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RESEARCH PAPER

Engaging citizen scientists: designing an open research system for collaborative problem exploration

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Abstract

Open Science aims to make scientific research and its dissemination accessible to all levels of society to foster openness and transparency. Engaging in a dialogue with society to explore real-world problems is particularly important to increase the relevance of information systems research. However, reaching out to citizens and engaging them in the research problem exploration process on a large scale is challenging for researchers. In this research, we build on existing prescriptive knowledge and design an open research system to involve citizens in the problem exploration process. Applying the design science research methodology, we report on the results and findings of one complete design cycle. We deliver design knowledge including (1) design requirements derived from the literature, (2) propose a set of design principles, (3) an instantiation of the design principles in the form of design features as well as a publicly available artifact, and (4) evaluations through a series of online experiments and two field studies with actual citizens. With this research project, we contribute design knowledge for the class of citizen science systems and present an approach and a publicly available instantiation that can be leveraged for open research problem exploration to engage with society members at large.

Keywords Research problem exploration · Open science · Citizen science · Design science research · Design principles

JEL Classification O360

Introduction

In recent calls, society and the scientific community have demanded more openness and transparency in scientific research in general (Maedche et al., 2024; Munafò et al., 2017; UNESCO, 2021) and specifically in the field of Information Systems (IS) (Burton-Jones et al., 2021). Openness and transparency are ways to foster reproducibility, progress, and trust in scientific research (Elliott, 2020). A promising approach to advance openness and transparency in scientific research is called Open Science. Open Science is an essential approach across the entire research process aiming to make science more transparent, reliable, and responsive to societal challenges (Burgelman et al., 2019; Jhangiani et al., 2019).

Open Science includes many different aspects and provides many dimensions to promote openness and transparency (Stracke, 2020). One aspect focusing on collaboration and participation by involving citizens in research is Citizen Science, which aims to open the research process to a broader audience (Levy & Germonprez, 2017). Recent studies demonstrate the potential of actively engaging citizens for different purposes, from urban planning to environmental protection and tasks ranging from data collection to data analysis (Crowston & Prestopnik, 2013; Fegert et al., 2020; Nielsen, 2020).

Scientific inquiry typically follows an iterative and cyclic process, including different phases in which various types of data are collected and revised (Brody, 1993; Godfrey-Smith, 2009). One of the first phases includes gathering information about the subject of inquiry. A

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proper understanding of the problem to be investigated is a key success factor in any research domain; or in other words, "coming up with the right answer to the wrong question does not create value" (Rai, 2017, p. iii). Identifying and formulating problems that matter requires substantial engagement with different stakeholders, especially in the case of ill-structured problems (Nielsen & Persson, 2016). In design-oriented research, for instance, the exploration of the problem space is emphasized as essential to gain a deep understanding and description of the problem (vom Brocke et al., 2020).

Today, citizens are mainly participating in the data collection phase (see Raddick et al., 2013; Silvertown, 2009). Nonetheless, citizens are known to be able to provide rich data regarding possible research topics, for example, by articulating themselves on social media platforms and sharing their opinions and real-world experiences (Lukyanenko & Parsons, 2020). Existing design knowledge on open innovation platforms (e.g., Kohler & Chesbrough (2020)) and design guidelines for crowdsourcing initiatives (e.g., Karachiwalla and Pinkow (2021)) are providing a first step towards fostering openness and transparency. However, such systems aim to support single activities focusing on open idea creation, open product development, and innovation to support decision-making in organizations involving customers and crowd workers (Zhang et al., 2008). Moreover, existing systems foster short-term business relationships and engage citizens through monetary awards (Karachiwalla & Pinkow, 2021). Citizen Science, though, aims to establish a partnership between researchers and intrinsically motivated citizens, focusing on the involvement of society in different phases of the scientific research process (Land-Zandstra et al., 2021). Compared to customers whose primary goal is to gain value from, for instance, a purchased product or service, citizen scientists are focusing on contributions to societal issues in collaboration with professional scientists or scientific institutions (Vohland et al., 2021). However, little is known about how to engage citizens systematically in scientific research processes to understand citizens'' needs and societal challenges. Specifically, there is a lack of design knowledge on designing systems that support engaging citizens to jointly explore the problematization phase and open the scientific research process. In this paper, we respond to recent calls to increase openness and transparency in IS research (Burton-Jones et al., 2021; Lukyanenko & Parsons, 2020) by identifying design principles for IS that support the systematic and structured involvement of citizens in the research problem exploration process following an Open Science paradigm. Moreover, the proposed design building on self-determination theory aims to trigger the motivation of citizens to participate in scientific inquiry through autonomy and relatedness. Therefore, we formulate the following research question:

How to design a research problem exploration system increasing autonomy and relatedness of citizens in the problem exploration process of scientific inquiry?

We apply a design science research (DSR) approach following Kuechler and Vaishnavi (2008) to answer this research question. The design knowledge we propose takes different forms: We derive design requirements, propose design principles, and instantiate design features for systems that enable the involvement of citizens on a large scale when exploring problems in scientific research processes. Furthermore, we provide a first step toward Open Science in IS research by delivering a novel and useful artifact that can be applied to explore problem spaces and discover scientific research problems involving citizens following an Open Science paradigm. We report on one complete cycle of the artifact design and the evaluation of the instantiated design principles using a series of online experiments and two field studies. Our results demonstrate the applicability and asses the use potential of our proposed research problem exploration system.

Conceptional foundations and related work

Problem exploration in scientific research

Scientific inquiry is considered an iterative and cyclical process with different phases in which various types of information are collected and continually revised (Brody, 1993; Godfrey-Smith, 2009). One of the first phases includes gathering information and resources through observations, definitions, and measurements of the subject of inquiry. The main objective is to gain a detailed understanding and description of the research problem and the subject of investigation. In design-oriented research, for example, many frameworks and process descriptions supporting design science researchers are proposing an explicit problem exploration phase (see Hevner et al., 2004; Kuechler & Vaishnavi, 2008; Peffers et al., 2007; Sein et al., 2011). During this phase, researchers aim to learn about the relevance, define the scope, and sense the size of the problem (vom Brocke et al., 2020). Additionally, the problem exploration phase is a development process from initial awareness until the problem formulation (Purao, 2021). Specifically, it has been argued that many design science projects that aim at societal and economic impact need to deal with complexity related to problem and solution spaces involving socio-technical phenomena that people perceive differently and are subject to constant change. The eDSR method was developed to deal with such complexity, which supports breaking down design science projects into self-contained components, so-called echelons, including a problem analysis echelon (Tuunanen et al., 2024). It has also been argued that problem elicitation will mark a particularly important contribution of research, specifically in times of artificial intelligence (AI), where solutions are largely autogenerated (yet sometimes seek their problems to solve in a value-adding and responsible way) (Tuunanen et al., 2024). Therefore, many well-established and well-accepted scientific research methods are available. Nielson provides a comprehensive overview of different methods and techniques for problem analysis applied in the field of IS (Nielsen, 2020). Most of the applied methods are qualitative methods, such as interviews or focus groups. Qualitative methods often require stakeholders or domain experts with dedicated knowledge about the problem (Wang & Noe, 2010). However, for researchers, it can be difficult to reach domain experts, and when it comes to topics that affect citizens in their everyday lives, they should be considered as the real-world domain experts. Additionally, most qualitative methods are time-consuming and do not scale well.

