PROCEEDINGS OF SCIENCE

The role of mental models in citizen science

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An increasing number of citizen science projects involve citizens on levels of participation that go beyond data collection and entail the co-creation of research questions and methods as well as the project pathway. The success of such projects depends on the establishment of shared knowledge, a task that can be especially challenging in citizen science that focuses on complex societal issues and the so-called wicked problems. We suggest that this challenge can be addressed through a deeper engagement with research on mental models—cognitive representations of external reality that largely define human thinking, decision-making and behaviour. Moreover, particular emphasis should be placed on the effective co-creation of shared mental models, whereby design thinking could provide valuable methodologies and tools. The objective of the workshop "Mental Models in Citizen Science" was to dive into mental model theory and design thinking toolbox and explore their potential for citizen science. This paper provides an overview of the workshop activities and insights and proposes a research agenda shaped around mental models and their role in citizen science.

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1. Introduction

Which image appears in citizens' minds when invited to participate in a citizen science project? How do they picture their involvement in such a project, and what are their expectations and predictions? How do they conceptualize complex societal issues like energy transition or sustainability in a citizen science project? In this paper, we argue that the answers to these crucial questions can define the course and outcome of a citizen science project, and call for a deeper engagement with research on mental models (MMs)—cognitive representations of the external reality, which allow individuals to make inferences about what will happen in a particular situation in the future [16]. It further highlights the importance of co-creating shared MMs and puts emphasis on the need to leverage methods and tools from design thinking—a research perspective that focuses on finding creative solutions for the so-called wicked problems. This paper provides background for research directions (Section 2), describes the case study and activities that shaped the workshop (Section 3), and proposes a research agenda (Section 4).

2. Related research

2.1 Mental models

MMs are internal cognitive structures of external reality that individuals develop in the course of their lives based on their experience and formal knowledge acquisition. These structures can represent events, activities, an object, or a subject area [10]. They allow individuals to interpret and understand their environment, but also to infer relationships, experience events "by proxy", predict the results of certain behavior, and, eventually, determine and control a course of action [10, 11]. As such, MMs have a value and reality of their own—individuals believe in them without direct reference to their accuracy or level of completeness, and are reluctant to give them up [21]. The importance of studying MMs to better understand human behaviour and decision-making has been acknowledged in numerous fields: from risk communication, business and organization science to natural resource management and climate change adaptation [1, 14, 18, 22].

Research on MMs involves a range of elicitation and analytical techniques. *Individual* MMs can be elicited using verbal and diagrammatic techniques and analyzed using metrics such as the number of functional linkages or the number of concepts [12]. A set of individual mental models in a team—*team* MMs—can be further explored using a comparative analysis, providing insights into the variation within the team. For example, the identification of common aspects of individual MMs can be used as a starting point for developing a shared model for coordinating actions in a team setting [15]. Finally, *shared* MMs are jointly constructed in the process of interaction in a team setting, for example, through a group model building [6, 13]. While this approach is more resource-intensive, it provides powerful means for co-creating a joint path towards a particular goal, especially when supported by collaborative modeling tools. Thus, the Mental Modeler—an online tool to facilitate science engagement—supports social practices of science through the development of scientific discourse and learning [9].

Over the decades, research into MMs has advanced our knowledge of the cognitive mechanisms that shape MMs, described elements of MMs, and currently provides an advanced

