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Web Technologies to Support Scientific Research and Education in Citizen Science—A Case Study in Germany

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Abstract: In citizen science, citizens are encouraged to participate in research, with web technologies promoting location-independent participation and broad knowledge sharing. In this study, web technologies were extracted from 112 citizen science projects listed on the "Bürger schaffen Wissen". Four indicators on web technologies—Online platforms, Educational tools, Social media, and Data sharing between projects—were chosen to quantify the extent to which web technologies are used within citizen science projects. The results show that the use of web technologies is already very well established in both the natural and social science projects and only the possibilities for data sharing between projects are limited.

Keywords: web technologies; citizen science; education; scientific research

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1. Introduction

Citizen science is an approach where citizens can get actively involved in research activities [1–3], which can build an interdisciplinary bridge between professional researchers and citizens. Citizen science projects cover a wide range of topics, from social- to natural sciences, with scientific research and education as overarching objectives [4,5]. In practice, the scientific knowledge background of citizens is enhanced [6,7] and the data generated become a useful source for scientific research [4]. Since citizen science evolved in the 1990s, its practice has been steadily growing in Europe [8,9]. In Germany, citizen science activities have been pushed forward through the German Research and Capacity Building Project "Citizens create knowledge, knowledge creates citizens" (BürGEr schaffen WISSen–Wissen schafft Bürger, (GEWISS)) funded by the German Ministry of Education and Research [10]. On the associated online platform "Bürger schaffen Wissen" [11], 112 citizen science projects are currently registered (as of February 2021), where the oldest project was launched in 1998 and the most recent in 2021. From this platform, the current state of citizen science in Germany can be derived [12–14]. Compared to 2017 [13], the number of registered citizen science projects increased by 40 projects by 2021.

Citizen science can have an important role in reaching the Sustainable Development Goals (SDGs) [15]. SDGs are 17 global goals adopted by all United Nations Member States as a blueprint to achieve a better and more sustainable future for all [16]. According to Fraisl et al. [17], the greatest correspondence between citizen science and SDGs can be found in SDG 15 "Life on Land", followed by SDG 11 "Sustainable Cities and Communities", SDG 3 "Good Health and Wellbeing", and SDG 6 "Clean Water and Sanitation" [17]. Within Germany, the contribution of citizen science to the SDGs was examined by Schleicher and Schmidt [14]. They found that the highest contribution could be observed for SDG 15 "Life on land" and SDG 4 "Quality of education" [14]. With regard to SDG 4, citizen science does not only support formal education in universities and schools, but also promotes education in diverse forms, including lifelong learning and general up-skilling [14].

The SDGs can also be promoted by information and communication technology (ICT), as it expands communication capabilities and speeds up data transfer. In terms of citizen engagement with the SDGs, these technologies can help citizens inform themselves about current issues as well as access government information so that they can participate in decision-making process [18–20]. Furthermore, ICTs facilitates location-independent participation in scientific projects [21,22] and improve citizens' ICT skills [6,7]. Data gathered from citizens can help monitor the progress on SDGs and can contribute to digitally represent and monitor the world [23].

In terms of citizen science, web 2.0 technologies represent the most important component of ICT. Web 2.0 technologies can be defined as websites and apps that allow others to create and share information. It has been shown in citizen science that web technologies can promote data flow [24]. They facilitate citizens collecting, analyzing, and interpreting data, and share the results on online platforms, as well as managing larger datasets by incorporating data collected from other citizens [25]. Data quality can be improved by using digital materials in education/training methods [26,27]. Information exchange is facilitated through social media [28]. The web technologies that are most important for citizen science were examined in another study. It found that easy access to the web and communication of scientific results were at the top of the list [29].

As the above-described studies imply, the research focus has been rather on the qualitative analysis of web technologies, whereas relatively little is known about the extent to which web technologies are actually used in citizen science projects. Such quantitative information can help to identify deficits between expectations and the actual state or identify needs for more technology in the projects. Nevertheless, each citizen science project has its own structure, design, resources, requirements, and goals, which makes the quantification of web technologies in the projects very difficult [30]. This study will address the research questions of how it is possible to quantify the use of web technologies in a large number of projects. Furthermore, it is about how scientific research and education in citizen science are supported by the use of web technologies and which future potentials there are. Therefore, the aim of this study is to analyze the current state of web technologies in citizen science within Germany: (1) to quantify the extent to which web technologies are used within citizen science projects, (2) to compare the use of web technologies in citizen science projects in different thematic backgrounds (natural and social sciences), and (3) to give an overview on the impact of web technologies in citizen science and future developments. In this study, web technologies were extracted from 112 citizen science projects and a quantitative analysis of selected web technologies was conducted.