Open science

Open Science is not a new approach. It can be traced back to the Middle Ages. The first documented science association was established in 1660: the Royal Society of London for Improving of Natural Knowledge, emphasizing openness and the inclusion of women (Willinsky, 2005). Recently, Open Science has been growing rapidly due to the worldwide internet and related new technologies, tools, and communication channels. Its main characteristics are transparency, openness, and reproducibility (Stracke, 2020). Parsons et al. extend the definition of Open Science with the concepts of rigorous, replicable, accumulative, and inclusive (Parsons et al., 2022). Open Science aims to cover the complete research process from the design to the review process, including sharing research material and data to foster better understanding, verification, and re-usage (Miguel et al., 2014; Nosek et al., 2015). Reproducibility describes the robustness and repeatability of research findings addressing, for example, design decisions in the data analysis (e.g., filtering the dataset) for consistent findings by different researchers (Silberzahn et al., 2018). Allen and Mehler identify three benefits of applying Open Science. First, more trust in science and the results; second, an investment in own future research; and third, new helpful services and systems emerge (Allen & Mehler, 2019).

One specific dimension of Open Science is focusing on collaboration and participation on a large scale, including scientists and non-scientists (Stracke, 2020). Citizen Science, “the (large scale) involvement of citizens in scientific endeavors not only as participants but as co-researchers” (Weinhardt et al., 2020, p. 273), is a prominent approach to foster public participation in research projects with the aim to close the gap between scientific and public perspectives on real-world problems (Weinhardt et al., 2020). For instance, the Galaxy Zoo project involved over 400,000 citizens in order to support researchers in the classification process of galaxies (Fortson et al., 2011). Bonney et al. (2009) distinguish three types of citizen science: First, contributory projects focusing on crowdsourced data collection (e.g., Bird Count). Second, collaborative projects focus on data collection and analysis by citizens (e.g., Galaxy Zoo). Third, co-creative activities where researchers and citizens work jointly on scientific projects. From a societal perspective, opening the scientific inquiry and engaging with citizens to understand problems and provide solutions has been recognized as an essential prerequisite for responsible research and innovation in IS and beyond (Davison et al., 2022; McCarthy et al., 2020). However, these studies report on situational and non-generalizable settings and do not provide design knowledge for systems motivating citizens in scientific research processes. Moreover, in the field of IS, there are recent calls for more intensive leveraging of the potential of citizen science (Lukyanenko & Parsons, 2020; Weinhardt et al., 2020). Additionally, technology plays an essential role in empowering the open sharing of data, information, and knowledge within the scientific community and the wider public to accelerate scientific research (Ramachandran et al., 2021). To close this gap, we build on existing descriptive and prescriptive knowledge in order to provide new design knowledge for research problem exploration systems to support researchers leveraging the potential of citizen scientists.

Open innovation

Leading industrial firms produced, developed, and exploited concepts for innovations in self-reliance during the twentieth century. Companies today are re-examining the fundamental approaches to managing their innovation initiatives. Open innovation is a new breed of innovation and forces organizations to reassess their business strategies (Chesbrough, 2003). Involving stakeholders, for instance, customers, in the innovation process opens up the company’s innovation funnel and potential perspectives or ideas for creating innovations, enriching the innovation process (Zhang et al., 2008). The underlying concept of open innovation is called “Wisdom of Crowds” stating that many are smarter than few, or in other words “groups are remarkably intelligent, and are often smarter than the smartest people in them” (Surowiecki, 2005, p. 22). One way of integrating customers into an early stage of the innovation process is leveraging idea competitions using web-based information technologies (Leimeister et al., 2009). One example can be found in IBM's "Innovation Jam," which includes more than 150,000 employees generating 46,000 ideas (Bjelland & Wood, 2008). Typically, in such contests, participants compete against each other to find the best solution or idea, and the best solution(s) or idea(s) are awarded by the seeking organization in the form of monetary awards (Karachiwalla & Pinkow, 2021).

Crowdsourcing platforms

Crowdsourcing is an increasingly important approach in practice and research. It is heavily used in the field of open innovation and co-creation to leverage the knowledge and experience of the crowd. Many frameworks exist that guide researchers and practitioners in designing crowdsourcing platforms and campaigns (Ghezzi et al., 2018; Karachiwalla & Pinkow, 2021; Kohler & Chesbrough, 2020; Seidel et al., 2018). For instance, the input-process-output framework provided by Ghezzi et al. (2018) states that a clear definition of the problem or task given to the crowd is essential in designing crowdsourcing initiatives.

However, open innovation contests typically address individual skills, experiences, and creativity to create and build on new ideas (Seidel et al., 2018). Open Science is a promising approach to extend the boundaries of the problem space exploration phase and invite citizens to participate in the scientific research process. However, existing design knowledge on crowdsourcing and open innovation systems guides researchers and designers to build systems that strongly focus on crowd workers executing specific tasks motivated through monetary awards. In the field of IS, citizen science is a partnership between researchers and people in their everyday lives. Citizens are (a) interested in the phenomenon to be investigated, (b) part of the collection, collaboration, or co-creation of scientific endeavors, and (c) not the direct subject of scientific inquiry (Levy & Germonprez, 2017). Moreover, there exists no dedicated design knowledge on how to design research problem exploration systems to engage and motivate citizens to participate in a structured way in the scientific process.

