How to Design Citizen-Science Activities: A Framework for Implementing Public Engagement Strategies in a Research Project

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Abstract Many studies have shown that volunteers have the potential to provide a valuable contribution to complex research projects. To reach this outcome, the environment in which contributors are engaged has to be carefully configured to foster collaboration while designing tasks with low interdependence. The broad term defining this integration of external contributions in scientific research is “open/citizen science”. Being this phenomenon relatively innovative in its capillary applications, theoretical frameworks and operative guidelines are still evolving. Our paper aims to contribute to this research field, examining and testing public engagement activities for a robotics research project, HeritageBot (HB). In detail, our paper explores the process of developing collaborative initiatives involving external actors in a set of HB’s scientific research tasks through a set of public engagement, “open”, activities. First, we will propose a theoretical framework that we designed to support our activities, and then, we will compare and select a set of methodologies for designing open/citizen-science strategies. Subsequently, we will focus on empirical episodes in which we were involved while developing HB’s public engagement solutions. Finally, we will introduce the experimental validation process of the identified solutions, showing also a summary of preliminary results.

1 Introduction

The capillary diffusion of Information and Communication Technology have enabled the emergence of open collaborative models which have provided new possibilities and advantages for complex scientific research projects. This process of opening the solution of a problem also to individuals not formally involved in the work is a well-known phenomenon in other sectors, as for example the case of open

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A. Lazazzara et al. (eds.), *Organizing for Digital Innovation*,
Lecture Notes in Information Systems and Organisation 27,
https://doi.org/10.1007/978-3-319-90500-6_12

source projects in the software industry [1, 2]. Different movements (e.g. open access, open science, crowdsourcing) have recently emerged, rising the interest on the concept of a broader scientific process, where everybody can access and contribute according to her/his own skills and abilities. To reach a meaningful level of public involvement, scientific projects have to design "spaces" of interactions and experiments where the volunteers' contributions can be valuable. Many scientific research projects have indeed successfully designed virtual participatory spaces, being able to benefit from the potentialities of distributed knowledge and at the same time disseminating scientific results to the public.[1] There are, in fact, many well-known benefits of opening up research projects to external contributions: i. the access to a large human computational power (e.g. through the so called crowdsourcing initiatives); ii. the possibility of raising a broader awareness and knowledge on scientific topics; iii. an early understanding of the market needs and expectations; iv. a large number of users testing early versions of the research outcomes.

This research will address the design and implementation of a citizen science process as part of a robotics research project. Even considering the mentioned potential benefits of an open approach to this field of research, cutting-edge robotics technologies are still generally hidden from the common citizen eye [3, 4]. There are several reasons for the existence of these participation barriers between scientists and citizens, ranging from the complexity of the specific research topic, to the tools and means needed to design and implement a robotic solution, till the time and effort needed to effectively open up the research to external contributions. The design and implementation of open—citizen science based public engagement activities in this type of projects presents a set of specific challenges, as for example: an adequate coordination and alignment of open-citizen science principles, with the projects' long term objectives (e.g. concerning intellectual property rights and sensitiveness of research issues); the nature of the products and the processes involving the scientific activities have to be diluted and divulged in a simplified manner, to overcome motivational and knowledge gaps between researchers and public; and goals, methodologies and protocols of such initiatives have to be clearly defined ex-ante. Such conditions make the whole process time consuming and represent a strong disincentive to researchers to open their project to external actors. There are however, projects that successfully integrated external actors in their innovation processes: Inmoov[2] and iCub.[3]

In this work, we will present the experience of designing a set of activities for public engagement to be integrated within the research activities of HeritageBot, a

[1]Notable example is the "Galaxy Zoo" project which, through the contribution of hundreds of thousands of volunteers categorized more than 50 million galaxies (www.galaxyzoo.org). Gravity Spy is another successful participatory initiative, counting more 8000 volunteers and more than 2 million classifications of gravitational waves detectors' outputs (https://www.zooniverse.org/projects/zooniverse/gravity-spy).

[2]Project's website: http://inmoov.fr/.

[3]Project's website: http://www.icub.org/.

market-aimed robotics development project. We will first provide an overview of the project and of the developed methodology's theoretical foundations. Then, we will systematize, through empirical episodes, our action research-based approach to public engagement strategy development. Finally, we will introduce our work-in-progress experimental methodology, instrumental to the validation of the developed strategy.

