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GEO CITIZEN SCIENCE AND THE ROLE OF PARTICIPATORY DESIGN IN THE FIELD OF GEOMORPHOLOGY

ABSTRACT

Citizen science, aiming at integrating citizens, their commitment and knowledge into scientific research, is a powerful way to create additional research outputs and scientific knowledge. This is particularly true when geospatial technology is used to enable citizens to contribute spatial data. While fields such as biology and ecology make abundant use of geo citizen science, only a limited number of projects approach topics related to geomorphology. Due to climate change and its impact on the Earth's surface, research activities that use citizen science are considered very useful to support the work of geomorphologists. However, geomorphology is a complex topic to engage with citizens. Thus, to reach and involve citizens in geomorphological research, we need spatial data collection tools that are tailored to their needs and raise their interest in geomorphology. For this, participatory design is a valuable option since it allows us to get comprehensive information about citizens and their requirements and to integrate this information into the development process. Now, does participatory design reveal requirements otherwise unknown to the developers? What additional efforts must be made when cooperating with citizens in participatory design? The ***citizenMorph*** project, which addresses these questions, found that detailed and valuable insights can be gained (regarding, e.g., information delivery, design issues, and community building), but also that additional efforts are required in terms of the composition of the project team, the interaction and communication during the development process, and the selection of methods, tools and material to be used.

KEYWORDS: collaborative GIS/web mapping, geomorphology, landscape dynamics, geo citizen science, participatory design

INTRODUCTION

In the face of climate change, research activities in geomorphology have become key to understand and respond to the increasing level of disturbance of Earth's landforms and landscapes. This includes the growing vulnerabilities exacerbated by climate extremes (e.g., extreme rainfall events, storms, and droughts) and climate change consequences such as landslides and rockfalls, glacier retreat, and melting of permafrost [*Naylor et al.*, 2017; *Spencer et al.*, 2017]. Even if geospatial technologies, such as remote sensing, allow the identification and monitoring of landscape changes at different scales, scientists are still constrained by the spatial and temporal resolution of the satellite imagery. Thus, in many cases there is a need to collect extensive field data to complement and validate remote sensing products, which is labor- and cost-intensive [*Galli et al.*, 2008; *Albrecht et al.*, 2016; *Fan et al.*, 2019].

In this context, citizen science, which aims at integrating citizens, their commitment and knowledge into scientific research, is a powerful way to create additional research outputs and scientific knowledge in the field of geomorphology. It does not only increase the resources

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available to scientists but it also fosters a partnership between citizens and scientists, it enhances citizens' interest and understanding of science, and draws their attention towards relevant and pressing scientific topics such as climate change and its impact [*Dickinson et al.*, 2012; *Nov et al.*, 2014]. By contributing to geomorphological research activities, citizens can learn more about their susceptible environment and landscape dynamics. This, ideally, leads to behavior change and a more sustainable human-nature interaction. Moreover, people's awareness of natural hazards including related risks may be increased, resulting in a reduced vulnerability of people and enabling them to better cope with the consequences of natural hazards [*Bonney et al.*, 2009; *Muttarak, Lutz*, 2014]. Thus, citizen science brings numerous benefits to the field of geomorphology.

Today, citizen science makes not only wide use of information and communication technologies (ICT) but also of geospatial technologies. This is known as geo citizen science [*Muray*, 2018]. In geo citizen science, especially, mobile, contributory web maps play an important role since they allow citizens to easily collect and report data. Reasons are the availability of mobile devices with camera, GPS and other sensors (to measure, e.g., temperature, light, and noise) that extended the possibilities for spatial data collection and reporting [*Haklay et al.*, 2018], and the popularity of (mobile) web maps among the public [*Thielmann et al.*, 2012].

