HOW AND WHEN TO INVOLVE CROWDS IN SCIENTIFIC RESEARCH

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Preface

Science is a fascinating enterprise that has a big impact on how we live in this world. Although the notion of an ivory tower may still apply in some corners, science has become more open and collaborative: Professional scientists in academia and industry are joined by millions of people from other stakeholder groups who actively participate in research. Whether it is by proposing new research questions, collecting data across the globe, providing input from the perspective of users, or creatively solving challenging problems, "crowds" or "citizens" make key contributions to the generation of new scientific knowledge, while also helping connect science and broader society.

This book discusses how and when to involve crowds in scientific research, and it provides guidance to researchers who want to set up so-called "crowd science" projects. A unique feature of our book is its strong conceptual foundation: We lay out structured frameworks that enable readers to understand the benefits and challenges of crowd involvement in general, and to consider crowd involvement in each of the major stages of the scientific research process. A broad range of examples from medicine, the natural sciences, the social sciences, as well as the humanities illustrate crowd science mechanisms and stimulate readers to think about applications closer to home. An integrated set of tools helps interested scientists to develop a strategy for involving crowds and get started with their own projects.

Readers will see many examples and hear from practitioners. We also draw on our own experience running crowd science projects and from working with both junior and senior scientists in designing and implementing projects to better achieve their scientific goals. Just as importantly, this book rests on a foundation of rigorous academic research on the organization of science, crowdsourcing, as well as crowd and citizen science. This includes research in the natural sciences and medicine, but also in the social sciences – especially management and economics of science. The social sciences equip us to think systematically about the benefits and costs of crowd involvement, and they point towards proven tools that can be used to address organizational challenges that invariably arise when trying to bring people together to accomplish shared goals.

Although we have seen clear benefits of crowd involvement, our goal is not to evangelize. Like any other approach to doing research, crowd science has strengths and weaknesses, and scientists need to consider carefully whether and how crowds can help them with their work. As such, this book will help readers to think critically about different forms of crowd involvement, the conditions under which crowd involvement is most effective, and how projects can be designed to increase the benefits from crowd involvement while reducing the associated challenges and costs.

This book has three parts. **Part I** (Chapters 1–3) sets the stage by discussing recent trends in crowd involvement, laying out a conceptual toolkit that will be used throughout the rest of the book, and introducing two tools organizers can use to design their projects. **Part II** (Chapters 4–12) covers the main stages of the scientific research process such as identifying research questions, collecting data, or diffusing results. For each of these stages, we discuss case examples of crowd involvement, empirical evidence on benefits and challenges, as well as practices that can help make projects more effective. We also provide templates that scientists can use to think more concretely about whether and how to involve crowds. In some chapters, we illustrate the use of these tools using "personas" – fictional characters whose research challenges allow us to discuss key decisions more concretely. We then discuss when it makes sense for organizers to involve crowds in multiple stages of the research. **Part III** (Chapters 13–15) covers cross-cutting themes that are relevant in all stages, such as project organization, motivation, and recruitment of crowd members, as well as research ethics and the sharing of project outputs. Chapter 16 concludes and lists all projects we discussed in this book, illustrating again how crowds can help advance science across many different fields and across all stages of the research process.

All readers will benefit from Part I, which will equip them with useful background, terminology, and tools that they will need regardless of what research they are doing or what kind of crowd involvement they are interested in. Readers who already have a sense for how crowds might help them may then focus on the respective stage of the research process in Part II, although skimming other chapters may point them towards new ideas and potential applications they had not yet thought about. The chapters in Part III should again be relevant to all readers, addressing common challenges and illustrating the discussion with examples from prior chapters.

This book is written primarily for scientists and project organizers who may involve crowds in their own research, be it in universities, public research institutions, museums, or even corporate R&D laboratories. However, the book should be of interest to a much broader audience: Science and innovation scholars who study crowdsourcing and related mechanisms, policymakers who create the institutional environment that may enable or hamper crowd involvement in scientific research, as well as funding agencies who receive proposals that entail crowd science mechanisms or who want to encourage crowd involvement in their funding calls. And we hope that our book will also be of interest to the crowd: The millions of people who are interested in helping advance science with their effort and experience, even if they are not working at scientific institutions and may not have formal scientific training. It is because of this large and diverse audience that we decided to make this book open access.

