Towards a Multidimensional Interaction Framework for Promoting Public Engagement in Citizen Science Projects

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Abstract

Citizen science (CS) projects are expanding into various fields and the number of CS applications is expanding. Despite this growth, engaging the public and sustaining their participation remains a challenge. Some studies have proposed that interacting with participants is an effective way to sustain their participation. This paper introduces a framework that outlines complementary levels of interaction including basic, incentivized, user-centered and action-oriented interactions. The interaction levels range from basic acknowledgments to instructions for taking action. The integration of these interactions within the spatial, temporal, and thematic dimensions is also discussed. The proposed framework is applied to a biodiversity CS project that involves different types of real-time feedback to participants based on the location, time, and image of the species observations. Location-based feedback is based on the species distribution models, and provides information on the probability of observing a certain species in a given location, as well as suggestions on the species to be observed in the participant's vicinity. Overall, the multi-dimensional interaction framework provides CS practitioners with insights into the various ways they can maintain communication with participants, whether through real-time machine-generated interactions or interactions between the project team and participants.

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Supplementary Material *Software (Source Code)*: `https://github.com/mlotfian/Biosentiers-CS-functionality`; archived at `swh:1:dir:ea7f31c8ebd948814342017d44fe7d930b28db90`

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1 Introduction

Citizen science (CS), public participation in scientific projects [3], is not a new concept as for a long time amateur naturalists have been collecting animal and plant specimens and contributing to museum collections [24]. With rapid technological advancements in recent years, the number of CS projects has expanded significantly [19]. The advantage of technology-supported CS is that it favours advanced data collection processes and then additional

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interaction capabilities [20]. Despite the increased number of CS projects, the two essential features of engagement, initiating and sustaining participation, continue to be important concerns [31, 11]. Accordingly, several studies have been conducted to better understand the motivations of participants in contributing to CS projects [21, 8]. Consequently, the importance of interaction with participants and providing them feedback has been mentioned frequently as the main factors to keep citizens engaged [27, 18]. Nonetheless, few projects have investigated the role of feedback on increasing engagement, and if they have, the interaction has been primarily one-way and in the form of a generic response message such as an acknowledgment note or general information regarding the project [27]. Yet, less emphasis has been paid to user-centered feedback and interactions, or interactions that are specific to the contributions made by each participant. Biodiversity CS projects are an excellent example of user-centered feedback. Image recognition techniques are utilized to provide participants with the name of the species captured in their wildlife images [29]. This feedback helps them to verify the species name before uploading the observation to the platform, ensuring accuracy and promoting greater participation. In these projects, the feedback is centered around the participant's submitted image of the species. Although feedback based on images is valuable, even more accurate feedback can be achieved by considering additional factors such as the location and time of the observation. For instance, feedback could be provided on the probability of encountering a particular species at a specific location and time. Thus, considering various dimensions to interact with the participants is one very important element.

Another important factor to consider while interacting with participants is their heterogeneity. For example, for some participants, interaction means receiving incentives, for others, it means receiving acknowledgments and recognition, for yet others, it means active communication about the validity of their contributions and the project's progress, and finally for others, it means receiving guidance on taking actions that may even go beyond the project's objectives and/or time frame. As a result, it is essential to conceptualize the project in such a way that it accounts for these varying levels of interaction.

The objective of this research is to design and implement a participation platform that maximizes citizen interactions and encourages public engagement. Such interactions should not be limited to user single contribution but should include advanced capabilities that support different levels of platform feedback to the citizens, promoting active public engagement. These principles should be supported by practical user-friendly interfaces and applications experimented in real contexts. This paper introduces a framework that favours four levels of possible interactions with CS participants. Moreover, we investigate how these interactions are integrated within the three dimensions of space, time and theme. Furthermore, as a proof of concept, we present a case study of an implemented biodiversity CS project that shows how our approach may be put into practice, focusing on the third level of our interaction framework. In conclusion, we present the potential for expanding the case study and provide examples of the adaptability of the interaction framework to other CS applications in diverse fields.

2 Participation and communication in CS

Active public participation in CS projects can lead to the acquisition and contribution of knowledge, as well as the desire and satisfaction of being a part of a process and a community [33]. There are different categorizations of CS levels of participation, which are mainly focused on the degree of engagement in the project [18]. One of the most known classifications of participants is the one defined by Haklay [13]. Haklay's ladder of participation includes four levels: crowdsourcing, distributed intelligence, participatory science, and extreme CS. As we progress through the levels, the usage of cognition in task performance increases, and participants become involved in greater phases of the project, such as in extreme CS where the participants are involved in problem definition, data collection, and analysis. In a later article [14], Haklay discussed the common conceptualizations of participation related to the misjudgment of participants based on their level of participation by categorizing low level participation (participating mainly to collect data) as "bad" and high level participation (participating in various phases of a project) as "good". He designed a matrix with four cells where the participation to a project depends on the level of knowledge and level of engagement needed for the project, thus four possibilities of low/high, low/low, high/low, and high/high level of knowledge and level of engagement.

While the majority of the literature has been on the level of engagement and participation as measured by the extent to which people contribute to a CS project, less emphasis has been placed on the level of interactions with participants. Various CS projects focus primarily on obtaining data from participants rather than connecting with and understanding their needs as well as giving some information back to them, resulting in a failure to engage people to continue participating as well as a failure to learn from the project [9, 7, 17]. Accordingly, maintaining active communication with participants is critical, but what are the numerous methods by which scientists might develop this interaction between themselves and the citizens? Is it simply the sharing of information or showing appreciation? While communication is critical, some people do not need to engage with one another in order to contribute to a project, while others require active communication and information exchange [12]. It is thus important to understand how to define communication in CS.