Project name	*citizenMorph* (Observation and Reporting of Landscape Dynamics by Citizens; citizenmorph.sbg.ac.at)
Funding agency	Top Citizen Science (TCS) initiative of the Austrian Science Fund (FWF), which aims to include citizen science components in ongoing FWF projects (i.e. main project)
Interaction between main FWF project and (TCS) project	The main project, MORPH (morph.zgis.at), focuses on the development of novel methods for mapping, monitoring and modeling spatial-temporal dynamics of surface morphology by integrating various optical and radar remote sensing data in Iceland. There is still a high demand for data gathered directly in the field (reporting on actual events, landform characteristics, landscape changes, collection of reference data and field photos). Since field data cannot be delivered by the scientists only, the involvement of citizens is inevitable: (1) their support in building a valuable field data database, and (2) their input to the development of the data collection solution well-tailored to their needs. MORPH takes advantage of the *citizenMorph* solution by involving citizens in the collection of field data, that can be used for 3D reconstruction of the surface using Structure from Motion (SfM) and dense image matching (DIM) methods, and for enriching and validating remote sensing based results as well as increasing their detail and information content (see figure below).
Project Objective	Develop a pilot solution (together with citizen representatives) that allows citizens to map and contribute field data (spatial data, attribute data, geotagged photos) on landforms, for example, mass movement features (e.g., rockfall, debris flow, and shallow landslide), volcanic features (e.g., lava flow, lahar, and mudpot), glacial features (e.g., moraine, drumlin, and hummock), and coastal features (e.g., cliff, coastal erosion, and sandspit).

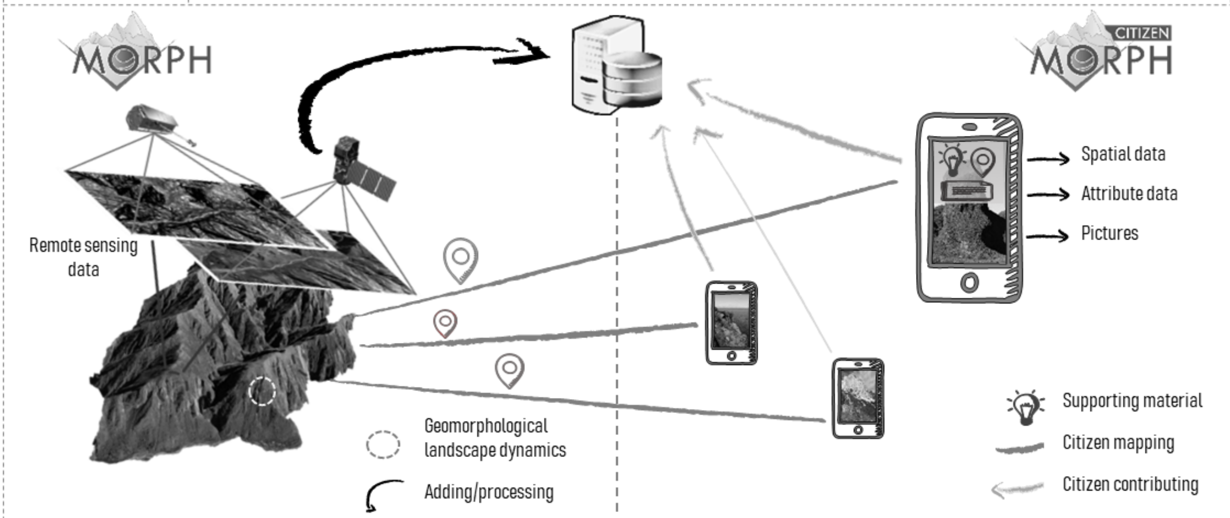

Fig. 1. The ***citizenMorph*** *project*

While in scientific fields such as biology and ecology (with a main focus on fauna and flora observation) many citizen science projects can be found [*Follet, Strezov*, 2015; *Hennig*, 2019; *Matear et al.*, 2019; *Johnson et al.*, 2020], only a limited number of projects approach topics related to geomorphology. Projects like "iCoast — Did the Coast Change?" from the USGS [*Liu et* *al.,* 2014], or "Landslide Reporter" from the NASA [*Juang et al.,* 2019], are examples that focus on observing and monitoring landscapes and geomorphological features (i.e., landforms). A reason for the limited number of initiatives that aim at integrating citizens in geomorphological research is that the field of geomorphology generally faces problems to engage citizens since it is not an easily comprehensible topic and often considered unexciting [*Simm,* 2008].