Self-determination theory

A successfully applied approach when designing systems to motivate and engage users is the Self-Determination Theory (SDT). The theory provides a mature and empirically validated approach to human motivation (Ryan & Deci, 2000). SDT defines a set of psychological needs supporting peoples' self-motivation and psychological well-being (Ryan et al., 2013). This includes autonomy (to engage in actions that reflect their true selves), relatedness (being connected to and experiencing caring for others), and competence (feeling able and effective) (Deci & Ryan, 1991). Moreover, SDT defines different types of motivation ranging from amotivation to intrinsic motivation—the higher the self-determination, the higher the intrinsic motivation (Ryan & Deci, 2000). SDT has been successfully used to explain causal relationships between design features and motivational outcomes in multiple application contexts. For instance, in designing for motivation and engagement in digital experiences (Peters et al., 2018), in grounding designing features to motivate the use of social media applications (Karahanna et al., 2018b), or in designing games to increase game enjoyment and play experience (Ryan et al., 2006).

In our study, we use SDT as a kernel theory to inform our proposed design and motivate and engage citizens to participate in the research problem exploration phase of the scientific inquiry. In the digital experience design, the sense of competence is often related to requirements, including challenges (e.g., the difficulty of a video game), positive feedback, and opportunities for learning (Peters et al., 2018). Since we are not focusing on such features, we build on the two constructs of autonomy and relatedness. Based on the two constructs, we derived design requirements and proposed design principles to open the scientific research process and increase the motivation and engagement for the class of citizen science systems.

The design science research project setting

This study is part of a larger DSR project that delivers design knowledge and an innovative solution (research problem exploration system) for the real-world problem (involvement of self-determined citizens in the scientific inquiry) field of Open Science (Gregor & Hevner, 2013). The primary objective of this research project is to provide design knowledge that supports researchers and citizens in jointly working on scientific research projects with a specific focus on the problem exploration phase. DSR aims to support researchers in designing and evaluating novel artifacts (Hevner et al., 2004). We adopted the DSR approach based on the process proposed by Kuechler and Vaishnavi (2008). As illustrated in Fig. 1, we iteratively designed and evaluated our proposed artifact in two complete design cycles. Similar to the approach by Toreini et al. (2022), the work presented in this paper focuses on reporting the theoretically grounded second design cycle. The following sections provide background information on the overall DSR project and illustrate our research goal.

In the first design cycle, we started with an exploratory literature review on systems supporting Open Science approaches. The findings highlight that previous research

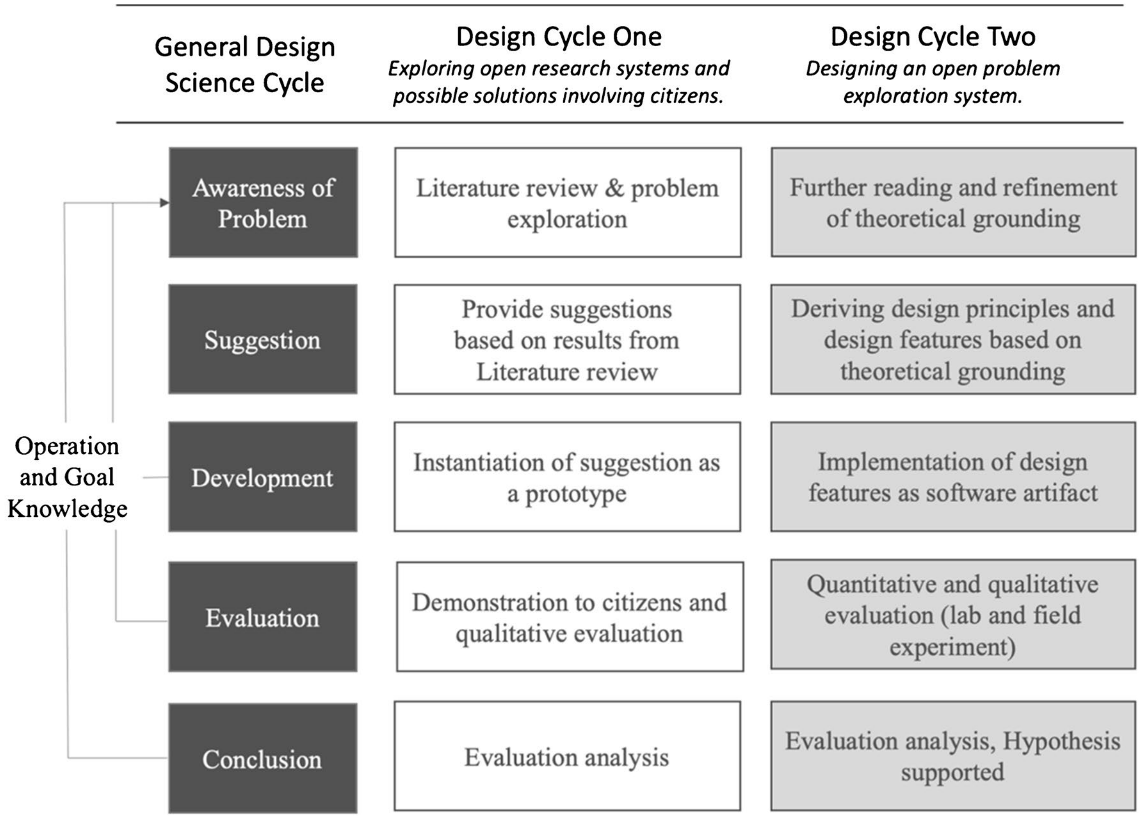

Fig. 1 Overview of the design cycles of the research project following Kuechler and Vaishnavi

emphasizes the importance of transparency and openness in scientific research in the field of IS and beyond (Burton-Jones et al., 2021). One essential purpose of Open Science is the responsibility of scholars to be open and accountable to society (Moravcsik, 2019). Moreover, from a societal perspective, engaging with society to understand problems and provide solutions is critical and constitutes a prerequisite for responsible research and innovation in research (Davison et al., 2022; McCarthy et al., 2020). In Design Science, specifically, transparency has been found to be an important quality criteria, and problem space transparency has been found to be one (out of six) fundamental transparency challenges (Hevner et al., 2024). Citizen Science is a prominent approach fostering extensive public participation in research projects aiming to close the gap between scientific and public perspectives on real-world problems (Weinhardt et al., 2020). Moreover, researchers have involved citizens in specific tasks or activities in research projects (e.g., Bird Count or Galaxy Zoo). In order to support the systematic involvement of citizens in the research process, we propose design knowledge for the class of citizen science systems to explore real-world problems jointly. In the first design cycle, we identified an initial set of design requirements (DR) from the literature and implemented a first prototypical implementation of a research problem exploration system. In order to evaluate the proposed design, we followed a formative evaluation strategy as suggested by Venable et al. (2016). The first evaluation aimed to demonstrate an early-stage prototype and evaluate its usability in an artificial setting (Sonnenberg & vom Brocke, 2012). Focusing on the system interaction and not on content generation, we recruited citizens using Prolific[1] to evaluate the proposed system's usability and functionality. Prolific is a versatile crowdsourcing data acquisition platform providing a large base of citizens across society with different backgrounds and is widely used as a dedicated research subject pool (Palan & Schitter, 2017). Moreover, citizens participating on large crowdsourcing platforms are typically familiar with tasks such as evaluating system functionalities in early stages and providing high-quality feedback, for instance, in reporting usability issues (Litman et al., 2021). Each participant was rewarded with a payment of five pounds (GBP). We invited participants to share their challenges and experiences regarding the topic "Home Office" as this setting recently revealed new challenges and unexpected problems for many workers and students (Guler et al., 2021; Hacker