2 Literature Review

Many scholars have investigated feasibility and best practices of research approaches based on "open" principles. Most of the literature on the topic evidences the increasing popularity of research initiative aiming at directly involving also amateurs and volunteer scientists into the discovery process. This phenomenon is summarized by the words "open science", defined as the "umbrella term encompassing the multitude of assumptions about the future of knowledge creation and dissemination" [5]. Open science scholars focus on proposing shared and multidisciplinary principles aiming at developing ethics, tools and workflows to promote transparency, reproducibility, dissemination and transfer of new knowledge [6]. The demand for a more participative—"open"—vision of science is driven by numerous factors. Among the most discussed drivers of openness, the increasing complexity of problems to be investigated by scientists, together with the exponential growth of data to be analyzed and the commitment to better understand society's needs and expectations, are generating the need of exploiting the potentialities of distributed human computational power [7]. Integrating citizens into research processes, has been proved to not only facilitate awareness and diffusion of the research-produced knowledge, but also to empower researchers themselves providing additional research possibilities [7, 8]. Nonetheless, the connotations of the term have raised debates regarding its benefits, limits, applicability and goals. Part of the literature perceives openness as an opportunity to dramatically increase the range of available expertise, thus expanding the spectrum of solvable problems [9, 10]. In other instances, openness is viewed as a democratization of knowledge, addressing the fact that scientific data, methodologies and findings are often unequally distributed. The latter picture in particular keeps up the barriers for: first, generating trust, legitimacy and funding for research projects [11, 12]; second, for promoting communication and collaboration between researchers [13–15]. Additionally, citizens' engagement with science, together with the dissemination of knowledge and benefits derived from research to the society as a whole, may also be hindered by not pursuing an "open" vision [16, 17]. Open-citizen science principles, however, are not without criticism. Some scholars have displayed concern about the facts that the incentives of doing research, and the control over the quality and utilization of the produced science, may as well be reduced [18–20].

Others argue that the design of open initiatives may take a level of effort and time (for example: to prepare and release data and documentation, to train citizen scientists, to set up an adequate communication infrastructure), that may surpass their potential benefits. Addressing this problem, Bonney [21] developed a series of citizen science projects design guidelines, but their application is mostly limited to environmental research. In the fields of technology science and robotics, exploiting the interests and curiosity of the people, may represent a promising opportunity to crowdsource data, ideas and solutions [3]. In fact, open-citizen science solutions share similarities with the open innovation concept [22], as they may "accelerate internal innovation and expand the market for external use of innovation". Is also evident that open science principles carry strong analogies with the open source movement, for which the convergence of means, benefits, limitations and methodologies have been documented in literature [e.g. 23]. However, the process of introducing the "open" formulas into market oriented research is complicated, as evidenced also by the lack of shared methodologies in this regard. By showing pre-production prototypes, or releasing sensible data regarding innovative products to the public, the risks of sensible information spillovers may increase, potentially reducing research products' value. This condition raises the strategic dilemma of how to open up to distributed knowledge while maximizing research products' security.

3 The Case: HeritageBot

The context of our research is a publicly funded, multidisciplinary, robotics research project, aimed at cultural heritage valorization and conservation: HeritageBot (HB). The objective is to develop a hybrid multifunctional modular, remotely controlled robotic device. HB is specifically conceived to be used in cultural patrimony preservation, valorization and fruition. Its innovative drone—walker configuration is particularly useful for architectural and archeological applications. In fact, the device is being designed to be extremely versatile and to allow to remotely obtain an optimal quantity of visual data and metrics from locations needing to be explored or visited. HB's research team is multidisciplinary. Together with the engineering sub-team (in charge of designing and assembling the robot) there are also researchers from economics, business, architecture, finance, legal and organizational studies. This integration of multiple research fields was motivated by the aim of producing a research product with a clear and immediate value for the market. In particular, our research laboratory leads the activities focused on studying and developing an open-citizen science framework to facilitate the integration of external actors in the project's workflow.