2. Materials and Methods

This study is based on the 112 citizen science projects from Germany listed on the central online platform "Bürger schaffen Wissen" [11]. Registration on "Bürger schaffen Wissen" is not mandatory for citizen science projects. Each registered project provides a summary of its research topic on "Bürger schaffen Wissen". All information on "Bürger schaffen Wissen" is freely available.

2.1. Information Extraction

Information on web technologies was extracted from "Bürger Schaffen Wissen" and the individual projects' websites/web apps. Information extraction was performed in January–February 2021 via manual inspection divided into extraction and subsequent verification.

The platform "Bürger schaffen Wissen" contained specific information on the name of projects with the link to the project-specific website/web app, and the geographic extent of projects, availability of social media Facebook and Twitter, and the availability of mobile apps were extracted. Subsequently, the project-specific websites/web apps were manually inspected for web technologies. All information extracted from "Bürger schaffen Wissen" and project-specific website/web apps was recorded in a tabular form. Web technologies were extracted, initially regardless of their abundancy and types. The information extracted is limited to the content visible by visitors without registering for each project.

2.2. Geographic Extent of Projects

Web technologies expand opportunities for location-independent participation in citizen science projects. When projects do not target specific locations, the study area can expand from the federal state to the national, regional, and world-wide scales.

2.3. Thematic Division of Projects

The thematic division of the projects allows the investigation of characteristics in the use of web technologies in the respective field. On "Bürger schaffen wissen" each project is described in several keywords, which were used for the thematic division. Due to the broad range of topics covered by the projects, it made the most sense to divide them into natural science and social science. Out of the 112 projects, 100 could be clearly assigned to one of the two sciences. The keywords animals "Tiere", climate "Klima", microorganisms "Mikroorganismen", plants "Pflanzen", waterbody "Gewässer" and weather "Wetter" were assigned to the natural sciences. On the other hand, the keywords archaeology "Archäologie", culture "Kultur", genealogy "Ahnenforschung", history "Geschichte", and society "Gesellschaft" were assigned to the social sciences. The keywords landuse "Landnutzung", city "Stadt", and technology "Technik" were not assigned to either science. Of the projects examined, 12 projects had keywords falling into both sciences. In these cases, the thematic division was made after a manual inspection on the project-specific website/web app, from which the respective project focus could be identified.

2.4. Determination of Indicators from Web Technologies

The extracted web technologies (Section 2.1) contained a wide range of web technologies. To quantify the use of web technologies, grouping and selection of web technologies was made. Selection criteria included the significance for citizen science based on literatures and the feasibility to check presence in the projects. While web technologies have been largely checkable in the projects, there have been some web technologies, especially in the field of user interaction, where this was not the case without logging into the project-specific platforms. Based on the criteria, four indicators were selected in this study (Figure 1: the availability of online platforms (Indicator 1), educational tools (Indicator 2), social media (Indicator 3), and data sharing between projects (Indicator 4)). The significance of the selected indicators for citizen science is explained below (Section 2.5) in the theoretical background of the indicators.

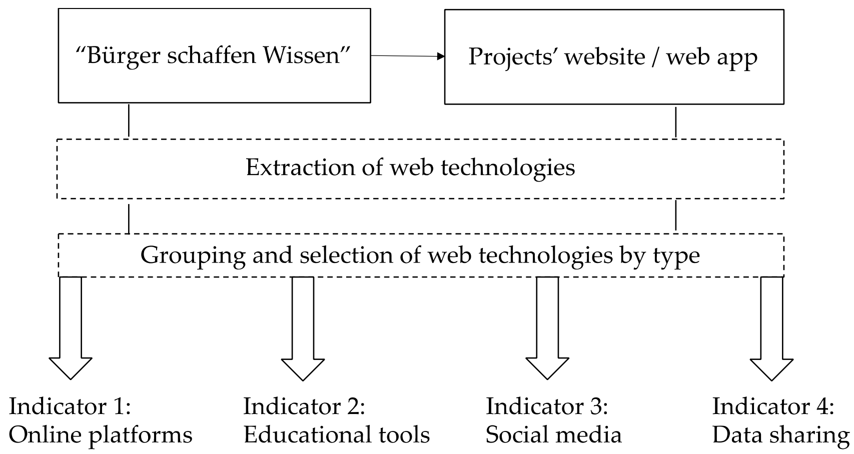

Figure 1. Workflow for indicator determination.