This book would not have been possible without the support from many people. First, we thank the project organizers and crowd members who shared their experiences and insights with us – including successes but also challenges and failures. We are also grateful to the participants in our Labs for Open Innovation in Science, as well as other initiatives we launched with support from the Austrian National Foundation for Research, Technology and Development through the grant for Open Innovation in Science. For several years, these participants have served as sounding boards as we developed our conceptual frameworks and project design tools. We learned much from hearing their ideas and working with them in designing and implementing crowd science projects. Second, many of the discussions in this book draw on projects and research studies we have performed with dear colleagues in the fields of management, economics, but also citizen science and related areas. We thank these colleagues, especially Susanne Beck, Chiara Franzoni, Christoph Grimpe, Patrick Lehner, and Katrin Vohland, for making our collaborations so interesting and productive. Third, we thank our academic mentors Wes Cohen, Paula Stephan, and Eric von Hippel. They have encouraged and fostered our interests in science and crowdsourcing and have equipped us with the methods and tools to do research in these areas for almost two decades. They have also shown us how important it is to reach beyond one's own academic community to share insights with policymakers and practitioners to help improve science and innovation processes.

Finally, we thank Arthur and Long, who have shared family time with this greedy project, supported us when times got tough, and offered their outsider perspectives – or simply a comforting hug – when we got stuck on an issue. This book is yours, too!

PART I

Introduction, conceptual foundations, and general tools

1. Setting the stage

1.1 CONTEMPORARY SCIENTIFIC RESEARCH AND THE RISE OF THE CROWD

Scientific research is essential to improving health and the environment, economic growth, and social welfare. Examples include mRNA technologies to fight the COVID-19 virus, comprehensive biodiversity data used to assess and preserve our natural environment, knowledge of socio-economic mechanisms that can help design policies to reduce poverty, or computational algorithms that can intelligently summarize vast amounts of information – while entertaining us with jokes. And it is just plain fascinating to learn about things such as the origin of the universe or how the human brain functions.

But research is facing many challenges: Many low-hanging fruits have been picked, the knowledge frontier advances, and the next steps require increasing investments of time and resources (Jones, 2009). The number of research papers published across disciplines has drastically increased over the past decades, but their disruptiveness appears to have dropped (Chu & Evans, 2021; Park et al., 2023). Many results fail to replicate (Ioannidis, 2005; Open Science Collaboration, 2015), requiring researchers to invest additional resources into making their own research more robust. Many of the problems that science is called to address are not confined to particular fields or even science per se; they are often "wicked" grand challenges that require collaboration across fields and the integration of technical, social, and political elements (George et al., 2016; Sauermann et al., 2020). And finally, many policymakers and funding agencies now demand that even scientists working on "basic research" make a case for how their research can have broader societal impacts (Davis & Laas, 2014).[1]

Given these challenges, an increasing number of researchers are involving crowds – individuals outside of their labs or research groups who respond to an open call for participation in scientific research projects. Involving crowds can help organizers produce more and better research while also enabling them to achieve broader impact with their work (Franzoni et al., 2022a). Consider just

1 https://beta.nsf.gov/funding/learn/broader-impacts#what.