[1] https://www.prolific.co/

et al., 2020). Overall, 30 crowd workers in the role of citizens with different backgrounds (mean age 27.9 years, 47% female, 50% male, 3% other) participated in the evaluation using the system (detailed instructions see Appendix 1. Online experiment task description). They explored the home office problem space by sharing 32 research problem descriptions. On average, it took participants 17.87 min (SD 3.25) to complete the study. After using the research problem exploration system, we asked the participants in open text fields for strengths, weaknesses, opportunities, and threats (SWOT) regarding the prototype in an additional questionnaire. We followed the process described by Leigh (2009) and analyzed the responses. Overall, the citizens provided 63 strengths, 44 weaknesses, 45 opportunities, and 33 threats.

The reported strengths, weaknesses, opportunities, and threats were grouped into 12 categories (see Appendix 3. SWOT analysis for more details). We discovered that most strengths (18) relate to ease of use/efficacy (e.g., "easy to use"). Weaknesses are related to exploration & organization (8) (e.g., "no ranking of top challenges with most likes" or "no possibility of comments"). Opportunities are most pronounced in statements related to the system's problem submission feature for citizens (18) (e.g., "more transparency for the problems of the citizens"). Threats most frequently deal with trolls/platform abuse (10) (e.g., "no 'censorship' of swear words, insults, or confidential data […]"). Based on the first demonstration, we found evidence that the initial prototypical implementation of the system lacked intrinsic motivation and engagement features. Specifically, the participants reported wanting to connect more with other citizens with similar challenges and discuss their problems or thoughts. Moreover, they stated that the purpose of submitting research problems is unclear and that there is no well-defined process description unfolding how the reported research problem descriptions will be integrated into the scientific inquiry. Based on the results of the SWOT analysis and our learnings from the first design cycle, we conducted a second cycle, building on the preliminary findings.

In the second design cycle, we reflected on the results and findings from the first cycle. Furthermore, as part of the second cycle, we refined the theoretical grounding and introduced the self-determination theory (Ryan & Deci, 2000) as our kernel theory. The underlying idea is that our design triggers the intrinsic motivation of citizens to participate actively in research problem exploration projects. Based on the previous finding and the kernel theory, we refined and extended the DRs. Grounded on the requirements, we propose an initial set of design principles (DP) and derived design features (DF). Furthermore, we clarified the explanatory description text and added a clear process description of how the submitted research problems are embedded in the scientific research process. Moreover, in the second cycle, we instantiated the DP and extended the prototypical implementation by implementing the derived DFs. Finally, we evaluated the prototype in an online experiment with 80 participants to better understand the impact of the DPs. Additionally, we evaluated the prototype in two field studies, inviting citizens to report their challenges in a naturalistic setting. The field studies aimed to evaluate the system in a natural setting with actual citizens, emphasizing external validity and assuring rigorous assessment of the effectiveness of the artifact (Venable et al., 2016). We invited citizens to participate voluntarily in the problem exploration phase of the scientific inquiry. Moreover, we stated that we take the most important challenges as input into a design seminar where students design a prototype for the challenge. All the participating citizens of the field studies did not receive any reward or payment for their contribution. In order to inform citizens about the ability to submit challenges regarding sustainability and home office topics. We used social media channels from the university, local newspaper announcements, and the institute's website to engage citizens with a call to action (Mejtoft et al., 2021). The experiment was designed as a between-subjects study with two groups: (1) the treatment group and (2) the baseline group as the control condition. The participating citizens were assigned randomly, and both groups were first provided with an introduction and an explanation of the task. The task included interacting with the provided research problem exploration system and contributing to home office challenges. After executing the task, we asked the participants about their experience using the problem exploration system. Additionally, we used the items provided by Ahuja et al. (2007) to measure the perceived autonomy and the items provided by Peters et al. (2018) to measure the perceived relatedness of the participants (for the complete list of items, see Table 4 in the Appendix).

A selected set of the most relevant challenges was further investigated in design-oriented research projects conducted by groups of students in a design seminar.

Designing the open research problem exploration system

Requirements

Grounded on the findings of the first cycle, we identified the need to involve citizens in the scientific research process more systematically. Additionally, we identified the lack of motivation and the lack of guidance and process description as the two major issues in the evaluation phase of the first cycle. To trigger the intrinsic motivation of citizens, we identified the SDT proposed by Ryan and Deci (2000) as a promising kernel theory. SDT is an established approach to human motivation and has been widely used in designing for motivation and engagement in digital experiences (e.g., Peters et al. (2018)). SDT addresses different factors to facilitate motivation. More precisely, SDT was developed focusing on intrinsic motivation or motivation based on the inherited satisfaction resulting from action for an individual to act on their environment in a self-determining fashion (Ryan & Deci, 2000). The psychological needs of autonomy and relatedness require satisfaction and are the underlying concepts supporting intrinsic motivation (Ryan & Deci, 2000). To increase the motivation of citizens to participate in the problem exploration phase of scientific inquiry, we leveraged SDT in our design process as kernel theory. Based on the two concepts of autonomy and relatedness provided by the SDT, we derived design requirements for research problem exploration systems.

Based on the literature introduced above and the findings of the first design cycle, we first derived a set of design requirements in the second cycle. As argued by McCarthy et al. (2020) and Davison et al. (2022), identifying relevant real-world problems requires the involvement of those affected already in the initial problem identification phase, which is crucial for the success of scientific research projects. Therefore, researchers must identify and involve the relevant stakeholders and discover their needs (Maedche et al., 2019). Tackling real-world challenges, citizens are affected stakeholders and must be involved in the problem exploration phase. We thus articulate the first and second design requirements as follows:

DR1: The system should enable the involvement of citizens to jointly explore the problem space of research projects together with researchers.
DR2: The system should enable researchers to identify the most relevant classes of problems in the problem space of a research project.