2.5. Investigated Web Technologies

2.5.1. Online Platforms

Indicator 1 addresses the use of the well-known online platforms (websites, web apps, and mobile apps) in citizen science projects [31–35]. Traditionally, projects are presented on a website; this is where interested citizens make initial contact with a project and are then directed to a web app. In contrast, web apps offer citizens numerous tools for active participation in projects, in addition to their informative role. Mobile apps are designed for mobile use considering, e.g., the user-friendliness on the small screen size and limited processing capacity [36,37]. They may perform the same tasks as web apps, but it is also possible that websites/web apps and mobile apps have complementary functions to each other [38].

2.5.2. Educational Tools

The two central objectives in citizen science projects are promotion of science and education, with both having synergistic effects on each other [6,18,39]. Education can promote the knowledge background of citizens [26,27], and thus improve scientific outcomes. At the same time, education can sensitize citizens to certain topics [6,18,31]. Indicator 2 put its focus on whether educational material (1), e-learning (2), and in-person learning (3) are offered. Digital delivery of educational materials (1) gives users access to specially tailored content [7,26]. Teachers might receive teaching materials on specific topics and can use it together with the project's web app/mobile app in their lessons [7]. E-learning (2) offers users the opportunity to independently take online courses in which they are guided through defined learning steps [40,41]. In-person learning (3) could, for example, be organized by a member of a citizen science project and can be delivered in the form of workshops, seminars, and trainings [26,27].

2.5.3. Social Media

Social media can raise the profile of projects and be the interface for online community building and communication between users [42]. Among the social media platforms, Facebook is used the most [33,43]. Facebook belongs to the category of social networking platforms. In comparison, Twitter is an important representative of microblogging platforms [44].

2.5.4. Data Sharing between Projects

The Representational State Transfer Application Programming Interfaces (REST APIs) are the most commonly used interfaces for data sharing between projects, enabling interaction between different systems and platforms [38,45,46]. Exchanging and modifying data via APIs is done using common Hypertext Transfer Protocol (HTTP) request methods such as POST (submit data), PUT (update existing data), DELETE (delete data), and GET (retrieve existing data). Including REST APIs in projects can promote their collaboration [38,47,48].

2.6. Data Analysis and Visualization

An overview of the current geographic extent of the projects is given by using circles which represent different geographic scales (federal state to world-wide) and a map of Germany showing the number of projects in each federal state. The map was visualized using QGIS [49].

Indicators 1 to 4 are each composed of subcategories, with Indicator 1 (Online platforms) comprising websites, web apps, and mobile apps, Indicator 2 (Educational tools) comprising e-learning, educational materials, and in-person learning, Indicator 3 (Social media) comprising Facebook and Twitter, and Indicator 4 (Data sharing between projects) comprising API. The percentage shares of the subcategories and their combinations in each indicator were quantified. The results on indicators were visualized using R [50] with ggplot and ggpubr packages. To study whether the use of web technologies is independent of the thematic backgrounds (natural and social sciences), Pearson's chi-square analysis [51], which measures an association between two categorial values, was applied to the data on Indicator 1 to Indicator 3, except Indicator 4 in which only one subcategory exists. The significance level was set to 0.05.

3. Results

3.1. Geographic Extent of Projects

Within the studied 112 projects, 23 projects cover world-wide scale, 9 regional scale (Europe), 36 national scale (Germany), and 44 federal state scale (Figure 2). On the federal state scale, the highest project number can be found in Berlin-Brandenburg (10 projects), followed by Bavaria (8) and North Rhine-Westphalia (8).