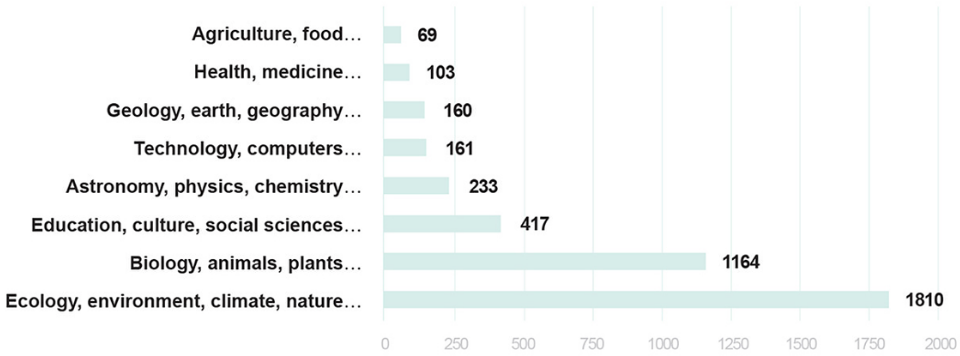
a few examples: Projects on the platform *Zooniverse* get help from more than 2.7 million crowd members to classify images of a diverse range of objects – from far-away galaxies to historical court records and blood cells (Lintott, 2019). The project *eBird* collects data on bird populations across the globe, which can then be used to study different topics such as biodiversity and climate change. *Tell Us! Accidental Injuries* crowdsourced research questions for medical research from patients, relatives, and medical professionals, resulting in novel research questions that professional scientists themselves had not thought about (Beck et al., 2022b). *Foldit* solves complex protein folding problems with the help of thousands of people playing a computer game (Khatib et al., 2011). *CurieuzeNeuzen* involves crowds in all stages of research on air quality – generating valuable data for researchers while also changing participants' attitudes and influencing environmental policies (Van Brussel & Huyse, 2018). What all these research projects have in common is that they involve crowds to address some of the challenges we outlined above, resulting in better and more impactful research.

We will discuss these projects – and many more – in the next chapters, and we will hear from project organizers who share their experiences. Stepping away from particular cases, however, we can identify four important general trends.

First, crowd involvement started in a smaller number of fields such as astronomy, biodiversity, and medicine. But crowd science projects now operate in virtually all fields of science – including economics, history, quantum physics, and many others. To illustrate, Figure 1.1 shows the distribution of projects across different fields in the spring of 2024, using project listings from the platform *Scistarter.org*. Looking at trends over time, data from the Austrian platform *Österreich forscht*[2] also show increasing diversification across fields (see Box 1.1). Crowd science mechanisms also diffuse widely across geographies – as evidenced by dedicated national and international organizations that bring together project organizers and participants to discuss new application areas, share best practices to improve project performance, and discuss policies that can support crowd science.[3] Thus, researchers across a broad range of fields and from different areas of the globe should find our book useful in considering whether and how to involve crowds.

[2] www.citizen-science.at.

[3] Examples include the European Citizen Science Association, the Association for Advancing Participatory Sciences (USA), CitizenScience.Asia, as well as the Australian Citizen Science Association.



Note: Number of active projects on the platform *SciStarter.org* by aggregated field (multiple classifications possible), as of February 2024 (n=4,117 classifications).

Figure 1.1 Crowd involvement across fields: data from SciStarter.org

BOX 1.1 DIVERSIFICATION OF CROWD SCIENCE ACROSS FIELDS

Over the last couple of years, citizen science has expanded from mainly ecological projects to a highly diverse field with projects and initiatives coming from all kinds of research backgrounds and institutions. We believe that this diversification process is not finished yet and that in the future we will experience an even more diverse range of citizen science projects.

-Daniel Dörler and Florian Heigl, founders of the *Österreich forscht* platform, personal communication.

Second, although many early projects involved crowd members in only a limited range of tasks such as data collection and data processing, organizers now work with crowds in a broader range of activities – spanning the whole research process from formulating research questions to acquiring funding, to data collection and analysis, to writing papers and disseminating results. Thus, even though the focus of crowd science projects continues to be on data collection and processing, researchers facing challenges in other aspects of their projects will also find many ideas in this book on how crowd involvement can help.

Third, crowd science projects increasingly integrate new technologies to support participants (e.g., mobile devices for data collection) but also to better manage projects and enable them to operate at a large scale. Perhaps the most dramatic developments relate to the use of artificial intelligence (AI), which can significantly increase project performance but also raise new challenges and ethical concerns. We will discuss the role of technology throughout this book, with a special focus on AI in section 15.3.

Fourth, although pioneering early organizers had to set up their own infrastructure and establish the value and legitimacy of crowd science, crowd science has now become institutionalized and easier to use. Among others, funding organizations now have dedicated mechanisms to support such projects, national policies encourage crowd involvement in science,[4] crowd science platforms allow organizers to start new projects quickly and at low costs, and facilitator organizations such as libraries, national museums, and educational institutions can provide access to potential participants. All of this means that the barriers to using crowd science are much lower than they used to be. At the same time, researchers may find it more difficult to navigate the increasingly complex project landscape. Our book will help by clarifying key issues to think about, by describing cases of success (and failure), and by offering tools that help readers to get started.