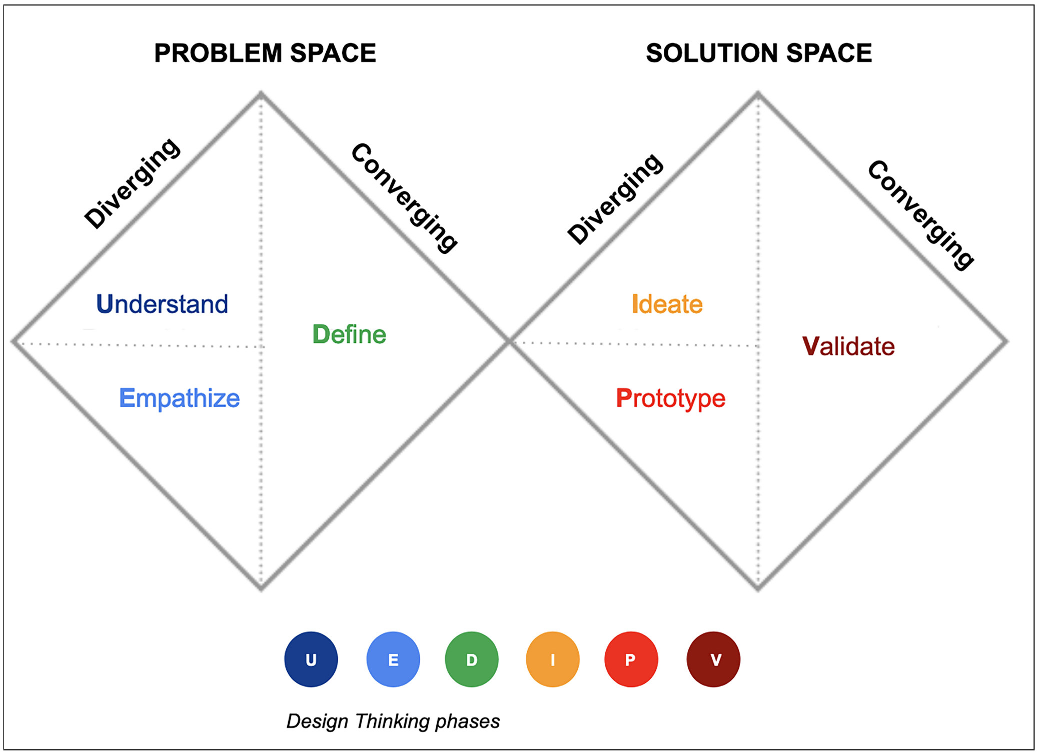

Figure 1: Double Diamond with Design Thinking phases. Adopted from [17, p.220] and [4], to appear.

toolbox of robust metrics and analytical techniques that can reveal various aspects of MMs depending on the research purpose at hand.

2.2 Design thinking

By the time the term "Design Thinking" was introduced in 1987 [19], the design thinking perspective had become an established practice in the design community. Sparked by the task of dealing with open-ended complex problems (i.e., wicked problems), the design thinking perspective explored and developed methodologies that emphasized finding the problem acting from the human experience, involving stakeholders, and incorporating co-creation methodologies [3]. This long-term experience with wicked problems has put design disciplines to the methodological forefront of finding creative solutions, and over the last decade, an increasing amount of fields (e.g., Institutes, Information Technology, Business) has turned to design disciplines in search of methods and techniques [3]. This growing attention, in turn, has led to the development of the design thinking framework.

The design thinking framework consists of six iterative phases: Understand, Empathise, Define, Ideate, Prototype, and Validate. While these phases can be implemented as such, it is common to apply the Double Diamond model (i.e., Diverge-Converge Model of Design) [17, p.220]. The model consists of two spaces, Problem and Solution, each further divided into the diverging and converging phases (see Figure 1). The diverging phase of the Problem space (Understand and Empathise) aims to understand the problems by collecting existing knowledge and experiences, empathise with stakeholders by looking for tensions, contradictions, and surprises, and elicit latent needs. Such deep emerging into the context of the problem unravels the point of departure to create the concept design challenge. The converging phase of the Problem space (Define) (re-)frames the design challenge by making choices from a human-centered point of view. The diverging phase of the Solution space (Ideate and Prototype) aims to generate a pool of ideas and create a prototype. The converging phase (Validate) uses several iterations to collect feedback and improve possible solutions.

Each of the phases in the two spaces has a rich set of methods and tools, targeted at a particular outcome. To give a few examples, a common method for the converging phase of the Problem space is affinity diagramming—a method based on bottom-up and intuitive (i.e., not learned) labelling of different kinds of data (e.g., interview quotes, observation notes, photographs) by multiple stakeholder groups. A common technique for the diverging phase in the Solution space is "How Might We", which is used to look at the problem differently by formulating questions that break up the problem/challenge, to get inspiration and ultimately find opportunities. Once the ideas are generated, a common technique for convergence is MoSCoW (Must have, Should have, Could have, Wishes) which allows one to group and prioritize solutions. What all the above mentioned techniques have in common is the deep embedding in co-creation which leads to a better understanding of human experience, creativity, and innovative solutions.

The synergy of research on MMs, with its advanced theory, metrics and analytical tools, and design thinking, with its expertise in co-creation and the harnessing of creativity, could provide a valuable toolbox to discover individual, team and shared MMs in the context of citizen science, building upon and expanding previous work on tools such as the Mental Modeler [9].

3. Workshop activities

The workshop introduced participants to the key concepts of MMs and design thinking to illustrate the power of their synergy for citizen science.

3.1 Energy transition case study

We used a citizen science pilot project on energy transition as a case study. The project, conducted in a Dutch city (Enschede) aims to co-create information materials on energy transition in a way that would speak to the broader public, contributing to a more inclusive process of the energy transition. Using this case study, we conducted two activities: understanding the team MMs of the energy transition (first cycle of the Understand and Empathise phase, i.e., diverging), and creating a shared MM of the project structure (the Define phase, i.e., converging).

Creating a team mental model of the energy transition. In projects involving complex phenomena such as energy transition, it is important for participants to get familiar with each other's conceptualization of the domain in question. This can be achieved through the joint exploration of a team MM. We illustrated this activity by engaging participants in a simplified version of affinity diagramming. In the first step participants worked individually, writing down answers to the question "What is energy transition to you?" on post-it notes. The notes were then collected, mixed, and redistributed among the participants. In the second step, participants explored the team MM of the energy transition by grouping and labelling post-its on the wall, working in silence to facilitate equal input. Reflecting upon the activity, participants discussed the sense of having equal voices, and highlighted the importance of having meaningful units of analysis (in this case, represented by the content of one post-it note) for such content-related exercises.