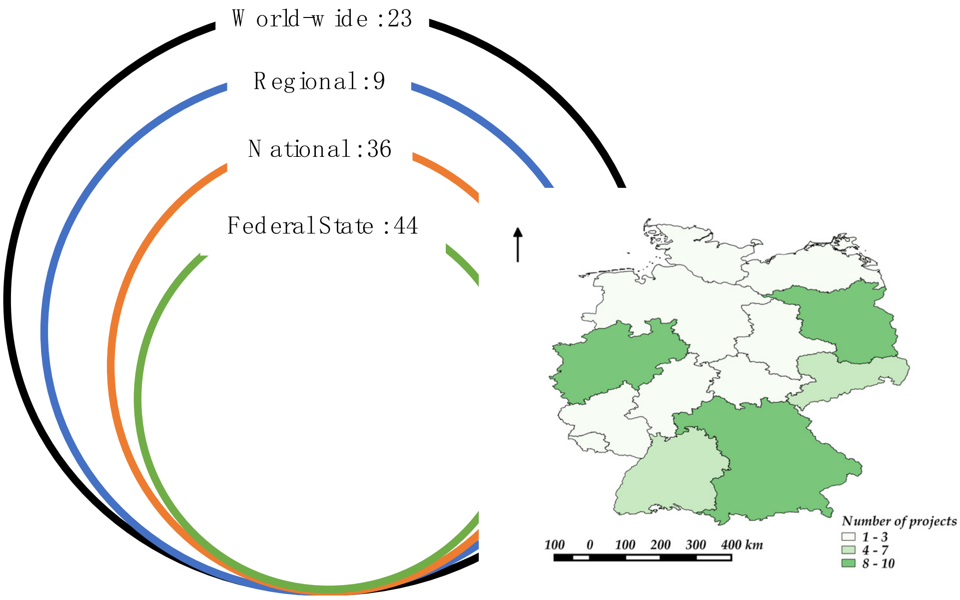

Figure 2. Geographic extent of the studied 112 projects.

3.2. Thematic Division

Out of the 112 citizen science projects, 76 projects were classified as natural science and 36 projects were classified as social science.

3.3. Indicators

3.3.1. Indicator 1—Online Platforms

Web apps have the highest prevalence (78.4% of all projects), followed by websites (42.5%) and mobile apps (29.4%). Overall, 56.5% of the projects offer only one platform out of three.

Divided into natural and social sciences, the proportion of online platforms was very similar, except for mobile apps (Figure 3). Web apps are most commonly used (natural science: 78.9%, social science: 77.8%), followed by websites (natural science: 43.4%, social science: 41.7%) and mobile apps (natural science: 42.1%, social science: 16.7%).