To reach and engage citizens, we need to provide spatial data collection tools that are tailored to their needs and preferences — including, in particular, their knowledge and interest in geomorphology. Technological solutions must be developed in a way that they encourage citizens' ongoing participation. Here, it must be stressed that developers still face challenges when developing spatial data products for laypeople. While abundant experience exists on the creation of GI/GIS tools for professionals, less knowledge is available regarding the development of solutions for the public. On the one hand, this target group is more diverse and unfamiliar to developers than traditional GI/GIS users; on the other hand, citizens who are not trained to work with spatial data products have different demands than traditional GI/GIS users; the problems they face are still not well known [e.g., *Tsou,* 2003].

The active and direct participation of future volunteers in the development process (i.e., participatory design) is a valuable option to meet this gap. Now, the question arises, does participatory design reveal requirements from the citizens otherwise unknown to the developers? What do the technological solutions developed together with citizens look like? What additional efforts must be made when cooperating with citizens in participatory design? The ***citizenMorph*** project (fig. 1), which is aimed at developing technological solutions for citizens to contribute (spatial) information on landforms, addresses these questions.

MATERIALS AND METHODS OF RESEARCHES

For the development of the ***citizenMorph*** solution (including requirements specification, design, implementation, and testing), participatory design provided the general and main idea behind the process. Related thereto, the prototyping process model and different methods and tools were used (fig. 2).

Participatory design is aimed at the direct and active involvement of target group representatives in the product development process [*Baek et al.,* 2007]. This refers to a shift from designing ***for*** users to designing ***with*** users [*Sanders,* 2002]. The core idea of participatory design is interpreted in manifold ways. In general, a distinction is made between weak and strong participatory design. In weak participatory design, even though user input is solicited, experts make the decisions. In strong participatory design, user representatives not only participate throughout the entire process but they also make the decisions [*Baek et al.,* 2007; *Kautz,* 2010; *Sanders, Brandt,* 2010]. Regardless of whether weak or strong participatory design is applied, the aim is always to bring user knowledge and skills (i.e., tacit knowledge; aspects developers usually do not know or are not familiar with) into the development process by cooperating with the future users, who are experts on their own requirements, needs, and preferences. Thus, participatory design provides users with a voice in product development processes. In addition to knowing users' requirements, this also refers to applying these findings when implementing solutions [*Hennig,* 2019]. This helps to create solutions that meet the requirements of the intended target group to a higher degree, that let users do whatever they aim to do in a better way, that deliver better user experience, and that have a higher acceptance of the product in use [*Steen et al.,* 2007; *Muller, Druin,* 2012].

In terms of the ***citizenMorph*** project, we used a mixture of strong and weak participatory design. Citizen representatives directly and actively participated in different activities of the development process, but they were only in some cases involved in decision-making. In addition, the prototyping process model was used. As an evolutionary software process model, it is particularly useful when developers are dealing with previously unknown or new topics and user groups [*Agarwal, Tayal,* 2009; *Bullinger,* 2009; *Kumar,* 2003]. Following the prototyping process model, in an iterative procedure, taking the initial and basic requirements, during the ***citizenMorph*** development process, prototypes were continuously (further) developed and improved until the relevant stakeholders (e.g., the citizen representatives, experts, and developers) were satisfied with the result. Based on the knowledge gained (i.e., the final requirements, design suggestions) and the prototypes developed, the final solution was implemented (fig. 2).

In the framework of the tasks defined by participatory design and prototyping process model (fig. 2), different methods were applied such as questionnaires and interviews, analysis of similar systems (AoSS), focus groups, brainstorming, mind mapping, personas, story boarding, affinity diagramming as well as digital and paper prototyping. For the implementation of the prototypes and the final system Survey123 for ArcGIS and the content management system (CMS) WordPress were used.