Citizens can play different roles when being part of a participatory knowledge production process. Different levels of implications can be identified, from contributory to participatory and actor levels with citizens being progressively involved in dialogue-based relationships and empowerment [15]. At the abstract level, an interaction space generates a common framework for exchange using bilateral communications. Different dimensions can be identified to qualify such interaction space from the physical, spatio-temporal, semantics and technological dimensions. According to Hekker and Taddichen [15] communication in CS can take two forms. First, communication in its most fundamental sense, which is information exchange and two-way dialogues. Second communication as a tool, to identify and reach the target audience, to motivate participants to contribute, to negotiate interests, to provide feedback, and to communicate results.

Given that there are various types of CS projects [3], the goals of communication vary based on the type of project. For contributory projects, where scientists design the project and members of the public primarily contribute data, the goals of communication for citizens are to follow instructions, learn and apply them, and the goals of communication for scientists are to promote participation, increase motivation, and sustain participation [15]. However, in other types of projects where citizens are involved in more steps of the project, such as co-created projects, where the project is designed collaboratively by scientists and members of the public, the main goals of communication for citizens are to provide expertise, negotiate interests, exchange knowledge, create something together, and so on, and the goals of communication for scientists are similar to the citizens with the addition of managing conflicts among the partners [15].

For interaction with citizens, continuous attention is given to the different mechanisms that can foster participation and especially rewards offered to citizens [5, 6]. Certainly, citizens are more likely to get involved if they are convinced of the project's importance.

Monetary rewards have been used and considered as a way to boost citizen participation [5], however, we believe that these methods may introduce biases in the participation process and the topic remains a subject of ongoing discussion in the scientific community. Online acknowledgement is indeed part of good practices but nevertheless they cannot generate further interactions. Rather than acknowledging or monetarizing them, citizens should be considered as active players that can significantly contribute to participatory projects, and giving them a sense of citizen contributors. Besides the studies on communication and interaction with citizens, categorization of these interactions taking into account multiple dimensions of space, time, and theme is missing, to the best of our knowledge.

3 Toward a multi-dimensional 4-level interaction framework

We introduce a multi-level framework for categorizing various levels of interaction with participants in CS projects, and then explain how these levels are integrated across the three dimensions of space, time, and theme. As there are diverse motivating factors to engage citizens in contributing to CS projects [21], some participants do not require any communication, while others demand active interaction to sustain their contribution. In this framework, illustrated in figure 1 four levels of interactions are defined: basic interaction, incentivized interaction, user-centered interaction, and action-oriented interaction.

Basic interaction: The first level includes basic feedback to the participants such as a thank you message after a contribution, or very general information about the state of the project. This level includes the participants whose input is independent of whether or not they are interacted with. They can be highly enthusiastic individuals who are passionate about a particular subject, such as bird watchers who are eager to report sightings and observations, as well as casual participants who may not be as actively engaged in the domain, but who are willing to contribute when the opportunity arises.

Incentivized interaction: This level includes interacting with the participants by rewarding them for their contribution. This interaction can take the form of rewards, which can be either tangible (such as vouchers) or intangible (such as points in a game or a certificate) [23]. These rewards are given in recognition of their contribution.

User-centered interaction: The third level includes providing feedback to participants, which are tailored to their contributions or in accordance to their preferences. This interaction level aims to maintain the contribution of participants that need to receive personalized feedback on their specific contributions. This feedback should not be general, but should rather be tailored to the individual's interests and preferences, taking into account the type of data they prefer to contribute, the location they prefer to contribute data from, and their preferred time for contributing data. In other words, the feedback should be user-centered and should address the three dimensions of space, time, and theme (combined or separated) to generate information that is specific to the participant.

Action-oriented interaction: This level of interaction involves providing participants with guidance and instructions that can be useful in performing an action. This level aims at maintaining the participants who are not only interested in receiving personalized feedback or useful information, but also desire guidance on ways they can actively contribute to the project's goals. For instance, in a biodiversity project, some participants may be more interested in finding out how they can help biodiversity, besides collecting observations. This can range from simple actions like planting a tree, to more elaborate measures like setting up bird feeders. These individuals seek guidance on actions they can take to assist with the project's objectives. The interaction at this level can go beyond the objective and time frame of the project depending on the type of actions that are proposed to the participants.

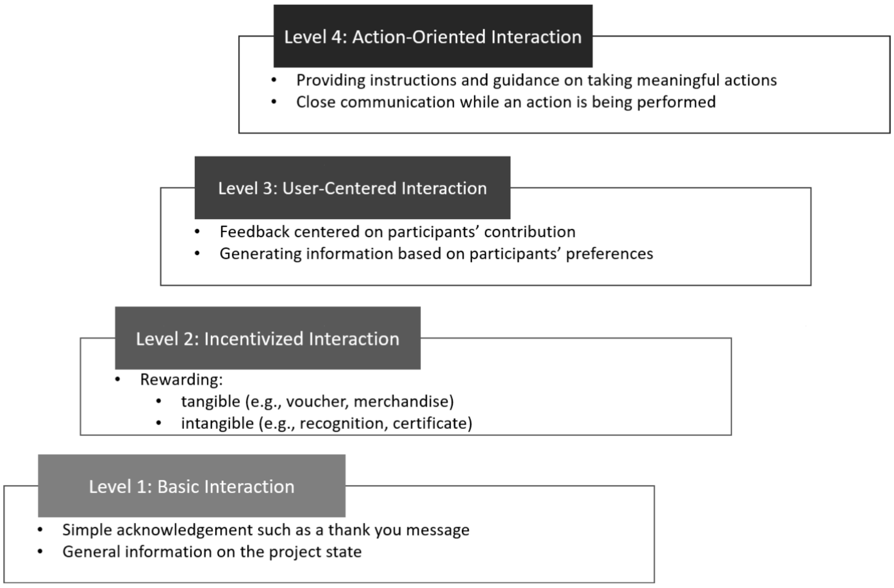

Figure 1 The four level interaction framework. The interaction starts at a basic level, and as we progress through the levels, the focus of interaction shifts towards the contributions and requirements of the participants.