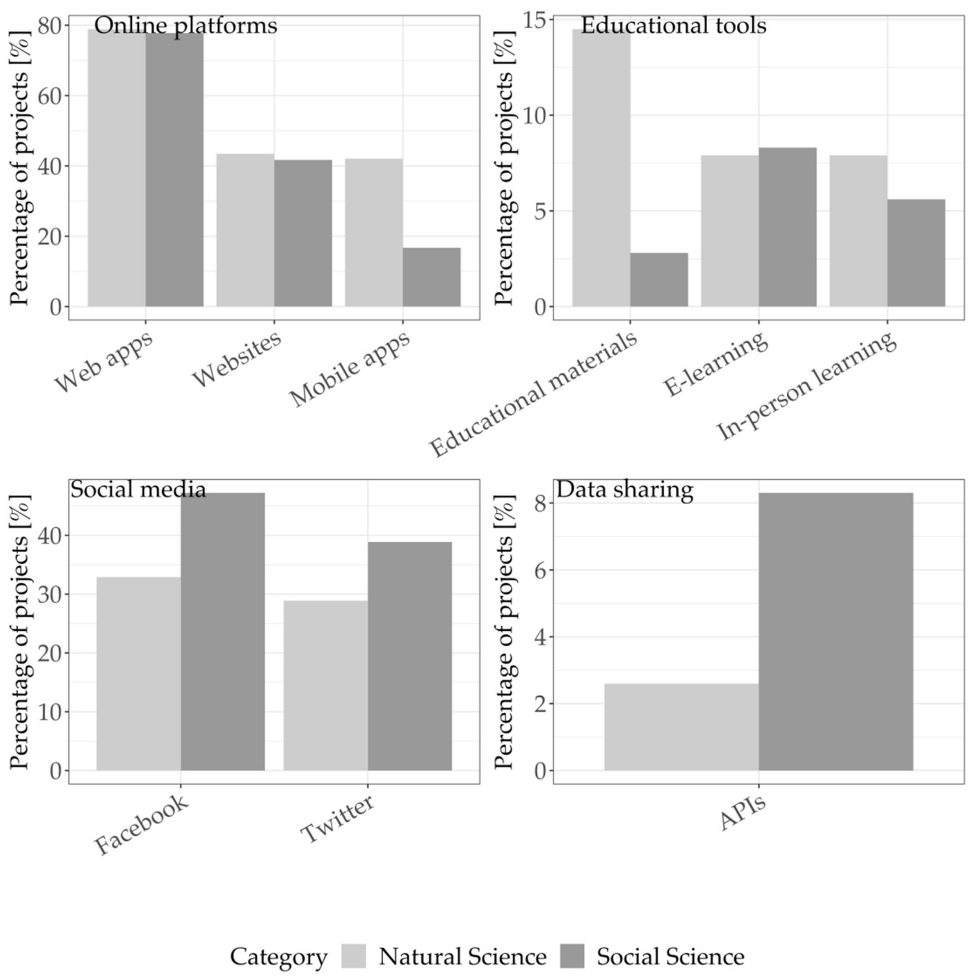

Figure 3. Proportions of projects using web technologies, divided by indicators and natural/social sciences (76 natural science projects, 36 social science projects). The total percentage can be over 100%, as some projects provide multiple options. Due to the large differences between the project shares within the indicators, different scales on the Y-axes were used.

The provision of multiple platforms (Figure 4) is less common in social science (27.8%) than in natural science (59.2%). Among the projects (Figure 4), the combination "Websites & Web apps" is the most prevalent in social science (11.1%), whereas in natural science the combination "Web apps & Mobile apps" is most common (30.3%). In contrast, the lowest proportions could be found in natural science (Figure 4) for the combination "Websites, Web apps, & Mobile apps" (5.3%), and in social science for the combination "Websites & Mobile apps" (2.8%). Pearson's chi-square analysis indicates an association between thematic backgrounds and the use of online platforms (p = 0.02).