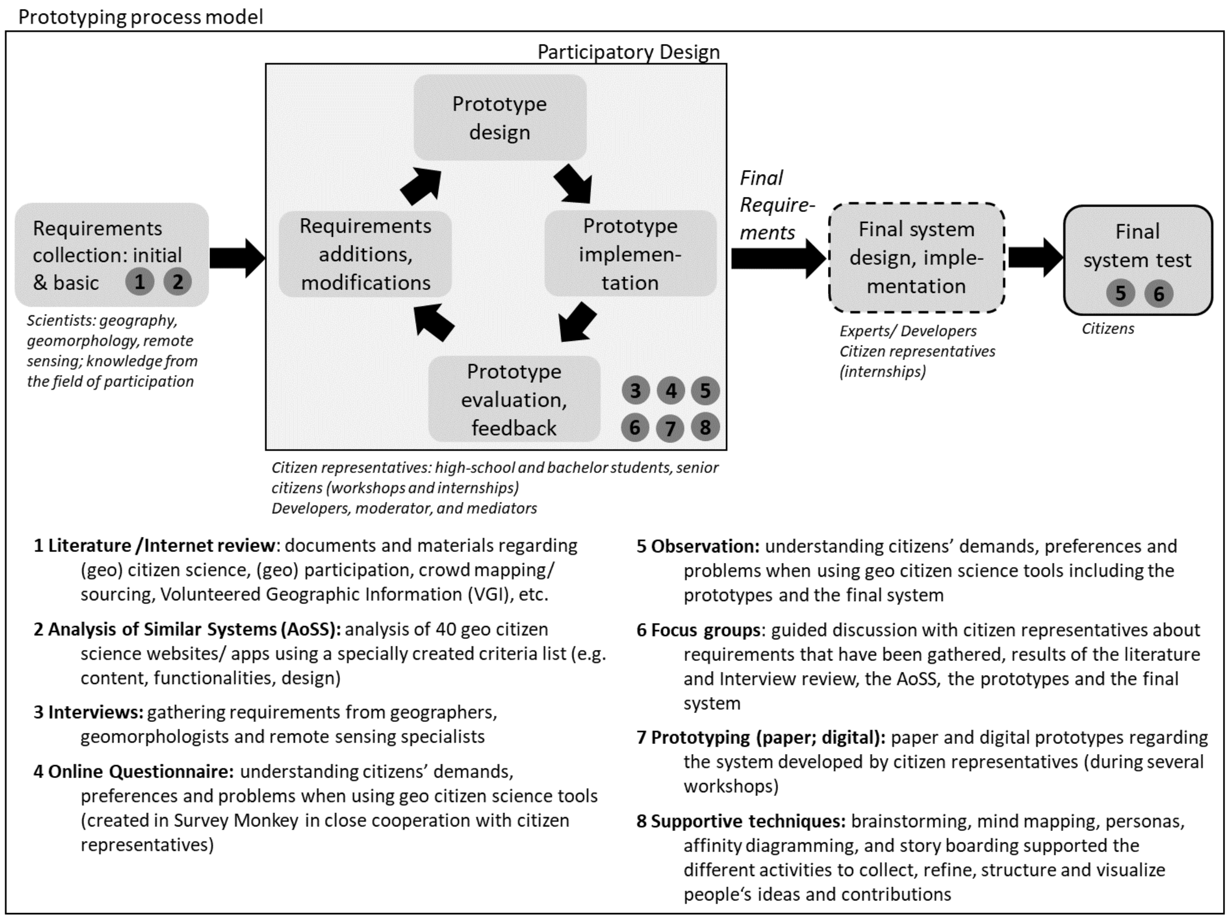

*Fig. 2. Workflow of the **citizenMorph** system development*

All in all, the citizen involvement can be summarized as follows: Citizen representatives from different backgrounds (25 high school students, 14 undergraduate students, and eight older adults) contributed to the requirements collection and the design of the ***citizenMorph*** solution based on prototypes created and discussed by them. Moreover, citizen representatives were responsible for the design and implementation of selected aspects and features of the ***citizenMorph*** solution. This mainly happened during several half-day workshops and four one-month internships for high school students.