1.2 CROWDS AND CITIZENS, PRODUCTIVITY AND DEMOCRATIZATION

This book explores the benefits (and challenges) of using "crowd science" mechanisms to increase research productivity. Yet, many of the projects we discuss are also called "citizen science". What is the relationship between crowd science and citizen science? We discuss this question in more detail in Franzoni et al. (2022a), but the short version is that the different terms do not really refer to fundamentally different projects. Rather, they draw attention to two different aspects of such projects.

The term "crowd science" draws attention to the fact that project organizers reach out to a large and often diverse crowd using an open call, allowing interested people to self-select into project participation. This mechanism has been studied in great detail by the literature on crowdsourcing (Afuah & Tucci, 2012; Dahlander et al., 2019). As discussed in more detail in section 2.2, the crowd could be all sorts of people, including general citizens but also specific groups such as patients, residents of a particular region, software developers, and even other scientists in a particular field. So, the focus of scholars studying crowd science is the implications of using an open call, broadcasting this call to a crowd, and letting interested people self-select. As examples throughout this book show, this self-selection of individuals with the required time, resources,

4 https://www.congress.gov/bill/114th-congress/house-bill/6414/text.

or knowledge can support research projects in all stages of the research process. We note that some people use the term crowd with a negative connotation, associating it with irrational behavior or de-individualization when crowd members blindly follow others (Borch, 2012). The conceptualization of crowds in the crowd science literature is much more neutral; indeed, it highlights the potential benefits that both professional scientists and project participants can gain through their collaboration.

"Citizen science" draws attention to the fact that most project participants are not professional scientists (Haklay et al., 2021). Citizens often participate in research in response to an open call from professional scientists, but they may also start projects on their own. So, using the citizen science lens, the focus is on the fact that participants are not professional scientists, that projects can run outside of established scientific institutions, and that professional and non-professional scientists with different cultures and knowledge need to figure out how to collaborate effectively. We note that the term citizen is not meant in a legal (citizenship) sense. There are ongoing discussions about potential alternative terms (e.g., community science, participatory sciences), but for now, citizen science remains the most common term used in this community (Cooper et al., 2021).

Most of the projects we discuss in this book can be looked at from both perspectives, crowd science and citizen science. For example, projects on the platform *Zooniverse* are started by professional scientists who ask for help with processing or analyzing image data. Thousands of people self-select to join such projects, which makes them so interesting from a crowd science perspective. At the same time, most participants are not professional scientists, making *Zooniverse* also a great example of citizen science. Of course, some projects might qualify as crowd science but not as citizen science, e.g., if scientists in one field use an open call directed at professional scientists from other fields. And there are citizen science projects that do not involve crowdsourcing, e.g., when a handful of citizens start a project to investigate air pollution in their town but do not invite the broader public to participate. We believe that the lenses of *both* crowd science and citizen science can provide important insights. As such, we will draw on both literatures, and most of our examples will qualify as both crowd and citizen science. We will primarily use the terminology of crowds and crowd science, but the occasional "citizen" will slip in – especially if we want to emphasize that participants are not professional scientists.

When assessing the opportunities and challenges arising from crowd involvement, it is important to clarify what goals a research project is trying to accomplish. In the crowd science literature, the emphasis tends to be on goals such as generating more research insights or better solutions to particular problems, often at lower costs and much faster than would have been possible without crowd involvement. In other words, the focus is on productivity in terms of the novelty, relevance, efficiency, and impact of scientific research.

Consider again the example of *Zooniverse*, where hundreds of thousands of volunteers enable professional scientists to generate massive data sets that have resulted in many highly cited academic articles in various fields (Sauermann & Franzoni, 2015). Another example is a sustainability-oriented project on the Greek island of Samothraki, where the experiential knowledge of local farmers allowed professional scientists to gain a better understanding of the causes of overgrazing and to co-develop solutions that actually work for the affected communities (Petridis et al., 2017).