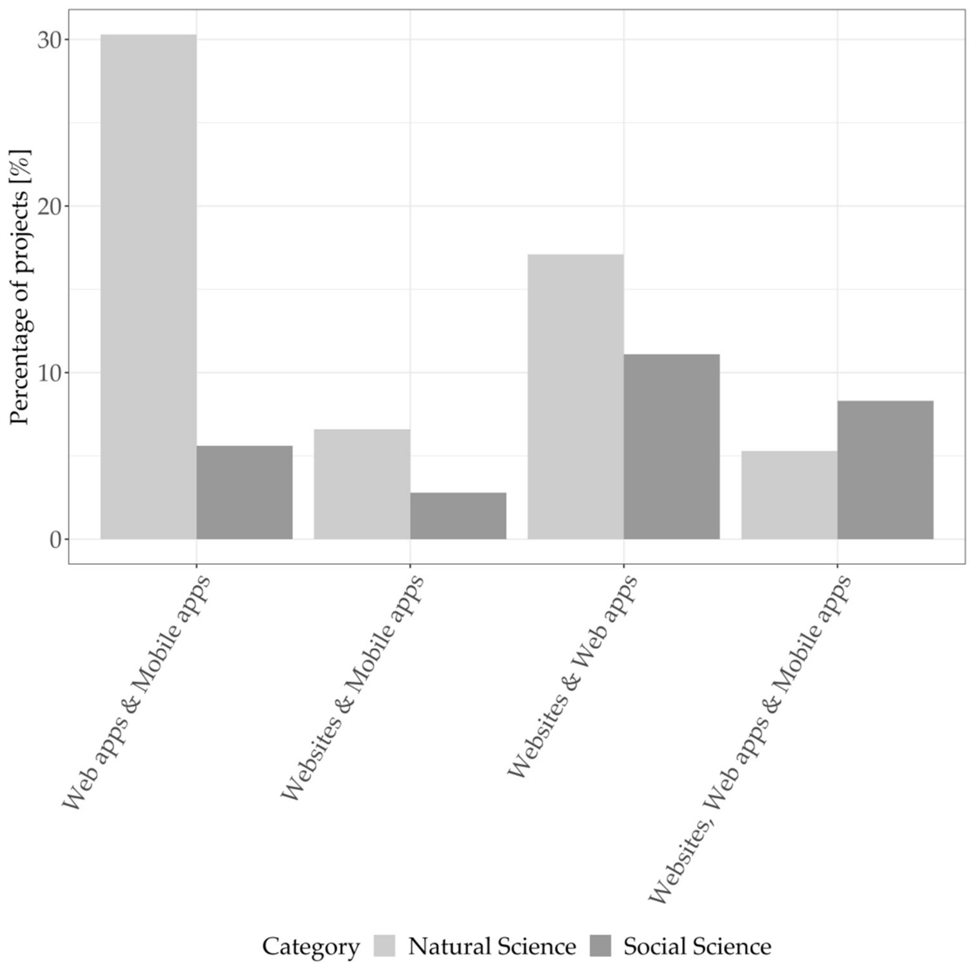

Figure 4. Proportions of projects using multiple platforms, divided by natural and social sciences (45 natural science projects, 10 social science projects).

3.3.2. Indicator 2—Educational Tools

Among educational tools, provision of educational materials (8.6% of all projects) is most common, followed by e-learning (8.1%) and in-person learning (6.7%). Only a limited number of projects (2.7%) offer more than one learning option, with exclusively the combination of in-person learning and e-learning available.

In comparison to social science projects (13.9%), natural science projects offer educational tools more often (27.6%), as seen in Figure 3. In particular, 14.5% of natural science projects offer educational materials, followed by e-learning (7.9%) and in-person learning (7.9%). Within social science, 8.3% of the projects offer e-learning, 5.6% offer in-person learning, and 2.8% offer educational materials.

The proportions of natural and social science projects offering multiple educational tools (in-person learning and e-learning) are similar, at 2.6% and 2.8%, respectively. Pearson's chi-square analysis indicates that the thematic backgrounds and the use of educational tools are independent of each other ($p = 0.40$).

3.3.3. Indicator 3—Social Media

More than half of the projects are connected to Facebook and/or Twitter (52.3% of all projects), where 21.7% are registered on both Facebook and Twitter, 18.3% exclusively on Facebook, and 12.2% on Twitter.

When divided into natural and social sciences (Figure 3), the proportion of projects registered on Facebook and Twitter is higher in social science (47.2% and 38.9%, respectively) than in natural science (32.9% and 28.9%). The highest proportion of projects are registered on both Facebook and Twitter (natural science: 18.4%, social science: 25.0%), followed by Facebook (natural science: 14.5%, social science: 22.2%) and Twitter (natural science: 10.5%, social science: 13.9%). Pearson's chi-square analysis indicates that the thematic backgrounds and the use of social media are independent of each other ($p = 0.40$).

3.3.4. Indicator 4—Data Sharing between Projects

Only a very limited number of projects offer APIs (5 out of 112), which can be found in two natural science projects and three social science projects (see Figure 3).

4. Discussion

In this study the use of web technologies in citizen science projects was analyzed. For this purpose, common web technologies were investigated, and their prevalence was quantified. Based on the projects registered on "Bürger Schaffen Wissen", it could be shown that both in natural and social science the use of web technologies is well established.

Four indicators were determined (availability of online platforms, educational tools, social media, and data sharing between projects) to illustrate the current involvement of web technologies in citizen science projects.

The determined indicators can be linked to SDG 15 "Life on land" and SDG 4 "Quality of education". Web technologies can help to ensure data quality and increase the amount of available data (SDG 15). Providing multiple online platforms (Indicator 1) equipped with different educational tools (Indicator 2) can improve access to education (SDG 4). This analysis does not measure the technical development or success of individual projects, it rather shows the general state of web technologies in citizen science. Due to the constant development of web technologies, the indicators defined here should be extended, if necessary, by newly introduced web technologies. The determined indicators here can also be used on the citizen science projects of other central citizen science platforms such as "Österreich forscht" [52].

Compared to the current state, shifts within the indicators are to be expected in the future for individual web technologies, while the applicability of the indicators remains unchanged. Citizens already have several ways to access citizen science projects today (Indicator 1). Websites and web apps currently outnumber mobile apps in citizen science projects. This could be especially seen in social science. In connection with the increasing shift from stationary to mobile use, the proportion of mobile apps is expected to continuously increase [6,22,46]. Websites and web apps will be retained due to their comprehensive functions, so the offering of multiple platforms is likely to increase steadily.