Furthermore, the four levels of interactions outlined before are incorporated within the framework of the three dimensions of space,time, and theme. Citizen observations are most frequently if not always built around the spatial (the where), temporal (the when) and thematic (the what) dimensions. In fact, spatial and temporal abstractions are fundamental to how humans perceive, conceptualize and experience their environment [26]. The respective roles of space and time have also been recognized in the development of interactive multimedia applications to both ensure contextual synchronization and then consistency [32]. For example, a given subject might have partial or complete knowledge of the spatial environment involved in multimedia interactions, as well as the one of the temporal coverage. A similar statement can be made regarding the thematic dimensions involved in such multimedia interactions. Indeed, in CS associated to geographical information, it makes sense to consider space, time and theme as fundamental information facets and structural dimensions to organise an interactive and active participatory framework.

When a participant makes a contribution, all the three dimensions converge since CS contributions occur in a specific location, at a certain time, and for a specified theme or subject. Figure 2 shows the connection between the three dimensions of space, time, and theme with various levels of interaction.

During the initial stage, all forms of participation are included within the convergence of the three dimensions to create a contribution. However, based on the requirements of the participant and the design of the project, the interaction with participants can be directed towards one specific dimension, two dimensions, or all three. Level 3 interaction falls under this category, where the interaction takes the form of user-centered feedback to the participant, and the feedback provided may vary based on the dimension.

The spatial dimension in a project can provide participants with location-based guidance, informing them of where a specific phenomenon is more likely to occur or what information can be collected at a particular location. However, some feedback is location-independent. For instance, the feedback can be tailored to the participant's preferred level of complexity by proposing tasks related to their needs, thus customizing their contribution experience. In some cases, feedback can encompass multiple dimensions, including both spatial and temporal elements, giving the participant personalized information asking where and when they would like to make a contribution. These types of feedback are often associated with environmental data collection, where both the location and timing of the data collection play important roles. This type of feedback can allow participants to maximize the impact of their contributions and help ensure that the data collected is relevant and useful.

Finally, at the highest level of interaction where there is an action involved, all three dimensions converge again, as an action takes place at a specific location, time, and in relation to a specific theme, thus integrating all three dimensions.

Retroactions between the interaction framework and the citizens can be made at different levels of interactions, whether the priority is given to the spatial (e.g., species observed at a given location), temporal (e.g., species observed at a given time) or thematic dimension (e.g., where and when a given species is observed). This emphasizes the prominent role played by the spatial and temporal dimensions which are not limited to conventional attributes as they provide to the user specific capabilities for the selection and retroaction of data. In relation to level 4, and as done for the first and second levels, actions performed by a citizen are conducted at a given location and time, and for a particular theme and thus all dimensions converge.

The Next section presents a case study that focuses on the third level of the interaction framework and the three dimensions of space, time, and theme.

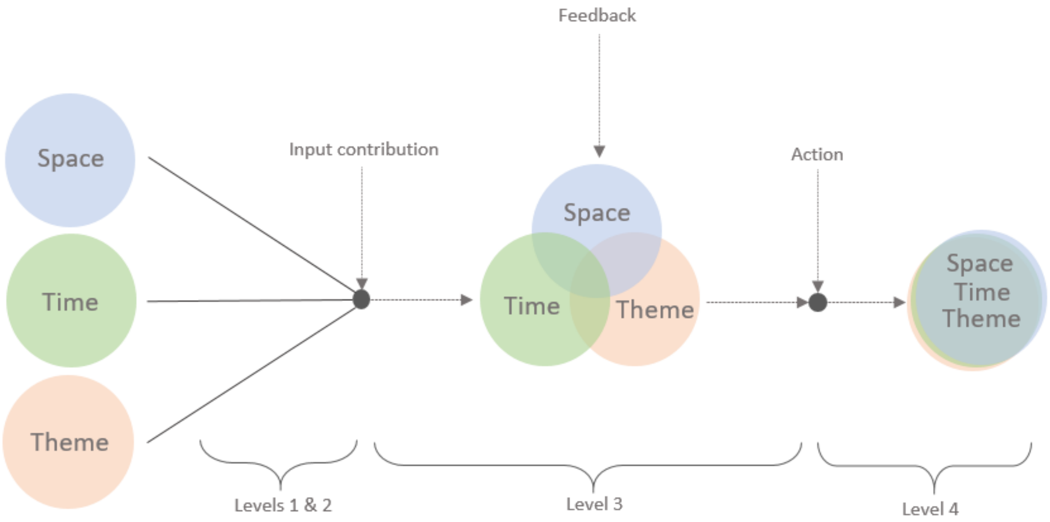

Figure 2 The connection between three dimensions of space, time and theme before and after contribution to a citizen science project, and their relation to the levels of interaction (see Figure 1). When a contribution is made, all three dimensions merge and a general feedback can be provided (levels 1 and 2). Subsequently, based on the contribution, feedback may focus on one or a combination of dimensions (level 3). If participants receive feedback on how to perform an action (level 4) and carry it out, the three dimensions converge once more.