Due to the heterogeneity of contributors, ensuring data quality is a major issue in citizen science and crowdsourcing (Lukyanenko et al., 2019). Furthermore, a clear definition of the task given to the crowd is essential in any crowdsourcing system (Ghezzi et al., 2018). To enable an appropriate understanding and description of the problem space, we proposed a conceptual model consisting of four key concepts following Maedche et al. (2019): (1) Needs informing (2) Goals that are satisfied by (3) Requirements while (1)—(3) are contextualized and influenced by different (4) Stakeholders. This leads to the third and fourth requirements:

DR3: The system should request structured and complete research problem specifications, ensuring high data quality.

DR4: The system should support citizens with no research background and knowledge in capturing new research problem descriptions.

One of the main goals of the proposed system is to increase transparency involving society in the initial phase of research processes and create a partnership between IS researchers and people in their everyday lives on a large scale (Levy & Germonprez, 2017), the fifth requirement is:

DR5: The system should ensure data and process transparency.

The need for relatedness is the psychological need to interact, be connected, and share experiences with others. The feeling of being connected with others can enhance motivation (Ryan & Deci, 2000). Exploring research problems in scientific inquiry is an interactive process between different stakeholders and requires interaction between them. To increase participants' motivation, the feeling of relatedness is relevant and needs to be considered in the design of problem exploration systems. Therefore, we introduce an additional design requirement:

DR6: The system should engage citizens in discussing research problem descriptions with others who have similar challenges or experiences.

The need for autonomy within SDT represents the psychological need to act authentically as oneself and to engage in activities freely, not because one should or must, for instance, because of social pressure or norms (Karahanna et al., 2018b). All people have the desire to be autonomous and to engage in actions that reflect themselves (Deci & Ryan, 1985). The perceived autonomy is high if activities are done because of personal interest. Because the participation of citizens in citizen scientist activities outside of paid scientific experiments is most often voluntary, participants' autonomy would typically be high. However, research problem exploration systems can provide autonomy within the system; for example, citizens may want to provide research problem descriptions to the full extent or just add their thoughts to existing ones. Also, the system asking questions regarding the research problem concepts should support choices in collecting different levels of problem descriptions to support autonomy (Sankaran et al., 2020). Therefore, we articulate the following two design requirements:

DR7: The system should provide multiple ways to create research problem description submissions.
DR8: The system should provide choices when asking for details on the research problem description.

Based on the feedback provided by citizens of the first design cycle reporting that it was unclear what would happen with their submitted research problem descriptions, we derived another requirement as follows:

DR9: The system should describe the entire research process and how citizens can contribute to the process by providing research problem descriptions.

Design principles and design features

Based on the identified design requirements, we derive an initial set of design principles to specify the design knowledge in an accessible form (Gregor et al., 2020). Additionally, our proposed DPs are informed by the concepts of autonomy and relatedness provided by the SDT. The first DP is derived from DR1, DR5, and DR6 and describes citizens' ability to browse research problems that have already been submitted and their descriptions (Levy & Germonprez, 2017; Maedche et al., 2019). Furthermore, based on the concept of relatedness, citizens should be able to extend existing research problem descriptions with their experiences or opinions. Based on DR2, DR3, DR7, and DR8, the second DP describes the ability to select important and relevant problems (Lukyanenko et al., 2019; Maedche et al., 2019). Citizens should be able to rate important and well-described research problems that other citizens have submitted. Based on the concept of autonomy, different forms of contributing, such as reporting a full problem description, commenting on existing descriptions, or rating the importance, allow citizens to collaborate on different levels during the problem exploration phase. The third DP, derived from DR3, DR4, DR5, DR8, and DR9, describes guidance abilities. Citizens can have different knowledge levels and experiences in scientific research. Therefore, the system should support citizens in creating new problem descriptions to guarantee that the descriptions fulfill a certain level of quality (Ghezzi et al., 2018; Lukyanenko et al., 2019). An overview of the initial design principles and the related design requirements are summarized in Table 1.

In the next step, we derive a preliminary set of design features (DFs) and map them to the DP. DFs are a specific way to implement DPs and describe the technical implementation of an abstract DP (Meth et al., 2015). Table 2 summarizes the initial set of DFs of the prototypical implementation and the mapping to the DPs.

Table 1 Overview of the design principles and the corresponding design requirements

Design principle	Name	Description	Related DR
DP1	Exposure	The system provides support to expose existing research problem descriptions to connect with other citizens and increase the completeness of problem descriptions	DR1, DR5, DR6
DP2	Participation	The system provides different levels of participation so that citizens can decide how to contribute to the research problem exploration phase	DR2, DR3, DR7, DR8
DP3	Guidance	The system provides guidance and templates to support citizens in collecting precise and structured research problem description formulations	DR3, DR4, DR5, DR8, DR9

Table 2 Overview of the design features and the corresponding design principles

Design feature	Description	Related DP
DF1	The system provides definitions and descriptions of problem space boundaries	DP3
DF2	Citizens can submit specific classes of research problems in the problem space	DP1
DF3	Citizens can explore and browse the problems of other citizens	DP1
DF4	Citizens can prioritize existing problems they perceive as important	DP2
DF5	Citizens are provided with problem description templates	DP3
DF6	The system can be accessed from any device containing a web browser	DP2, DP3
DF7	User authentication and non-anonymous sharing of content is required	DP3
DF8	The system provides guidance for citizens to submit structured problem descriptions	DP3
DF9	The system should enable commenting existing research problem descriptions to allow for exchanging additional information, thoughts, and experiences	DP2
DF10	The CA should support different levels of research problem description fidelity	DP2, DP3
DF11	The system should provide a transparent and well-defined process description of the underlying scientific research process	DP3

Implementation

In the implementation phase, we instantiated the previously derived DFs in the form of a first prototype of the system called MyResearchChallenge. MyResearchChallenge is a web application using Python built on top of the web framework Django.[2] The data is stored in a central database using MySQL.[3]