On four occasions (indoor and outdoor environment), the citizen representatives tested the final system:

- Excursion to the Berchtesgaden National Park, Germany, and the Weißbach Nature Park, Austria (14 participants; heterogeneous group; 2019 July 11).

- Excursion/workshop in Höfn, Iceland (15 participants; heterogeneous group; 2019 Sept. 5).
- Workshop at Lomonosov State University Moscow, Russia (eight undergraduate students; 2019 Sept. 19).
- Workshop (i.e., international GIS day) at Salzburg University (58 high school and undergraduate students; 2019 Nov. 13).

Feedback from the testers was gathered by using observation techniques (direct observation) and survey techniques (focus groups). This gave insight into the problems the testers faced using the ***citizenMorph*** solution and it provided input for improvement.

RESULTS OF RESEARCHES AND THEIR DISCUSSION

The different stakeholders directed different requirements towards the ***citizenMorph*** solution. In addition to the scientists (e.g., geomorphologists, remote sensing experts, geographers), citizens delivered extensive requirements regarding the ***citizenMorph*** technological solution. Selected requirements were categorized under four groups (i.e., usability and design, help and support, data contribution, as well as community and contact) and are presented in table 1.

Table 1. (Selected) requirements of scientists and citizens regarding the ***citizenMorph*** *solution*

	Requirements/ needs/ preferences
General usability/ design	• Easy to access and use, self-explanatory, attractive design • Well-written and understandable text with short, dense and well-structured content • Customizable text size (readability) • Possibility to enlarge and flip images • Online and offline use with different (mobile) devices • Use of multimedia to provide information and support: e.g., audio files, video, images
Help/ support/ guidance	• Possibility to select the amount of information to be presented; availability of different ways to get information (read, listen etc.) • Information about personal benefits, and possibilities to learn something new • Information about the related domains, project baseline information • Information about how to collect and report data • Information about how to take images (e.g., single image, image series) • Information about safety/ security issues when being on-site, • Information on issues such as data privacy and intellectual property rights (IPR)
Data contribution	• Intuitive to use with comfortable, easy and quick input (only relevant questions) • Possibility to skip questions • Support in identifying landforms: guiding the users by rules and information • Possibility to add a single image of the landform but also a series of images • Possibility to contribute data on-site and/ or at home using different devices • Possibility to edit data entries after submission
Community/ contact	• Directly addressing the volunteers in the context of the project • Direct feedback to the volunteers regarding project progress and citizens' data input • Opportunities for contact and exchange with others (i.e., citizens, project team) • Opportunities to have insight into the project team and community behind • Optional provision and collection of only few personal data

The final ***citizenMorph*** solution — designed and implemented based on the requirements specified and the prototypes created (by the citizen representatives) — consists of different components (fig. 3):

- a data contribution component (implemented as a smart form/survey; arcg.is/15WPKv0);
- an extended internet presence (implemented as CMS website; citizenmorph.sbg.ac.at);

- social webbing services and applications (along with the CMS website);
- different, specially designed (multimedia) features.

The data contribution component is the central element of the ***citizenMorph*** system. Implemented as a smart form/survey, the volunteers contribute data by answering questions related to a landform observed (fig. 3). This refers to single- and multi-choice questions (e.g., personal data of the volunteers such as email, category, and type of the landform observed), adding images of the landform, and mapping the landform location (using a contributory map). Moreover, the data contribution component provides information that is particularly important for the citizens to facilitate and support the data contribution process (e.g., project baseline information, support and guidance for collecting and reporting data, data privacy and safety/ security issues while being on-site and collecting data). Key is that the volunteers can choose between different levels of information (little/no information: expand/collapse multiline text boxes; detailed information: click links to be pointed to the ***citizenMorph*** website where comprehensive information is available). This approach brings different benefits: it allows providing survey-relevant explanations and guidelines only when and if needed and, it prevents demotivation of the volunteers who are not overwhelmed by unwanted information when getting to know and filling the survey.