4 Case study

To delve deeper into the framework, we have carried out a case study that presents the interaction with participants within a biodiversity CS project. The case study presented here highlights three categories of feedback based on the dimensions of space, time, and theme. This feedback demonstrates the third level of interaction in our framework, illustrated in Figure 1, which entails providing feedback to participants in the form of personalized insights. The aim of this case study is to provide a concrete example of how the framework operates and how it can be applied in a real practice, serving as a proof of concept for its usefulness in other CS projects.

BioSenCS[2,3] invites the public to collect biodiversity observations (with a focus on bird species) and at the same time applies automatic data validation to the observations while volunteers contribute and provides them with real-time user-centered feedback[22]. The main objectives of BioSenCS in relation to the third level of the interaction framework are as follows:

- Provide participants with real-time feedback based on the location, time, and image of the species observation
- Boost public engagement as a result of user-centered feedback
- Provide a learning opportunity for the participants through the feedback
- Enhance data quality through learning from automatic feedback

BioSenCS is implemented using the Django framework[4], which is a Python-based free and open-source web framework, and we used a PostgreSQL[5]/PostGIS[6] database for constructing our data models and preserving the collected observations. The high-level architecture of BioSenCS application is illustrated in figure 3.

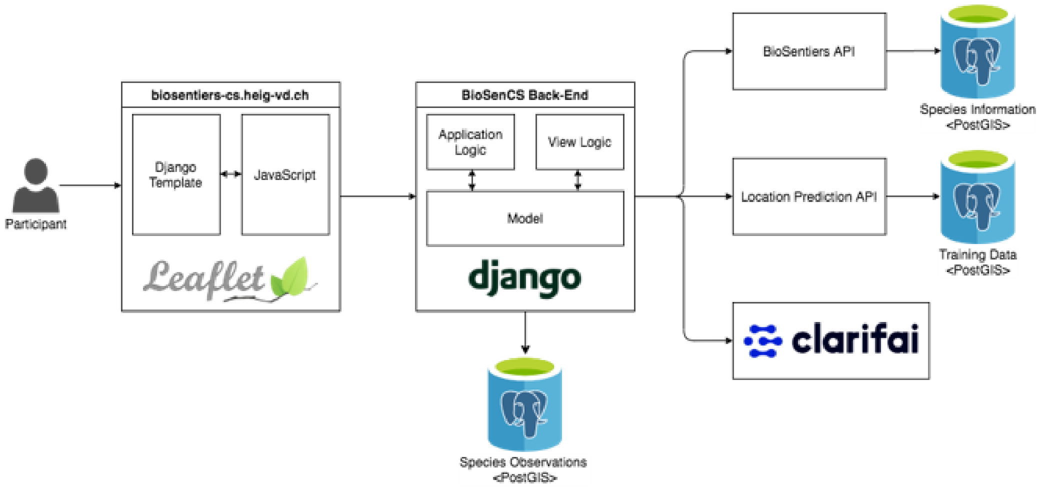

Figure 3 The high-level architecture of BioSenCS application.

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[2] `https://biosentiers-cs.heig-vd.ch/`
[3] `https://github.com/mlotfian/Biosentiers-CS-functionality`
[4] `https://www.djangoproject.com/`
[5] `https://www.postgresql.org/`
[6] `https://postgis.net/`

The primary goals of this case study are to utilize an automated system to validate or filter observations and to provide real-time feedback to participants. The process involves an automatic filtering system, as depicted in Figure 4. When a participant submits an observation, it is first evaluated by the automatic system. If the observation does not meet certain criteria, it is marked as an unusual observation and the participant is provided with feedback including a detailed explanation of why the observation was flagged, which the feedback is based on any dimension of space, time, and theme separately or combined.

At this point, the participants have two options. They can either make changes to the observation based on the feedback received, or they can choose to proceed with the original submission, moving the observation to the final expert validation stage. If the expert determines that more information is needed, they will provide additional feedback to the participant.

The automatic validation process includes three elements: date validation, image validation, and location validation. The image and location validation utilize machine learning (ML) algorithms, while the date validation is performed by comparing the observation dates to a static dataset provided by ecologists. The dates dataset is accessible through the BioSentiers API (Application Programming Interface) (Figure 3).

Location validation is only applied to bird species, but image and date validation are applied to all four organisms: bird, butterfly, tree, and flower. The following sections concentrate on the third level of the interaction framework (See Figure 1) and integrate the three dimensions (See Figure 2) of theme, time, and space respectively, in the order they are presented.

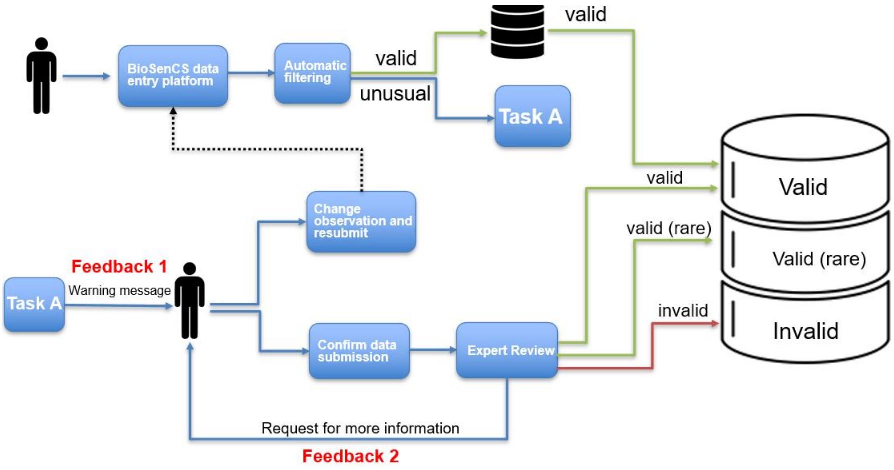

Figure 4 The automatic data validation procedure applied in BioSenCS.