Leveraging state-of-the-art web technologies enables citizens to access the application via any device containing a web browser (DF6). Researchers can describe the boundaries of the problem space by providing a title, a brief description, the timeframe of participation (e.g., a particular month), and an illustrative image (DF1). Citizens can explore existing research problem descriptions (DF3) or capture new ones (DF2). Throughout the research problem exploration, citizens can vote for research problem descriptions they perceive as important and relevant for further scientific investigations (DF4). To capture new research problem descriptions, citizens must register with a dedicated user (DF7). During the submission process, users can decide to publish the description anonymously or by providing a nickname. To submit new problem descriptions, a simple conversation agent (C9A guides users through the description and submission process (DF8). Existing research has shown that CAs can be used as facilitators to promote data exploration and lower barriers to citizen engagement in research projects and documentation of citizens' content generation (Stein et al., 2024; Tavanapour et al., 2019). The integrated CA is implemented using RASA,[4] an open-source chatbot framework, providing features for interaction with databases, application programming interfaces, conversational flow, and interactive learning with reinforcement neural networks (Sharma, 2020). In the conversation with the users, the agent asks questions regarding the concepts, needs, goals, requirements, and stakeholders described in the problem space model provided by Maedche et al. (2019). The four concepts also serve as a template to capture and structure new problem descriptions (DF5). After submitting a new problem, the description is stored in the central database and is publicly available for other citizens to explore and vote.

Supporting the psychological need for relatedness, citizens can browse and extend existing research problem descriptions by providing additional inputs (DF9). This allows citizens to interact with others facing similar problems and enables sharing thoughts or experiences on research problems. The system offers different contribution levels in the research problem exploration phase to fulfill the need for autonomy. Citizens can contribute by providing a comprehensive description or extending an existing research problem description. Also, the CA provides features to submit only a short description or describe additional details regarding the problem (DF10). To increase the transparency of the research process and shed light on what will happen with the submitted research problem descriptions, we added a new section on the landing page explaining the different phases of the research project and provided a timeline for each activity (DF11). Figure 2 illustrates the derived DFs and their implementation in the web application MyResearchChallenge from both design cycles.

Evaluation

In the evaluation phase of the second cycle, we evaluated our proposed design in an online experiment and two field studies. The aim of the online experiment was to evaluate the internal validity of the artifact. In a controlled setting we analyzed the effectiveness of the proposed design principles (DP1 and DP2) supporting the concepts of relatedness and autonomy derived from SDT. In the field studies, we evaluated the system and its external validity in a real-world scenario with citizens participating voluntarily in the study. In both settings, the focus of the evaluation was on the system interaction and the effectiveness of the artifact rather than on the content provided by the citizens. In the online experiment, we used the topic "Home Office," and in the field studies, we used the topics "Home Office" and "Sustainability" as the problem space to be explored. We invited citizens to interact with the system and submit their problems and challenges regarding the topics.

Online experiment

The experiment was designed to include a treatment group and a baseline group. Online experiments are a powerful method to involve a large audience with high internal validity (Karahanna et al., 2018a). In reference to Gregor and Jones, we expressed testable propositions based on our design and tested them in the online experiment (Gregor & Jones, 2007). The experiment aimed to evaluate the modified and implemented design principles and to test the propositions derived from the design principles. First, we wanted to know if the principle of exposure leads to more relatedness than in the baseline (P1). Second, if the principle of participation leads to more autonomy in the problem exploration phase than in the baseline (P2).

The treatment group interacted with the implemented artifact based on the proposed design to submit challenges or extend existing challenge descriptions, as illustrated in

[2] https://www.djangoproject.com/

[3] https://www.mysql.com/

[4] https://rasa.com/

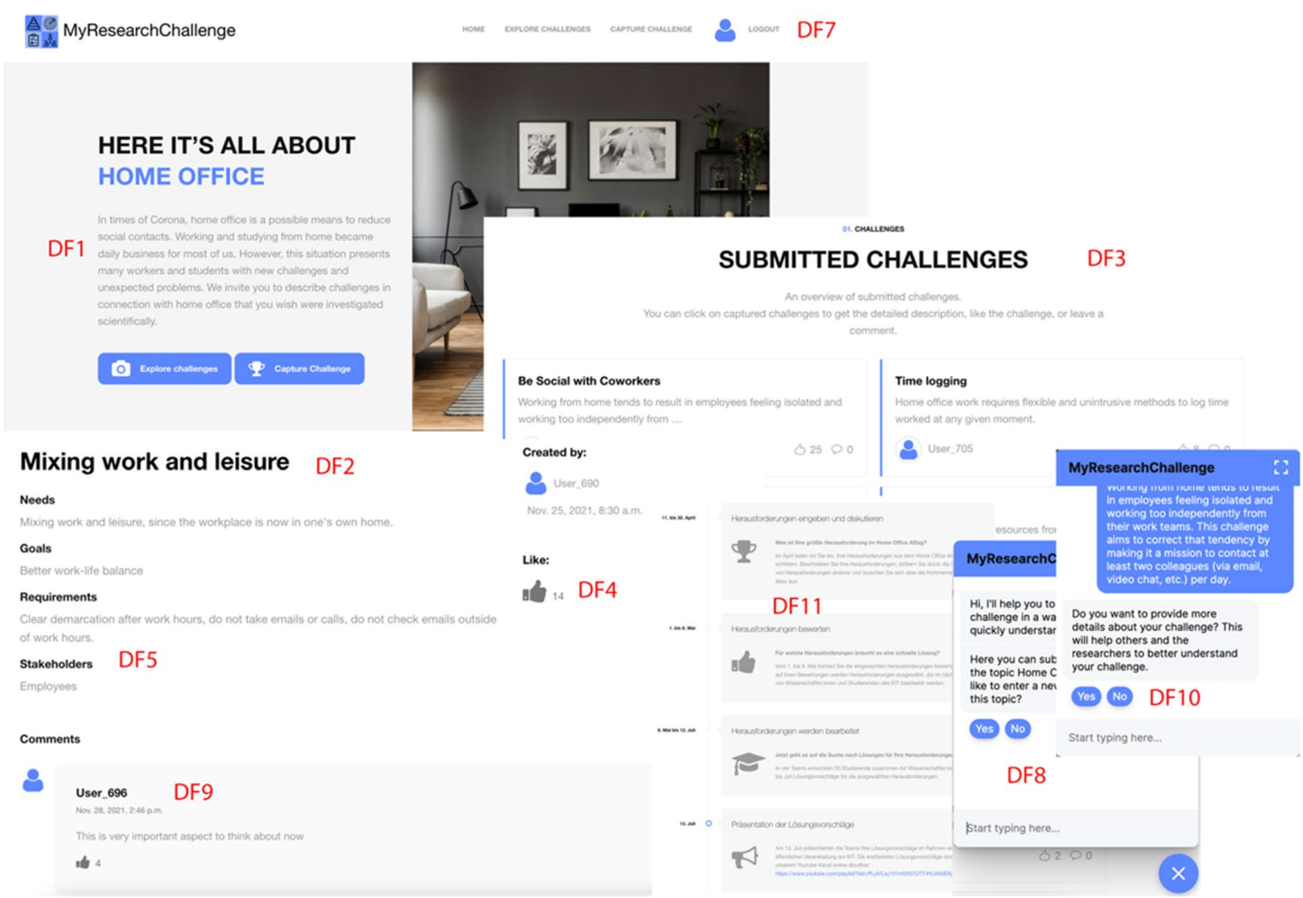

Fig. 2 Overview of the revised research problem exploration system MyResearchChallenge