Creating a shared mental model of the project structure. In projects involving multiple stakeholders, it is important to accommodate specific needs, preferences, and potential barriers to participation, such as time limitations, financial resources, geographical restrictions, technology access. This can be achieved through the co-creation of a shared MM of the project structure, by exploring each others' needs and preferences (diverging), followed by voting on the components to be prioritized (converging). To illustrate one way of conducting this activity, we introduced the participants to a "How might we?" exercise (diverging), followed by the MoSCoW voting technique (converging). Participants worked in pairs to think of a persona and their potential needs and preferences related to the project. Reflection upon the activity revealed a variety of personas (e.g., a retired participant eager to contribute many hours but also avoid digital technology) and possible solutions, which served as the first step towards a shared MM of the project structure.

3.2 Mental models for citizen science for health

The workshop activities demonstrated that for many citizen science projects, MMs can facilitate citizen scientists and scientists in understanding each others' realities, bringing together different viewpoints, and working towards a shared vision or goal. Moving beyond the energy transition case study, "Citizen Science for Health" (CS4H) was suggested as another domain that could engage deeper with MMs. In so-called "Personal Science" projects, citizens put forward their own hypothesis for their personal "experiment", track their own health and make adjustments to improve it [7]. Other CS4H projects involve patients or clients as co-researchers throughout every step of the entire research cycle [5, 8]. While co-design techniques increase the likelihood of the outcome or final product suiting the needs and preferences of the citizens involved, they generally require higher-order cognitive skills from citizens such as creative thinking, empathizing, conceptualization, and thinking ahead. Such activities may be difficult for people who experience communication or cognitive challenges, such as people with low literacy skills, Autism Spectrum Disorder (ASD) or (mild) intellectual disabilities [2, 20]. Their lives and experiences—and thus, MMs—differ significantly from the general population and are often missing from (citizen) science projects. Therefore, we need accessible and inclusive tools and methods that are grounded in research on MMs to make citizen science inclusive and reduce health inequalities. Apart from informing the design of inclusive methods, MMs could also provide insights into the impact and potential change of people's own reality that could ultimately result in healthier behavior change.

4. Mental models in citizen science: a research agenda

Different types of MMs—individual, team, shared—can be used for a variety of purposes in a citizen science project. Figure 2 represents the first sketch of the MMs types, their potential roles in citizen science projects, and methods. Thus, individual MMs can be used for measuring the impact of citizen science on an individual level. A comparative analysis of team MMs (a set of individual MMs in a team) can be used to explore the variation in participants' conceptualization of the domain in question, and to identify common aspects to serve as a starting point for collaboration [15]. Finally, shared MMs—constructed in team settings—allow one to co-create a shared vision

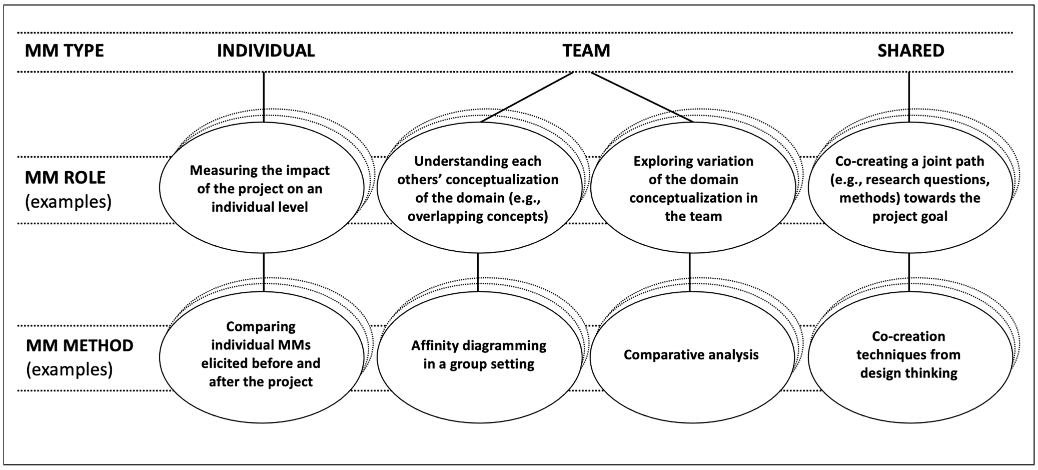

Figure 2: Examples of roles and methods for engaging with various type of MMs in citizen science.

of various aspects of the project. Moreover, MMs can inform the development of tools and methods adaptable to the various cognitive abilities of participants.

Figure 2 is by no means exhaustive and only provides a few examples. More research is needed for a more systematic and informed engagement with mental models and design thinking techniques in the context of citizen science. In particular, we propose the following questions to shape the research agenda:

1. What is the scope of roles that different types of MMs can play at different stages of a citizen science project?

2. Which analytical techniques from MM research could be transferred to the analysis of MMs in the context of more inclusive citizen science?

3. Which design thinking techniques could advance the co-creation of shared MMs for a more inclusive citizen science?

Addressing these questions in a systematic way will result in a unique methodological toolbox to be used in the context of citizen science. The synergy of research on mental models (with its attention to the structure of MMs) and design thinking (with its attention to the inclusion and creativity) opens new opportunities for making citizen science projects accessible and inclusive.

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PoS(CitSci2022)118

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