4.1 Theme: Observation Image Verification

The image filtering screens the contributed images that do not include the reported species (bird, flower, tree, or butterfly). The feedback obtained in image filtering focuses on the theme dimension of the observation, specifically the type of species. To perform image filtering, we used an artificial intelligence (AI) platform called Clarifai[7]. Clarifai is an AI company

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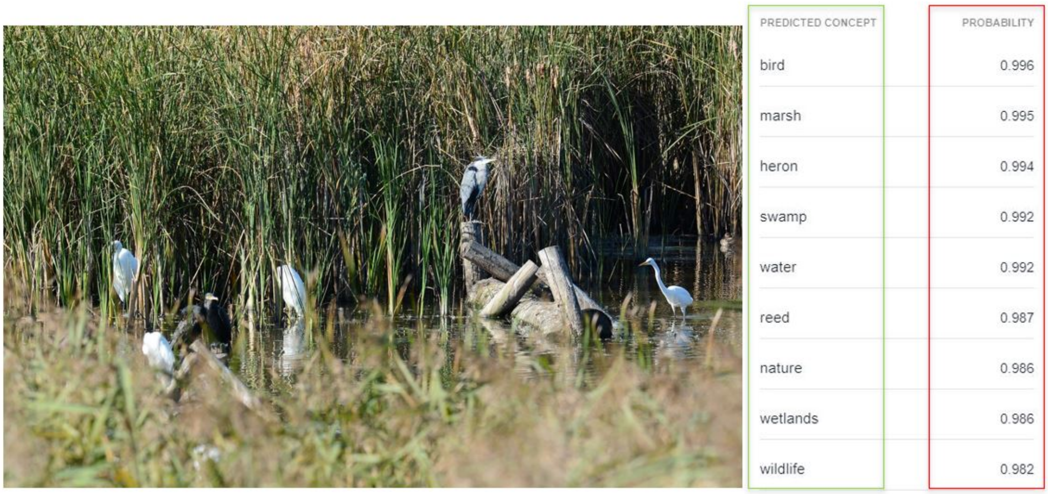
[7] `https://www.clarifai.com/`

that specializes in computer vision. It provides pre-trained models[8] as well as the option of training a model with a custom dataset. Clarifai offers services via its API (1000 free API calls per month), which has a fast response time and can be integrated into AI-powered mobile or web applications. We used its general model[9] to determine, for example, whether an image with bird tag really contains a bird or not. Once an image is sent to Clarifai's API, the model generates a set of possible tags that are present in the image along with their probability scores (See figure 5). We flagged an observation and sent a feedback to the participant, if the probability of having the species in the uploaded image was less than 85 percent. Figure 6 (b) illustrates the real-time image feedback to the participants.



PREDICTED CONCEPT	PROBABILITY
bird	0.996
marsh	0.995
heron	0.994
swamp	0.992
water	0.992
reed	0.987
nature	0.986
wetlands	0.986
wildlife	0.982

Figure 5 An example of Clarifai predicted tags and their probabilities for an observation contributed to BioSenCS.

4.2 Time: Observation Date Verification

The date filter focuses on the time dimension of the observation and verifies whether or not, given a species name, the observation date falls within the species visibility period (the time where the species is mostly probable to be observed). Accordingly, we have used a dataset, which includes information of the visibility period of the species and is accessible through an API called BioSentiers[10][16], and the observation date is verified using the two attributes of `periodStart` and `periodEnd` in the database. If the observation date is outside the species visibility period, the observation is considered as an outlier and the participant receives a feedback with information about the months (or the periods) the species can normally be observed, and asking the participant to verify the added observation (e.g. species name or the date). The final decision is however given to the participant, and the participant is not forced to modify the observation. The observation is however flagged in our database in a boolean attribute `flagDate` to be verified by experts later on. Figure 6 (a) illustrates the real-time date feedback to the participant.

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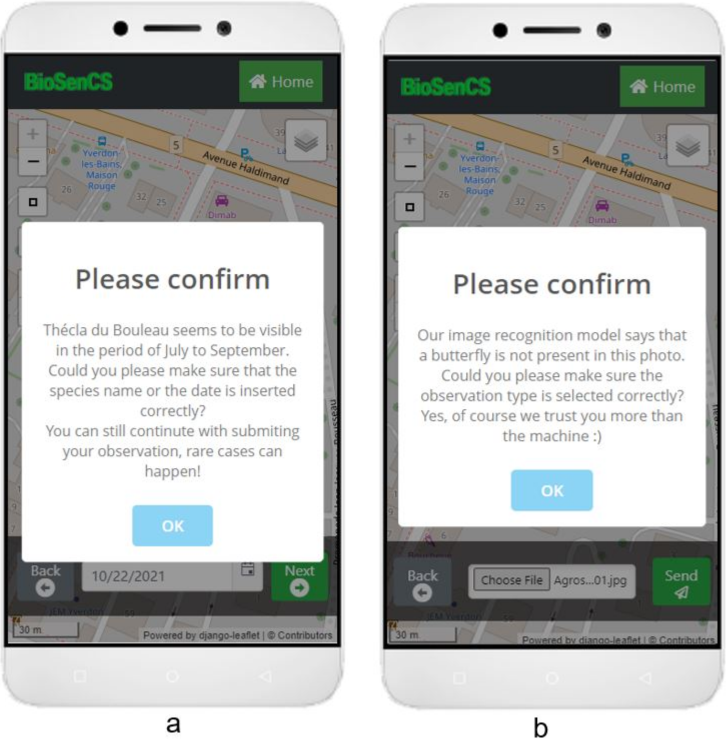
[8] https://www.clarifai.com/developers/pre-trained-models