It was found that among the analyzed educational tools, educational materials are provided most often (Indicator 2). In the future, in-person learning is expected to increase in a virtual environment, including online meetings and virtual reality [53,54]. In particular, the exchange between project members and citizens can be improved through direct communication/guidance. It is likely that the learning experience in the e-learning environment will be enriched by other technologies, such as virtual learning assistants (pedagogical conversational agents) [55], once these technologies become easy to implement. The provision of educational materials, in-person learning, and e-learning could develop in parallel, so it is expected that more projects will offer a combination of educational tools and the educational offering will expand. Currently, social media (Indicator 3) is a popular means of promoting projects. It is also the place where much of the communication between participants takes place. In comparison to in-person campaigns where citizens are contacted to actively participate in a project [28], social media reaches a much larger group of people. It is expected that projects will be promoted primarily through social media, and that in-person campaigns will serve more as an additional boost. If projects do not have their own communication platform, social media is increasingly seen as a basis for building an online community where knowledge and experience can be shared within a large group. This can be seen on Facebook and Twitter, which are part of the majority of citizen science projects. In the future, social media choices will steadily expand, with media-sharing tools such as Pinterest, YouTube, and Instagram in particular growing in terms of promoting projects and broadcasting activities [56]. In comparison to all other web technologies, data sharing between projects/APIs functionality (Indicator 4) is now provided to only a very limited number of projects. The low numbers may be explained by the high technical effort required to implement data sharing tools, such as API. Modern data science largely requires such standard interfaces for collaboration. Implementing this interface in citizen science creates synergies through data sharing, avoidance of repetition, and cross-project data analysis. Projects with frequently studied parameters like weather and land use can especially benefit from this. More projects are expected to provide APIs when their implementation becomes easier.

The projects listed on "Bürger Schaffen Wissen" rather addressed federal state and national scale. Along with the further development of web technologies, it is to be expected that more projects will be able to be present at a regional or world-wide scale if needed.

The division of citizen science projects into natural and social sciences revealed a higher number of projects assigned to natural science than to social science. This is in line with findings of other studies [14,57] which also noted that citizen science has its origins in natural science. In the results, it is noticeable that the social media and data sharing between projects have similar proportions in both natural and social sciences, whereas there are differences in online platforms and educational tools. Pearson's chi-square analysis indicates an association between the thematic backgrounds and the use of online platforms (Indicator 1). These differences can be explained by the individual objectives in the two research fields. Compared to social science, data collection in natural science usually takes place in the field [18,57], so it needs to be possible to transmit observational data via mobile devices at any time from any place. As a result, natural science often offers additional mobile apps, increasing the number of combinations of online platforms. When recording observations in natural science, e.g., of animal and plant species, background knowledge is needed, which is provided in citizen science through the provision of educational tools [26,27]. It is expected that participants in citizen science projects, regardless of natural or social science, will have even more choices offered by web technologies in the future.

5. Conclusions

This study examined the use of web technologies in citizen science projects registered on "Bürger Schaffen Wissen". Due to limitations in the availability of data, there were some limitations in the selection and analysis of web technologies. For example, in the case of social media, no platforms other than Facebook and Twitter could be analyzed. Furthermore, web technologies on data sharing between projects had to be limited to one subcategory API, as no data was available for other comparable tools. In this context, it should also be noted that only information for visitors without registration on project-specific platforms was extracted. Depending on the design of the respective platforms, extraction of web technologies could also have been omitted in limited individual cases. Another limitation of this study is that there may be other citizen science projects outside of "Bürger schaffen Wissen" that could not be included in this study. To our knowledge, there is no other central directory for Germany that lists all citizen science projects. However, in general it would be a good comparison if future studies can examine local, community-based citizen science projects that may not be listed with "Bürger Schaffen Wissen" and identify the methods these projects use to collect, record, and share data.

In the future, the range of web technologies will continue to grow as new types of web technologies are added. The focus will continue to be on improving data collection, the learning experience, communication, and data sharing. The types of web technologies selected in this study cover the important aspects of citizen science. Although not all web technologies could be covered, it was possible to show that web technologies are already well integrated into citizen science projects.

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