4 Developing Public Engagement Initiatives

Approaching the problem of developing public engagement strategies in the context of a robotics research project was not without issues. The aim to bring to the market HB product, together with the complicated nature of the device, challenges the design method to follow for an open—citizen science solution. Therefore, in order to face the complexity of the task, we developed a hybrid methodological approach [24] (Table 1). We build on the general citizen science guidelines defined by Bonney [21], integrated with the principles of action research methodology, as proposed by [25], to define a set of HB contextualized operative steps. In our case, the first step was coincident with the *diagnostic* phase of the AR methodology, functional "*to the identification of the primary problems that are the underlying causes of the organization's desire for change*" [26]. This was the most challenging stage of our research because the team was multidisciplinary and we, as organizational specialists, had very limited knowledge on some of the other fields, as for example robotics and mechatronics. In order to share the different perspectives and knowledge bases a series of collective meetings and private interviews with the various sub-teams from the different fields involved were conducted. During the meetings, we gathered also an extensive quantity of documentation and audio-visual material regarding the device, including pre-production blueprints, 3D renders and work-in-progress photos. Additionally, thanks to valuable ideas coming from all the other team members, we defined a set of initial goals for our specific research goal: I. Promote the awareness on the project. II. Facilitate knowledge dissemination. III. Attract and valorize the distributed knowledge of extra-organizational actors.

The following step, coinciding with the action planning phase, involved the identification of activities that were compatible with both the market-aimed nature of project and the defined public engagement goals. Many potential activities were identified, including a parallel incubator based on open hardware and open source principles, a gamified virtual 3D robot configurator and a series of robotics

Table 1 Hybrid methodological approach: citizen science—Action research

Citizen science Bonney et al.	Action research Susman and Evered	HeritageBot research project
Choose a scientific question	Diagnosis	Meetings – Interviews with research team
Form scientist/evaluator team	Action planning	Identification of compatible initiatives
Develop, test, refine protocols		Pilot testing
Recruit participants	Action taking	Launch initiatives and experiments
Train participants		
Accept, edit, and display data	Evaluating	Analysis of the metrics and KPIs
Analyze and interpret data		
Disseminate results	Specifying learning	Tweaking
Measure outcomes		

workshops. However, only two of the identified activities were, at the same time feasible in terms of time and cost, fully compatible with the project's market-aimed nature, and representative of the proposed public engagement goals.

4.1 The Social Micro-Blogging Initiative

The first of the conducted activities, also encompassing the widest audience, regards the utilization of social media platforms—specifically Facebook, Instagram and Twitter—to periodically publish project-related content. All the content was presented in the form of micro-blog entries [12, 27] as news, updates, curiosities and insights regarding the HB project were regularly proposed to the public. The different social platforms were used according to their peculiarities, to develop a cross promotional, informative online space. Since the launch of the social initiatives, the published content has covered all the main activities and shareable results of the research team. Given that "science is by nature complicated, making it all the more important that good science writing should be simple, clean and clear" [28], all the information and material collected during previous team-wide meetings was accurately diluted, reformulated, and posted on each social platform in an easy to read and "appealing" form. After iteratively adjusting the type and presentation of the content, following the AR cycle, the social strategy was ultimately a success in terms of visibility growth and knowledge diffusion, also considering that the profiles' promotion was strictly organic (non-paid). In particular, the initiative provided satisfactory results on facebook (with an average reach of 793 users for videos, 186 users for pictures and 46 followers) and Instagram (averaging 13 likes per post and 34 followers). The social activities also provided insights on the preferences of the public in regards of content typology. The most liked posts were the ones containing videos, animations or pictures of the various phases of the prototypes' construction, accompanied by brief, simple descriptions. The least liked posts were those proposing technical content such as diagrams and simulation videos. In any case, the social approach failed to incentivize public active participation, as comments were rare.