[9] https://www.clarifai.com/models/image-recognition-ai

[10] https://biosentiers.heig-vd.ch/api/species



Please confirm

Thécla du Bouleau seems to be visible in the period of July to September. Could you please make sure that the species name or the date is inserted correctly?
You can still continute with submiting your observation, rare cases can happen!

OK

Back 10/22/2021 Next

Please confirm

Our image recognition model says that a butterfly is not present in this photo. Could you please make sure the observation type is selected correctly? Yes, of course we trust you more than the machine :)

OK

Back Choose File Agros...01.jpg Send

Figure 6 Automatic date (a) and image (b) feedback in BioSenCS application.

4.3 Space: Observation Location Verification

Location verification focuses on the space dimension of the observation, and thus the corresponding feedback is centered on the participant's location. To perform location validation, we determined how the environmental variables surrounding the observation location corresponded to the species habitat characteristics. To accomplish this, we generated models of the distribution of the species in relation to the environmental variables in our study area (Switzerland). Accordingly, we used species distribution modeling (SDM) techniques [10] for bird species in Switzerland. SDM is a class of numerical models that explain how the presence or absence of a species at a given location is related to environmental (e.g. temperature, precipitation, etc.) and landscape characteristics (e.g. land cover, elevation, slope, etc.) [10]. These techniques are used to gain ecological and evolutionary insights as well as to predict distributions across landscapes, which requires spatial and/or temporal extrapolation. SDM can be used to understand how a species' distribution is correlated with its location, as well as to predict the locations of species occurrence where no data is available. To generate SDM two important datasets are required: the species abundance data and the environmental variables.

For the species dataset, we used eBird data [28] for Switzerland from 2016 to 2020, and for the environmental variables we used land cover (to obtain landscape proportions such as the percentage of forest, water bodies, etc. in a given area), elevation, slope, and NDVI (Normalized Difference Vegetation Index). Additionally, to generate SDMs, four algorithms were trained and compared based on their performance: Naive Bayesian (NB)[30], Random Forest (RF)[4], Balanced Random Forest (B-RF)[2], and a Deep Neural Network (DNN)[1]. The models trained with Balanced-RF performed better compared to the other three algorithms, and thus they were used to verify the location of new contributed observations.

For each species, we obtained two output distributions maps: a binary classification, and a map of probability of occurrence of the species over the whole of Switzerland. Figure 7 illustrates the map of probability of occurrence for Common kingfisher species. As shown in the figure, Common kingfisher can be mainly observed in the northern, and north west parts of Switzerland with high probability to be observed near lakes and water bodies.

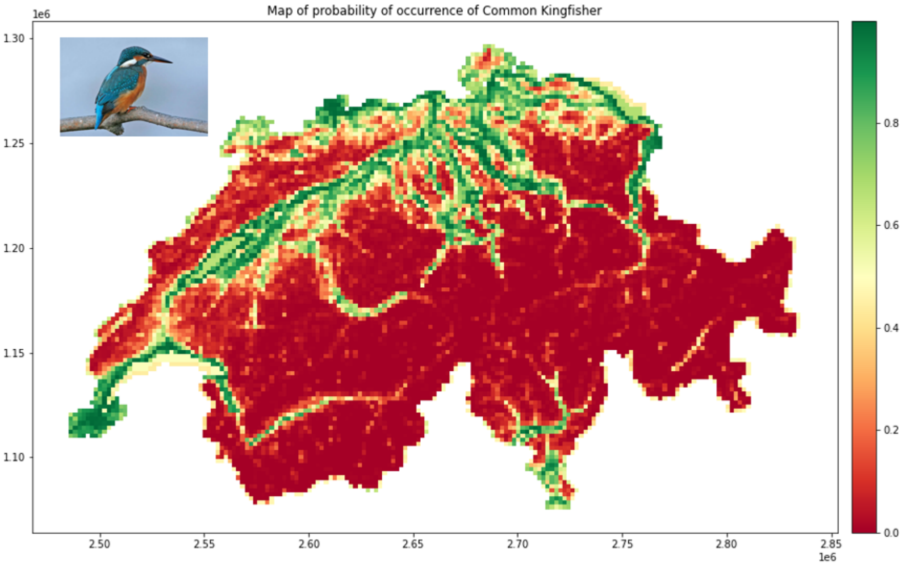


Figure 7 Classification of probability of occurrence of Common kingfisher.

Once training the algorithms and choosing the best performant one, in this case Balanced-RF, the trained models were saved to be used for validating new contributed observations. We developed an API called BioLocation, that uses the trained models and that is integrated to the BioSenCS application to validate new observations while also providing user-centered suggestions on the top-five high-probable species that can be observed around the participant's location. The API takes the species name and location and returns the probability of observing the species in a $2km^2$ neighbourhood around the given location. The probability is given back to the participant as a real time feedback with information on species habitat characteristics. Additionally, the API can take the location and suggests the possible species that can be observed in the participant's proximity. Figure 8 illustrates the process of real time feedback generation taking into account the space dimension.