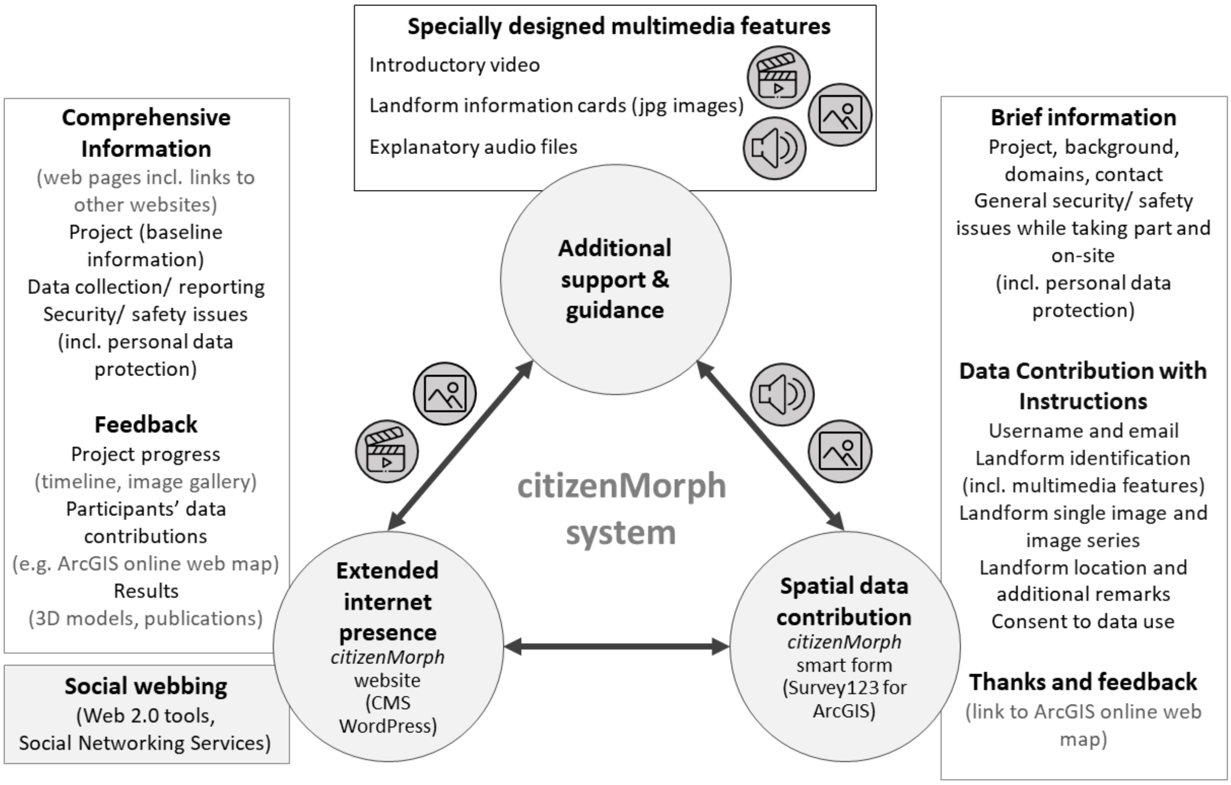

*Fig. 3. The **citizenMorph** system and components*

The extended internet presence (i.e., ***citizenMorph*** CMS website) complements the data contribution component by delivering detailed information on the different topics (i.e., project baseline information, support and guidance for collecting and reporting data, data privacy information, and safety/ security issues). Further, it informs the citizens about the project progress (e.g., publications, events) and gives feedback about the data contributed by the citizens using an ArcGIS online web map and 3D models created from their photo series contributed.