Fig. 2. The baseline group interacted with the same system without the DFs implementing the principle of exposure (supporting P1) and participation (supporting P2). A screenshot of the baseline system is illustrated in Fig. 3 in the Appendix. A priory power analysis using the G*Power software (Faul et al., 2009) with a medium effect size ($g = 0.50$) resulted in 80 participants for the experiment (Kang, 2021). Similar to the evaluation in the first cycle, the online experiment aims to evaluate the system in a controlled environment. Therefore, we decided to invite citizens in the form of students from our university panel. To discover and explore real-world problems regarding home office and homeschooling, we invited 90 participants from the universities' panel and asked them to submit and discuss their challenges experienced during home office. On average, it took the participants 19 minutes and 31 s to complete the study. We paid 5 Euros for each participant to trigger basic extrinsic motivation. After cleaning the data, 80 valid[5] datasets remained. The dataset included 50 male and 29 female students (one with no answer) with an average age of 24.5 years.

Table 3 Citizens' submissions in the field studies

Submission	Home office challenges	Sustainability challenges	Total
Challenges	26	25	51
Likes	69	38	117
Comments	10	2	12

We applied a one-way ANOVA to test the treatment and baseline groups. Homogeneity of variances was asserted using Levene's Test (Levene, 1960), which showed that equal variances could be assumed for autonomy ($p = 0.38$) and for relatedness ($p = 0.21$). A graphical summary of the distribution of each sample can be found in the appendix (see Appendix 5. Online experiment sample distribution). The 46 participants in the treatment group reported an average value for relatedness of 2.93 (SD = 0.99) and an average

[5] Five participants did not pass the attention check. Another five participants did not complete the questionnaire at the end and where also removed from the analysis.

value for autonomy of 3.95 (SD = 0.80); the 34 participants in the baseline group reported an average value for relatedness of 2.51 (SD = 0.84) and an average value for autonomy 3.21 (SD = 1.02). The effect of relatedness, therefore, was significant, $F = 4.16$, $p = 0.045$, and the effect of autonomy, therefore, was also significant, $F = 13.49$, $p < 0.001$.

Field studies

In two field studies, citizens could use MyResearchChallenge to submit their individual challenges for four weeks. We provided eight subtopics citizens could select to submit their challenge. During the participatory action, two researchers (one professor and one PhD student) with the corresponding expertise were responsible for each subtopic. Also, citizens could browse existing challenges on the web application to get inspired by other challenges or discuss challenges with other citizens by adding comments. After the collection phase, the voting phase started for one week. In the voting phase, citizens could vote for challenges they find interesting or relevant and want to be further investigated by scientific researchers. Table 3 summarizes the results of the collected submissions in the four different subtopics.

After finishing both phases, we analyzed the system usage data. During the collection and voting phase, 1444 citizens visited the publicly available web application, and 5114 page loads were requested. Overall, citizens submitted 51 challenges with an average text length of 813 characters, 12 comments, and 117 likes on MyResearchChallenge. The average time spent on MyResearchChallenge was four minutes and 18 s. Furthermore, we found evidence that the perceived relevance of the challenges provided by the citizens increased over time based on the like counts. The first half of the submitted challenges in the collection phase received an average value of 2.25 (SD = 1.91) likes, and the second half received an average of 3.82 (SD = 2.16) likes. The effect of the perceived relevance in the second half was significant, $F = 5.02$, $p = 0.042$.

Regarding the different participation levels, we analyzed the interaction with the CA and provided details concerning the submitted challenges. 62.7% of the citizens answered all the additional questions asked by the CA related to the problem description conceptualization proposed by Maedche et al. (2019). The average text length for challenges providing answers for all questions was 1034 characters (SD = 554). For the other challenges, the average text length was 439 characters (SD = 311). Additionally, challenges where other citizens participated by adding comments received an average of 5.00 likes (SD = 2.00), and challenges without comments received an average of 1.70 likes (SD = 1.78). Therefore, the perceived importance is significantly higher, $F = 19.94$, $p < 0.001$.

During the voting phase, citizens could select important topics they want to be further investigated by the corresponding experts. For instance, in the subtopic “Physical Activity and Health” of home office challenges, the submission entitled “Lack of commuting” was rated as the most important. Citizens reported that the lack of commuting is perceived as a challenge and leads to a reduction in physical activities. In the subtopic “Motivation and Leadership” the challenge with the title "Staying in touch with employees as a manager" was voted the most relevant. Moreover, they reported that the lack of exchange leads to understanding, opinion-forming, and cohesion issues in home office settings. In another example provided in the subtopic “Collaboration Tools,” citizens selected the challenge describing the lack of short informal and often spontaneous interactions as the most important. Brief exchanges among colleagues are perceived as an important part of everyday work and are often missing in home office environments.

For each subtopic’s most important challenge, groups of students designed prototypes in a design seminar. We invited all participating citizens to the final presentation, where the students presented their proposed designs and demonstrated the prototypes to them. Moreover, a short demonstration video of the prototype was created and made publicly available on YouTube for each solution.

Discussion

In this paper, we present design knowledge for the research problem exploration phase of scientific inquiry following an Open Science paradigm. Applying design science research (DSR) as described by Kuechler and Vaishnavi (2008), we deliver design requirements, propose design features, and present a set of design principles for research problem exploration systems. Furthermore, we present a publicly available implementation of the system. The aim of the designed system is to engage and involve citizens on a large scale in the problem-exploration phase of scientific research processes. We provide a novel artifact that enables citizens to engage and collaborate in scientific research inquiry to understand citizens’ needs and societal challenges.