If the probability of observing a species in a particular location is higher than 50 percent (to account for randomness, as agreed when implementing the project), the generated feedback will simply provide complementary information to the participant, such as the possible places where the species is more probable to be observed. However, if the probability is less than 50 percent, the participant will be asked to confirm the validity of the observation (either the location or the species name). After receiving the feedback, the participant has the option to alter the observation based on the given information or leave it unchanged. Figure 9, a and b illustrate the two possible location feedback, and c illustrates the top five species probable to be observed around the location of the participant.

The feedback generated in this case study either focuses solely on one dimension, such as only the observation date or location, or a combination of dimensions, such as in the user-centered species suggestion which integrates space (user location) and theme (species names). Furthermore, when a participant encounters an unknown species, the top five

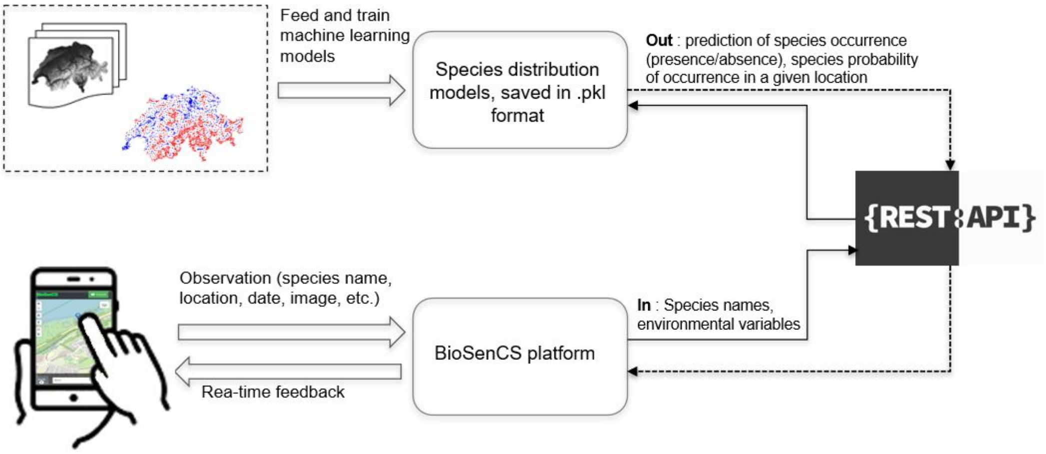
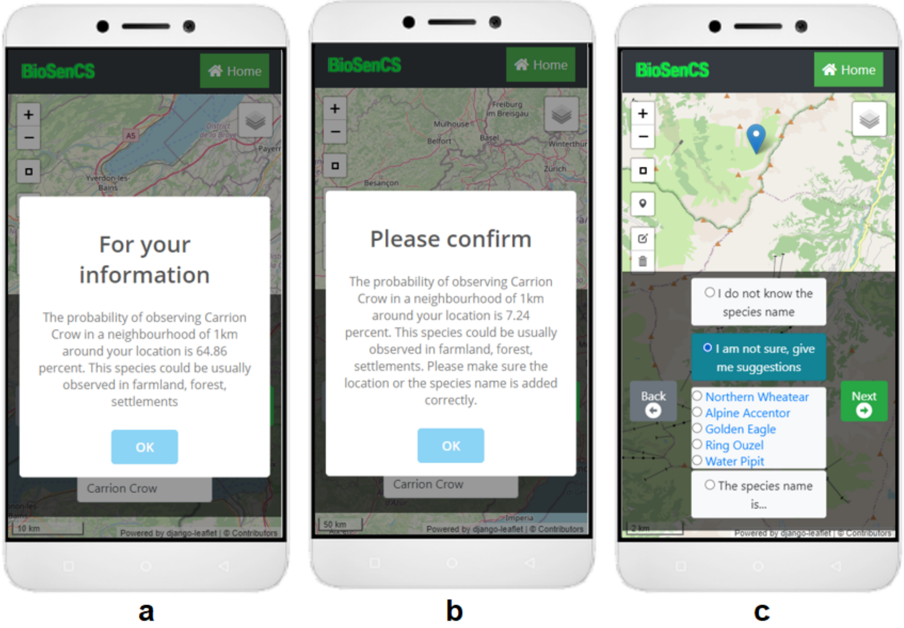


Figure 8 Real time location feedback generation.

suggestions can assist in identifying the species from the list, thus again a combination of space and theme dimensions. Additionally, the feedback on the time dimension can provide information on the visibility period of different species, allowing participants to determine when they can observe species of interest, thus combining the time and theme dimensions.

Finally, a user test was conducted to gather feedback on the BioSenCS application interface and explore participant views on receiving automatic feedback. The application was promoted through targeted emails sent directly to students and colleagues within our university, as well as through social media platforms such as Facebook and LinkedIn. Additionally, word of mouth played a role in spreading awareness about the application. A thorough testing phase lasting three weeks was conducted, resulting in 224 visits to the application. Out of these visitors, 38 users successfully created an account, and 14 individuals actively participated in collecting observations. Additionally, during this three-week timeframe, a total of 230 observations were collected.