The CMS website also includes social webbing services and applications. Thus, citizens can get in contact with the scientist, developers and other volunteers. They can contribute and exchange ideas using the ***citizenMorph*** blog. Community building is also supported by offline events, which are announced in advance and then reported on the CMS website.

To motivate as well to support and guide the volunteers in collecting and reporting data different, specially designed (multimedia) features have been created. Citizen representatives not only identified the clear need for these features, but they also designed and implemented them:

- an introductory video (available on the main page of the ***citizenMorph*** website) was created to explain the relevance of the project, give some background on geomorphology, encourage citizens to contribute, and explain how to get started;
- six audio files (available throughout the smart form filling) explain briefly the project objectives and deliver instructions on how to fill in the smart form/survey;
- 33 information cards (jpg images available during the smart form filling and on the ***citizenMorph*** website) give relevant information on the different landforms to support citizens in the identification of the landform observed.

Benefits and additional efforts related to participatory design involving citizens

Several benefits come from using participatory design when developing the ***citizenMorph*** system. This refers to the benefits regarding participatory design in general (table 2) and additional benefits for the ***citizenMorph*** project. Below we present some selected advantages.

Table 2. Benefits from using participatory design [based on Hennig, Vogler, 2016]

	Benefits
General	• Get to know the users and learn profoundly about their background, experience, and needs • Prevent and reduce communication problems (e.g., misunderstanding) between developers and users, missing perspective on their life circumstances • Positive effects on the quality and time required of the design process • Toolkit of new ideas
During the process	• Obtain valuable input from the target group • Address people's unawareness on their own needs and their incapacity to describe them reliably • Support developers to identify, describe and recognize the requirements of the target audience and apply them in the design and implementation stage • Deliver a stable foundation for the direction of the solution development • Avoid undesirable developments
Afterwards	• Guarantee that the solution delivers good user experience (i.e., accessibility and usability) • Increase acceptance for the solution in use (including all components and materials related) • Ensure that the implemented solution meets the needs of the users (i.e., having users' needs find their way into solution design and implementation) and having a better match between a solution and the user needs and preferences • Increase solution publicity by the help of the individuals involved in the development process

The citizen representatives underlined the importance of providing the right amount of information to the volunteers, in an interesting and pleasant way. In this context, they highlighted the need for different levels of information to meet the needs of the different kinds of participants ranging from more experienced users (e.g., ongoing participation) to very beginners (e.g., initial participation). Further, to face people's rejection to read text on a smartphone screen [*Hennig, Vogler*, 2016], the citizen representatives required audio files as alternatives to reading. The audio files were created by the citizen represents to guarantee, among others, the use of terms easy to understand by people not familiar with geomorphology and using spatial data products. They focused on providing audio files delivering all information necessary while being entertaining and not appearing “educational”.

The citizen representatives stressed the importance of an appealing design regarding all components and materials. This is in line with other studies that emphasize the role of design as an essential aspect to motivate people to take part in an activity [*Hennig*, 2019]. Several ideas for the design of the website and the data contribution component were developed, in particular, during the high school students’ internships such as use of colors, images, and symbols.

Community feeling and the possibility to collaborate with others are important issues to drive people to participate [*Panek*, 2016]. In general, the community behind an online project relies on computer-mediated interaction and communication [*McCully et al.,* 2011]. This usually requires user accounts (i.e., user registration). The citizen representatives heavily discussed this topic. On the one hand, filling the survey without registration and login and, thus, the possibility to submit data anonymously was seen very positive. It simplifies and speeds up the contribution process, and it leads to fewer concerns on data privacy. On the other hand, citizen representatives mentioned that having a registration option would enhance community building and possibilities to get in contact with each other. To face this issue (i.e., support community building), the ***citizenMorph*** system encompasses social webbing activities that are not linked to the data contribution process (e.g., ***citizenMorph*** blog). Further, asking the participants for username and email during the form filling process (optional question) makes it possible to contact the volunteers to involve them in further activities, when and if wanted.