Focusing on the second design cycle, we instantiated the proposed design and evaluated the prototypical implementation by inviting citizens to participate. The results of the online experiment revealed evidence that our proposed design leads to more autonomy and relatedness while using the system compared to the baseline without the design features supporting the principle of exposure and participation. Furthermore, in the field studies, we collected 51 real-world challenges provided by citizens. The analysis of the system usage data showed evidence that the perceived importance of the submitted challenges increased over time and stimulated discussion among citizens.

Our study contributes to the latest literature on Open Science rooted in different research fields and to recent calls for more openness in the field of IS (Burgelman et al., 2019; Burton-Jones et al., 2021). Openness and transparency are the two main concepts of Open Science supported by dimensions such as collaborative research (Stracke, 2020). While these elements can be found in our conceptualization, we provide (a) an alternative approach for research problem explorations and (b) design knowledge for research problem exploration systems. The design goal of our proposed artifact was not to entirely replace existing research methods applied by scientists in the problematization phase of scientific inquiry. Our proposed approach complements existing methods in opening the knowledge-creation process, supporting the engagement of citizens in certain topics to reveal more insights from experts or interested citizens regarding certain problem spaces (Weinhardt et al., 2020).

Regarding the generalizability of the proposed solution, we suggest two future directions: First, we believe that the proposed design for Open Science systems can also be applied in other stages of scientific inquiry. In this study, we applied and evaluated the design in the problem exploration phase. However, citizens could also be involved in different phases of the research process, such as the design and evaluation phases. Second, the use of Open Science systems is not limited to the field of IS. Such systems can be applied across disciplines and enrich research processes in other disciplines. For instance, in urban research, citizens' involvement and concerns are crucial to developing liveable smart cities (Müller et al., 2018). Open Science systems can support urban designers and increase the engagement and involvement of citizens in city development on a large scale.

The proposed design knowledge of this study is a first step towards Open Science systems in the field of IS. Citizens are known to enrich research processes by providing valuable data (Lukyanenko & Parsons, 2020). Recent studies actively engage citizens for different purposes, from urban planning to environmental protection and tasks from data collection to data analysis (see Crowston & Prestopnik, 2013; Fegert et al., 2020; Nielsen, 2020). In this paper, we present design knowledge for the broader class of citizen science systems. The proposed design principles and their instantiations illustrate how to design systems in order to engage citizens in a structured and systematic way in scientific inquiry on a large scale. The presented approach and the design knowledge should guide other researchers and practitioners to open their research processes and connect with society. In order to ensure that the provided design knowledge can be applied in different contexts for the same class of problems, it is necessary to elaborate on the reusability of the DPs. One possible approach could be applying the reusability evaluation framework proposed by Ivari et al. (Iivari et al., 2021). Together with a group of selected designers of research process support systems, the reusability of the proposed DPs could be evaluated and further developed in future research.

However, opening the research process and involving citizens can also be critical, and the generated content needs to be curated. Online social media platforms are primarily targeted by bots. Bots are used to produce spam and disseminate false information on online social networks (Gnanasekar, 2021). Moreover, enabling citizens to submit problem descriptions and the feature to discuss the descriptions can lead to conflicts between citizens. Researchers engaging citizens need to control the generated content, for instance, as gatekeepers to detect platform abuse and potential conflicts between citizens (Kaufhold & Reuter, 2019).

The class of systems described through our design principles reveals similarities to other types of systems, such as sensemaking systems (Seidel et al., 2018) or open innovation systems (Bullinger et al., 2010; Kohler & Chesbrough, 2020). However, the applied concepts and the kernel theories are different. Sensemaking systems aim to "identify and define relevant problems and provide feasible solutions" (Seidel et al., 2018, p. 239), and open innovation systems address individuals' skills, experiences, and creativity to collect ideas and comments on others' ideas. The proposed system design aims to engage citizens in scientific inquiry by providing features derived from the self-determination theory supporting autonomy and relatedness (Ryan & Deci, 2000) in the problem exploration phase. Additionally, the system provides guidance in structuring the problem descriptions based on the conceptual problem space model proposed by Maedche et al. (2019) to collect complete and precise problem descriptions.

We believe that systems like the proposed MyResearchChallenge can serve researchers as an alternative to the existing methods and techniques in the research problem exploration phase (see Nielsen (2020)). Additionally, including citizens in collecting and discussing real-world challenges extends the borders of problem exploration spaces. Therefore, tools supporting the Open Science approach by engaging and motivating citizens to collaborate in scientific research projects is one step towards closing the gap between scientific and public perspectives on real-world problems (Weinhardt et al., 2020).

This study comes with several limitations. First, the system design lacks the scientific researchers' perspectives and needs. In this paper, we focus only on the citizens' perspective on research problem exploration systems. Second, the evaluation of the system in the two field studies included a small number of participants, and the evaluation was done by exploring problems and challenges regarding the home office topic. Important boundary conditions are (a) the domain regarding other problem spaces and (b) other fields with different participants and backgrounds. However, we used the prior theory as justificatory knowledge and the results of the evaluations, thus allowing for the generalization of our findings (Lee & Baskerville, 2003). Moreover, we evaluated our design regarding the concepts of relatedness and autonomy described by the SDT in an online experiment with paid participants. This allowed us to evaluate the system features in a controlled environment. However, the evaluation lacks a profound understanding of self-motivated citizens based on the proposed design in a naturalistic setting. Third, due to data protection and privacy issues, we were forced to enable anonymous participation in the online field studies. Therefore, we could not collect any demographic data and evaluate the external validity of the proposed design with the complete cross-section of society.

Conclusion

Open Science is an important approach to make research and its findings more transparent and accessible. In this paper, we investigate how Open Science systems need to be designed to open the research process and engage citizens to participate in the problem exploration phase. We identified design requirements to motivate and involve citizens in a structured manner in scientific inquiry. We proposed a set of design principles—instantiated and implemented in the form of design features—that we revised through building and evaluating a prototypical implementation. The formulated design principles are not limited to research problem exploration systems. Still, they can be expected to be relevant in several settings where researchers are interested in collaborating with other scientists or non-scientists on a structured and large scale. The relevance of Open Science has increased over the last decades and is relevant in nearly every research field. Not only is Open Science supporting researchers to understand research results better and, in the long run, improving research and science in general, but it also connects society with scientific research and can help address the societal challenges of our times.

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Data Availability The data that support the findings of this study are available on request from the corresponding author, Michael Gau.

Declarations

This study was reviewed and approved by Institutional Review Board of the University of Liechtenstein. Participants indicated their consent to the terms of the study via a checkbox on the information page.

Competing interests The authors declare that they have no conflict of interest.

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