4.2 The HeritageBot Seminar Survey

The second activity concerns the inclusion of a public engagement experiment in the context of a project-related seminar. This was organized by the HeritageBot's business development team and was aimed at students of a start-upping course (organized by ImprendiLab). During the seminar, both the business and technological aspects of HB were introduced. The capabilities and functionalities of the robot were thoroughly explained as so were its potential fields of application. At the end of the seminar, after introducing the project's public engagement goals, a public engagement survey was administered to the students (23 respondents). The survey questions aimed at obtaining feedback on specific aspects of the device that were still in progress (for example: how should the robot be named; how could it be improved) and especially at identifying the participation drivers. The results showed that the seminar was welcomed by the students with interest and enthusiasm as 87% of them answered “Yes, I would like to know more” to the question “would you like to participate in additional seminars regarding HeritageBot?”. Further proof of the interest on the project was the fact that the attending students also raised numerous questions and generated debates about the device and the project. The students’ reaction and the survey’s results evidenced a potential willingness to contribute to the development of the device. Additionally, 95% of the students enjoyed the seminar experience, 91% liked the HeritageBot idea, and some also started following the project’s social profiles. The seminar survey activity evidenced the need to make the participation experience simple, non-linear (allowing the users to ask questions regarding what they are interested in), rewarding and entertaining (interactive). However, as pointed by all the research team members, it would be an impractical and costly solution to organize a series of seminars to engage a wider audience.

5 Developing and Validating the *Ad Hoc* 3D Simulator

On the basis of the previously cited two experiences we developed a public engagement solution for the project by combining the identified positive aspects of both social and seminar activities. In particular, we developed a system that combines the potential online visibility and low cost of social media with, to some extent, the interactive, nonlinear and rewarding experience of a workshop (Fig. 1). The solution takes the form of an *ad hoc* 3D simulator aimed at: i. Allowing potential volunteers to autonomously obtain information about the project and participate, reducing the interdependencies between non-expert actors and the research team, typical in workshops and seminars; ii. Providing an online space, an interface, capable of attracting the user’s attention by making the project interesting; iii. Proposing a rewarding experience, adding 3D exploration sections, to let the user “play” with the device under development, interactive videos and non-linear navigation of the interface.

Specifically, the solution consists in an interactive animated infographic containing information about the device presented in a simple, non-technical manner (Fig. 2). The interested user will be able to navigate the platform at will, exploring the different sections as he prefers. The presented content, extrapolated in part from the most popular posts shared on social media, and in part based on the topics that gathered higher participation during the survey experiment, ranges from explanations of the different parts of the robot to the presentation of the different participation channels.

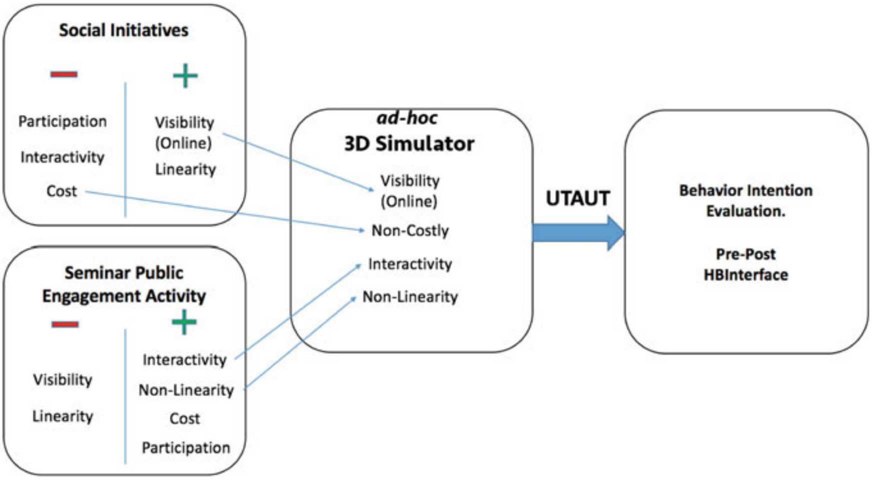

Fig. 1 From the initial activities to the *ad hoc* 3D simulator

Fig. 2 HeritageBot *ad hoc* 3D simulator, alpha version, screenshot (in Italian)—Selection of the part of the device to explore

These informative sections are enriched with a significant number of interactive audio-visual content including a 3D device visualization section. The content was provided by the HeritageBot team over the course of the team wide meetings. In order to validate this solution, we constructed a pilot experiment. The validation process involved two questionnaires, based on the Unified Theory of technology