To exploit the potential of participatory design when collaborating with laypeople additional efforts must be considered. First, this refers to the project team. In line with Fidgeon [2005], professionals from multiple disciplines (e.g., domain experts, developers), user representatives, and moderators with good knowledge of the domain to guide the workshops were involved in the ***citizenMorph*** solution development process. Besides, as suggested by Hennig and Vogler [2016], to ease the cooperation and communication between experts and citizens, mediators (e.g., with pedagogical background) were involved. This proved to be very helpful: the work process was improved and fast-tracked since the mediators provided suitable explanations and ensured that the citizen representatives were not overwhelmed with the tasks, methods and tools, and scope of the work. Moreover, the invitation of external experts gave different insights into geomorphology and geo citizen science. This was well-received by the citizen representatives (i.e., motivating, raising interest in the topic).

In the development of the ***citizenMorph*** solution, offline meetings and gatherings turned out to be key. This provided an appropriate setting to explain complicated topics related to geomorphology, geo citizen science, and solution development. This corroborates that the more complicated a participation activity is, the higher the need for face-to-face interaction and communication [*McCully et al.*, 2011; *Seeger et al.,* 2014]. In addition, the citizen representatives enjoyed and were motivated by the community feeling and the possibility to collaborate with others.

Participatory design requires appropriate ways to involve the future users [*Sanders*, 2002]. Thus, only techniques and tools that proved suitable to be understood and applied by laypeople were used. Related to requirements gathering, in the context of user-centered design (UCD) several techniques are described to be known and easy to use by laypeople [e.g., *Bevan*, 2003; *Hallewell Haslwanter et al.,* 2018]. This is different for tools suitable to be used by citizens taking part in the implementation process of spatial data products. Here, free of charge applications that can easily be installed and used on personal computers and/or smartphones are useful. This allows citizen representatives to further familiarize and use tools also at home. In addition, suitable supportive material must be available. This includes, for instance, information on the project and the topic behind, methods and tools to be used. All material must be easy to access and understand, and in line with the representatives’ needs and preferences in terms of content (e.g., background, knowledge, and skills) as well as design, usability, and accessibility issues. This required us to create various own materials that adequately support the citizen representatives in their work.

CONCLUSIONS

Encouraging citizens to become aware of the constant changes in their surrounding landscape and report them can significantly support scientific work in the field of geomorphology — particularly related to questions connected to climate change consequences. Nevertheless, geomorphology is a topic complex to engage with citizens, and, thus, to benefit from citizen science. The ***citizenMorph*** project contributes to filling the gap in citizen science that approach topics related to geomorphology, which have received little attention so far. Citizens in this sense (i.e., in the context of ***citizenMorph***) become scientists who, among other tasks, contribute to creating a field data database, observing and reporting visible changes in their surroundings, and actively getting involved in the monitoring process.

Exploiting the potential of citizen science technological solutions tailored to the volunteers (e.g., their needs, interests, and motivations) play an important role. Here, participatory design is a promising approach to involve citizens and their requirements in the development of suitable applications. The findings of the ***citizenMorph*** project confirmed this. The active and direct participation of the future volunteers in the development process delivered detailed, valuable, and otherwise unknown insights, for example, into the usability of the solution, how to adequately deliver information, and, on issues related to the data contribution process.

However, it was challenging to implement and harmonize the different requirements of different citizen representatives, and to find a trade-off between technical feasibility, time and effort needed for implementation and consideration of user needs. Here, the use of participatory design involving citizens required additional efforts referring, e.g., to the composition of the project team encompassing not only experts, developers and citizen representatives but also moderators and mediators, the importance of offline interaction and communication, and the selection and provision of techniques, tools, and supportive materials suitable for laypeople.

The findings presented in this paper, on how to use participatory design involving citizens are a first starting point that needs to be further refined. This refers, for instance, to approaches and tools that allow an even stronger integration of citizens in the development process and, thus, delivering even more suitable technological solutions for geo citizen science.

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