Following the completion of the testing period, participants were provided with a questionnaire that encompassed general inquiries about the application's usability. Additionally, participants were asked to evaluate the extent to which they found the feedback information useful and whether receiving feedback heightened their motivation to contribute to the project. These questions were rated on a 5-point Likert scale, with 1 representing "not at all useful/motivating" and 5 denoting "very useful/motivating." The average score for the usefulness of feedback was 3.33, while the average score for the impact of feedback on motivation was 3.5. To assess the impact of feedback on enhancing data quality, we examined the relationship between the number of flagged observations (O_F) and the total number of contributed observations (O_T) per user. By analyzing the correlation between the ratio of flagged observations to the total number of observations (O_F/O_T) and O_T, we discovered a statistically significant negative correlation of -0.63 (p-value = 0.036). This indicates that participants who made a higher number of contributions had fewer flagged observations. Essentially, this suggests that participants either utilized the feedback provided to improve their observations before submitting them (e.g., verifying accurate location pin placement) or developed the ability to provide higher quality data. Although we did not obtain explicit statistical evidence regarding the correlation between contribution over time and data quality, the findings imply that increased participant contributions lead to a reduced number of flagged observations, thus indicating higher quality data. However, a longer testing period would enable a clearer understanding of how feedback influenced data quality over time.



For your information

The probability of observing Carrion Crow in a neighbourhood of 1km around your location is 64.86 percent. This species could be usually observed in farmland, forest, settlements

Please confirm

The probability of observing Carrion Crow in a neighbourhood of 1km around your location is 7.24 percent. This species could be usually observed in farmland, forest, settlements. Please make sure the location or the species name is added correctly.

○ I do not know the species name
○ I am not sure, give me suggestions
○ Northern Wheatear
○ Alpine Accentor
○ Golden Eagle
○ Ring Ouzel
○ Water Pipit
○ The species name is...

Figure 9 Location feedback if probability of occurrence of species is higher (a) and lower (b) than 50%, and user-centered suggestion (c).

5 Discussion and conclusion

CS projects are rapidly expanding into various fields and the number of applications is growing, thanks to technological advancements [25]. Despite this growth, there is still a challenge in engaging the public to participate. One approach to sustaining participants' engagement is through interaction with the participants [15]. Accordingly, some projects provide general feedback to the participants, such as an acknowledgment of their contribution, or feedback focused on one aspect of their participation. However, the needs and preferences of participants may vary and require personalized feedback. This paper introduces a framework that categorizes different types of interactions with participants while considering three dimensions of space, time, and theme, when interacting with them for a more effective outcome.

The framework outlines four levels of interaction, beginning with the simplest form, such as acknowledging the participant, then is incentivized interaction offering tangible benefits like certificates or rewards to participants. The next level, user-centered interaction, is centered around the participant and involves two-way interaction, where feedback is tailored to their contributions and they are given the opportunity to interact with the project and express their preferences. The final level is action-oriented, providing instructions, guidance, and support to help the participant take meaningful actions. Additionally, the integration of the interaction levels within the three dimensions of space, time, and theme is discussed in this article. The feedback in level 3 can concentrate on one dimension or a combination of all three, while in level 4 interaction, all dimensions are combined, as an action is carried out at a particular location and time, and for a specific theme.

The biodiversity CS case study highlighted in this article emphasizes user-centered interaction and focuses on the third level of the interaction framework. The feedback provided is based on location, time, and images of the observations. The participants receive location-based feedback on the likelihood of observing a specific species at a given location, and also receive suggestions for species to observe in their vicinity, combining both spatial and thematic dimensions. Although this case study provides multi-dimensional user-centered feedback, to fully realize its potential, a two-way interaction between participants and the project is necessary. To accomplish this, the three main questions of "where," "when," and "what" can help guide participants to receive targeted feedback. The following are examples of how the feedback in the case study can be expanded in each of the three dimensions.

- Spatial
    - Ask participants where they prefer to observe species.
    - Find out what types of environments participants prefer for collecting observations.
    - Based on their previous observations, suggest other locations they might be interested in visiting.
    - If participants have a particular species in mind, suggest likely locations where they can observe it.
- Temporal
    - Ask participants when they like to collect observations.
    - If they have a specific species in mind, recommend the best times to observe it.
    - Identify species that can be observed during the given time frame.
- Thematic
    - Ask participants what types of species they like to observe.
    - Find out what individual species they prefer to observe.
    - Based on their history of observations, suggest other species they might also be interested in observing.

The guidance questions mentioned above for generating user-centered feedback are focused on the biodiversity field, however, they can be adapted to other areas depending on the project's objectives and the participants' preferences. For instance, in a CS urban planning project aimed at mapping street and sidewalk quality, the spatial dimension could involve identifying and proposing areas with data gaps near participants, inviting them to collect data in such areas, and providing them with information on the quality of streets and sidewalks along their planned route.

Additionally, BioSenCS aims to expand by offering interaction at the fourth level (action-oriented) of the proposed framework in this article. This interaction can include providing support for preserving biodiversity such as through recommendations on appropriate plant species to grow in specific locations and at specific time frames, or offering guidance on building a garden pond, including information on necessary materials, estimated time required, and the best time to start construction based on the participant's location. The fourth level interaction involves not only providing information but also maintaining a connection with the participants throughout the entire action-taking process. This connection can be through either automated and machine interactions, such as verifying the actions to be taken given a location and time, or through online or in-person interaction with the project team.

Overall, this article aims to present ways in which CS practitioners can interact with their participants, taking into account spatial, temporal, and thematic dimensions. The goal of categorization of interaction levels presented in this article is not to assign positive or negative labels to the levels, but rather to provide different methods to maintain community involvement in CS projects. The choice of interaction methods can be adjusted based on the project's goals, its timeline, the preferences of the participants, and may consist of a single approach or a combination of approaches. Finally, the purpose of this article is not to give detailed instructions on how to interact with or provide feedback to the participants, but rather to present an overall perspective, supported by a relevant case study.

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