Acceptance and Use of Technology (UTAUT) [29], as we find some of its constructs to be compatible with open—citizen science goals. In particular, the pilot experiment aimed at measuring if the subjects' behavior intention regarding actively participating in a research project was influenced by the availability of an interactive online interface simulating some characteristics of the final research product. As for today, the UTAUT based experimental methodology was tested with a group of economics students. These students were selected based on availability and willingness to participate. The experiment itself was configured as follows: The sampled students were asked to complete a preliminary questionnaire, with minimum information about the HeritageBot project provided by the experiment coordinators, aimed at gathering demographic data, information regarding their knowledge of robots and their opinion on different public engagement initiatives. The subsequent phase involved the exploration of the *ad hoc* 3D simulator: the students were allowed to navigate the demonstrative interface freely in order to evaluate its informative power. At the end of this phase the students were asked to answer a final questionnaire aimed at collecting their opinions on the demo platform and measuring their willingness to participate in the research project. The test was executed in two separate instances with two different groups, and received a total of 43 valid responses. The first test involved 20 undergraduate students. From these, only 50% completed the experiment correctly, hinting that the experimental methodology had to be made simpler and more straight forward for respondents. Following some improvements to the protocol, the test was repeated with a second group of students. This time the completion rate was way higher, as about 90% of the students (33) provided valid responses. Demographic composition of respondents is summarized in Table 2.

Table 2 Respondents demographic data

Character		Frequency	Percentage (%)
Gender	Male	16	37.2
	Female	27	62.8
Age	<20	1	2.3
	20 < X < 25	24	55.8
	25 < X < 30	12	27.9
	>30	6	14
Education	University degree	14	32.5
	High school	29	67.5
Declared level of knowledge about robots	Low	26	60.5
	Medium	14	32.5
	High	3	7

6 Preliminary Results

The number of valid responses collected, as for today, is insufficient to perform an in-depth analysis of the scale reliability and internal constructs' consistency [30]. However, we were able to obtain some interesting insights on the perception of proposed solutions' validity in incentivizing public engagement for the HB project. As previously explained, in the first questionnaire students were asked to provide information on their interest in participating, on their perceived difficulty involved in contributing to the project and their opinion on the usefulness of some proposed initiatives.

Questions regarding the students' opinion on the project were structured in a 6 point Likert scale, to avoid central tendency. Results for the first questionnaire (in Table 3) showed that there is a widespread perception (mean over 3.5), among

Table 3 Descriptive statistics of first questionnaire—6 point Likert scale

Indicator	Scale	Mean	Std. deviation	N.
How difficult do you think it is to contribute to the project in a useful way?	1—Very Easy 6—Very Hard	4.02	1.471772046	43
How much would you be interested in participating in the project? (available only if answered "Yes" to "Would you like to participate in the HeritageBot Project?")	1—Not Interested 6—Very Interested	3.75	1.040833	28
How difficult do you think it would be for you to contribute? (available only if answered "Yes" to "Do you feel capable of contributing to the HeritageBot Project?")	1—Very Easy 6—Very Hard	4.21	1.100745298	28
How much would you be interested in contributing to the project if you felt capable? (available only if answered "Yes" to "Do you feel capable of contributing to the HeritageBot Project?")	1—Not Interested 6—Very Interested	4.06	1.032795559	15
How much time do you think it would take you to obtain the knowledge necessary to become capable of contributing? (available only if answered "Yes" to "Do you feel capable of contributing to the HeritageBot Project?")	1—Not much time 6—A lot of time	4.4	0.632455532	15
How useful do you think a series of robotics workshops would be in disseminating the knowledge needed to contribute to the project in a useful way?	1—Not useful 6—Very useful	4.333	1.161720059	43
How useful do you think an online demo platform would be in incentivizing public participation in the project?	1—Not useful 6—Very useful	4.761	1.007521078	43

Meaning of values in the "scale" column

students of a high difficulty, level of effort and time needed in obtaining the knowledge to usefully participate in the project. However, interest in participating was also noticeable both among those who felt capable (63% of respondents) and those who didn't (37% of respondents). The proposed idea of an online demo platform was also considered very useful in the preliminary questionnaire.

