arguments with which you can try to convince [others] that the [nitrate] levels should be lowered" (male citizen, 42 years).

For four of the interviewees, the use of the box has led to a deeper discussion of the topic, which also goes beyond the box:

> "So simply the discussion within the family, with the children, that we talk more often about such topics" (male citizen, 51 years).

For two citizens, the box was an incentive to look further and deeper into the topic in the future:

> "I don't believe that once we have gone through these experiments here in the house, that it will be a topic that is closed for us. I believe that we will continue to pursue this topic, at least here in the house. [...] The use of the nitrogen box has meant […] that interest could really be passed on to our daughter. And I hope that many other users see it the same way" (male citizen, 51 years).

> "This whole thing that I want to go deeper now, that I want to get back into chemistry now. [...] I definitely want to deal with this subject more now. Not only observe, but also do experiments. To really approach it in a completely different way. To go deeper, that's what I'm in the mood for again" (male citizen, 67 years).

From the interviews it can be concluded that changes using the box were primarily observed in the form of attitudes and knowledge. Concrete changes in behavior in this sense were not reported by the citizens.

DISCUSSION AND CONCLUSIONS

The nitrogen problem is a complex, multi-faceted issue with a multitude of potential impacts on human and ecological health (Galloway et al., 2003). Other citizen science studies that have conducted nitrate monitoring with the help of citizens tend to focus on the scientific data that could be obtained from the project (Bishop et al., 2020; Hegarty et al., 2021; Thornhill et al., 2018). In contrast, educational aspects are less in focus. To meet educational demands of the citizen science project, it was essential to embed the topic of nitrate in a larger context and to create opportunities for a basic or even extended understanding, depending on the capacities of the citizens. In this exploratory study on a novel concept of supporting educational goals in a citizen science context, some initial findings regarding the usability and effectiveness of home experiments could be derived.

Educational materials accompanying home experiments have proven to be an effective motivational tool. With the help of the box, which of course is only partly comparable with the web-based learning tools by Herodotou et al. (2018), some of the guidelines for supporting learning in citizen science projects could be implemented. For example, it allowed citizens to conduct their own investigations focusing on 'learning by doing'. Thus, the nitrogen box with home experiments was primarily perceived as a good opportunity to deepen content knowledge. As in other citizen science studies, the deepening and broadening of content knowledge relates to the content that was focused on in the respective project (Aivelo & Huovelin, 2020; Baptista et al., 2018). Depending on the previous level of knowledge of the citizens, specialized knowledge could be consolidated as well as considerably expanded. The resulting in-depth examination of the topic also contributed to a reflection and questioning of one's own behavior in terms of sustainable environmental action. Another fruitful aspect of the home experiments was their communicative value, which arose from the use of the box within the family, such as with one's own children.

While through the use of the box citizens have certainly observed effects on their own attitudes, they have not communicated any concrete behavioral changes. Some gave the reasons for this directly and saw themselves, for example, as limited in their options because they cannot or do not want to do without a car due to their place of residence. The observation of little or only a few isolated behavioral changes was also made by Lüsse et al. (2022a) in a review of various citizen science projects in formal school contexts. Phillips et al. (2018) have outlined the extent to which behavior change can occur as a result of participation in citizen science. In some cases, significant behavioral changes were observed, in other cases not, or at least not clearly. Further research is therefore needed here for more in-depth insights.

In the citizen science context, the heterogeneity of the target group is greater than in the school context, which also poses challenges. Participants with previous knowledge of the topic learned little new, but mainly consolidated their existing knowledge. Other participants perceived the content as very demanding and extensive. The higher level of challenge was not evaluated negatively here, but it did require the citizens to allocate more time in order to be able to fully engage and concentrate on the contents. Depending on the private and professional capacities of the citizens, this is not always possible. The time factor should be taken into account in adult education (Lieb, 1991; Russell, 2006) and can be a reason why some of the respondents preferred the experiments that quickly led to a result compared to long-term experiments.

Therefore, provided material should reach as wide a target group as possible without over- or under-challenging both in terms of content and in terms of the time involved. It is important to clearly label the complexity of the materials, so that both simple, easily understandable content and experiments are included as well as more complex material. Another possibility, although more preparation-intensive, is to provide different experiment kits so that the participants can decide for themselves whether they want to receive a comprehensive kit or just a more concise, simpler kit.

In total, more men than women participated in the study as it was already the case in Pateman et al. (2021). The participation of citizens with an academic background was also greater than that of citizens without an academic degree. However, quantitative statements cannot be made here due to the small number of participants. The relatively small sample size can be regarded as one limitation of the study, although there is nevertheless a great deal of heterogeneity among the respondents. Moreover, a risk of bias can be assumed as for the most part the people who agreed to be interviewed were those who already showed a greater interest and motivation for the topic.

For future projects, it would be desirable to create more opportunities for collaborative research and exchange of ideas among citizen scientists, since social aspects are counted as one of the essential motivating factors in adult learning (Lieb, 1991). The social aspects and personal exchange have been limited due to the COVID-19 pandemic. Face-to-face event formats should therefore be sought out in the future whenever possible. One, hitherto relatively unexplored possibility are citizen labs, in which experiments are conducted with adults in university or mobile laboratories, similar to school labs, and which can play an important role in communication between science and the public (Scheifele & Burkett, 2016). Citizen labs could be a useful complement to the home experiments, as they offer more space for communication and support. This way of working could be particularly suitable for citizens who have little prior knowledge of the topic and who find it more difficult to work out the content completely independently. At the same time, citizen labs are less flexible than home experiments and therefore probably represent a further complement rather than a substitute to home experiments, as different target groups may be addressed.

All in all, the use of home experiments in the context of citizen science offers a remarkable opportunity not only to communicate subject-specific content, but also to bring people into dialogue and to work together to develop a common understanding of science. Our suggestion is that home experiments are particularly effective for projects with chemistry aspects or projects that touch upon controversial topics and would benefit from further discussion.

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