The second questionnaire provided some interesting insights on the usefulness of the 3D simulator platform—social initiatives approach. A summary of questions and responses can be found in Table 4. All answers for the proposed questions were again configured as a 6 point Likert scale where 1 meant "strongly disagree" and 6 "strongly agree". The UTAUT constructs used as base for the proposed questions are: Performance Expectancy (PE), Effort Expectancy (EE), Facilitating Conditions (FC) and behavior intention (BI). PE is intended as the perceived effectiveness of the 3D simulator platform in providing the information needed to usefully contribute to the project. EE is intended as the perceived effort needed to navigate the platform and to obtain desired information. FC measures the perception of effectiveness of the demo platform and the social profiles, in facilitating the user participation. BI represents the intention of the respondent in participating to the project. Results (Table 4) indicate that the sample of students, on average, moderately agrees with the statements proposed for PE1 and PE2. In regards of EE, in all four questions, the students involved in the tests agrees that the platform

Table 4 Descriptive statistics for second questionnaire—Answers in 6 point Likert scale where 1 meant "strongly disagree" and 6 "strongly agree"

UTAUT construct	Indicator	Mean	Std. deviation	N.
PE1	After using the demo platform, I feel I can contribute usefully to the project	3.48837	1.054967682	43
PE2	I think the demo platform can be useful to provide necessary information to non-experts interested in contributing, usefully, to the project	3.79069	1.059158236	43
EE1	I think the demo platform provides information in an easy to understand, to non-experts, manner	4.09302	1.15085793	43
EE2	I believe the demo platform is easy to navigate	4.20930	1.186393887	43
EE3	I think the 3D explorative sections made the demo experience more rewarding	4.60465	1.094130115	43
EE4	I think the interactivity of the demo platform makes the project more interesting	4.53488	1.076786162	43
FC1	I think the social—demo approach is useful to facilitate a public participation in the HeritageBot research	4	1.133893419	43
FC2	I think is easy to contribute to the project through the demo and the social platforms	3.81395	1.052340112	43
BI1	I am interested in participating in the HeritageBot project	3.67441	1.128018284	43
BI2	I intend to participate actively through the social platforms	3.37209	1.291423279	43

provides an easy to access and to navigate mean to obtain information on the project and on the participation channels. The most appreciated features were the 3D exploration sections and the interface's interactivity. The sample also agrees on the validity of the social media and the demo platform as facilitating solutions for public participation (FC1 and FC2). For the BI construct, the students declared a moderate intention of contributing to the project and actively participating through dedicated social media profiles. Overall these preliminary results are satisfactory, indicating an effectiveness of the proposed solutions in terms of knowledge dissemination, ease of access to information and facilitating solution for the participation of external volunteers in the HB research.

7 Conclusions

We addressed the case of designing and introducing public engagement initiatives in the research process of a robotics research project (HB). We found that the market oriented nature of HB, together with the complex nature of the device, challenges the introduction of traditional open—citizen science propositions. We started assessing the problem of determining an appropriate methodology by analyzing the open and citizen science related literature, as well as by exploring successful initiatives based on these principles. A lack of well-established theoretical frameworks, compatible with the characteristics of the HB project, emerged by our literature review. Thus, we worked to fill this gap, developing a hybrid methodological approach to determine a series of guidelines useful to design public-engagement initiatives. By combining the traditional citizen science process with AR methodology, we identified two initial activities fully compatible with the project's characteristics and objectives: social network micro blogging and seminar public engagement survey. From the results of these two experiences, we recognized the need of creating an online space aimed at reducing the interdependence between potential volunteers and research team, providing easy to access information about the project and facilitating the participation through the social channels. We, therefore, developed *ad hoc* 3D Simulator combining the positive elements observed during the social and seminar initiatives into one comprehensive and interactive interface. The UTAUT-based validation experiment for this solution provided positive preliminary results. The group of students involved in the validation process agreed, on average, on the informative power of the solution. In particular, the most appreciated features were the 3D exploration sections and the interface's interactivity. The sample also on average agrees on the validity of social media and demo platform as solutions for facilitating public participation. Even if these results suggest an actual effectiveness of the identified solutions, a broader scale experiment will be needed in order to allow more in depth analyses. These will be especially aimed at confirming the validity of the solutions identified and of the proposed methodology for developing public engagement activities in highly complex scientific research projects.

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