Discussions in the citizen science community remind us that involving crowds (and especially non-professional citizens) can also accomplish other goals: It can increase participants' science literacy and awareness of problems, help steer science towards topics that matter to the public, increase public support for science, and help advocate for socio-political changes. These goals go beyond scientific productivity per se, and we have associated them with the "democratization view" of citizen science in prior work (Sauermann et al., 2020). Although we will occasionally highlight opportunities to accomplish such broader goals, the focus of this book will be on productivity: We will discuss when and how involving crowds can help researchers generate better research and more effective solutions in a more efficient way.

BOX 1.2 CROWD SCIENCE VERSUS CITIZEN SCIENCE

Crowd science and citizen science are two lenses on the same phenomenon:

- Crowd science lens: Focuses on the fact that contributors self-select in response to an open call for contributions. Emphasizes benefits in terms of greater productivity of research.
- Citizen science lens: Focuses on the fact that contributors are not professional scientists. Emphasizes benefits in terms of productivity but also the democratization of science.

1.3 FLOW OF CHAPTERS

The following Chapter 2 provides the conceptual foundation for the book. This includes a process-model of scientific research that clarifies *when* the crowd can get involved (e.g., identifying research questions, collecting data, and writing up results), a discussion of *who* the crowd is, a framework to characterize *what* the crowd contributes at a particular stage of the research, and a discussion of distinct underlying reasons *why* involving crowds can help projects accomplish their scientific goals.

Chapter 3 introduces two practical tools that researchers can use to decide whether and how to involve crowds in their research projects. The 4Q Tool encourages researchers to think about their goals as well as the “pains” and “gains” of how they currently perform a particular stage of the research. The Crowd Science Design Canvas builds upon that analysis to map out and guide major decisions that organizers must make to leverage benefits from crowd involvement.

Chapters 4–11 form the heart of this book: We discuss crowd involvement in different stages of the research process, illustrating both benefits and challenges with case examples from a variety of fields. We also highlight conditions under which involving crowds promises to be more versus less effective. Four of these chapters include “getting started” sections that show how the 4Q Tool and the Crowd Science Design Canvas can guide organizers through key decisions, using fictional characters as examples.[5] Our website www.sciencewithcrowds.org complements these chapters by providing customized templates for all stages of the research process, including stages that do not have a “getting started” section. Additionally, the website provides access to high-resolution versions of all figures and tables featured in the book.

Chapter 12 ties together the different stages by discussing potential synergies and tensions that can arise when organizers involve crowds in multiple stages of the research process. This chapter helps readers to think about the breadth of crowd involvement and to consider how design choices at one stage may depend on the choices made at other stages.

Chapters 13–14 cover cross-cutting organizational challenges that project organizers face when involving crowds, regardless of the particular stage of the research process. This includes recruiting and motivating contributors, coordinating and integrating crowd contributions, and providing learning opportunities that increase project effectiveness. Of course, we will also discuss how to overcome those challenges – including the potential of AI as a tool to complement the crowd’s efforts and to organize crowd involvement more effectively.

Chapter 15 focuses on cross-cutting issues related to research integrity and ethics. Among other subjects, we will discuss how projects can increase research quality and prevent research misconduct. We also recognize ethical challenges arising from involving crowds as active researchers (rather than just as research subjects), including the sharing of benefits and data protection.

[5] Although the persona cases are fictional, they are inspired by real projects that we have seen or discussed with scientists.

Finally, we touch upon questions around the interactions between crowds and artificial intelligence.

Throughout the book, we illustrate our discussion using many different examples. When describing example projects, we draw on a variety of sources such as project websites, project reports, research papers analyzing projects, discussions with project organizers, and sometimes even our own involvement (as organizers or crowd members). Although we tried to collect detailed information, our descriptions will often focus on key aspects that are most relevant for a particular topic. We will not try to be complete, we may ignore certain nuances, and projects may change and evolve over time. Thus, the purpose of describing examples is to demonstrate the great variety of crowd science projects, to help readers understand the opportunities and challenges of involving crowds, and to illustrate design decisions that organizers can make. The Project Index in Chapter 16 includes a complete listing of all the projects we discuss, along with links that allow interested readers to find additional information. For easier identification, all projects listed in that index are written in italics throughout the book.

2. Conceptual foundations

2.1 *WHEN* THE CROWD IS INVOLVED: STAGES OF THE RESEARCH PROCESS

Crowds can participate in many different aspects of research. We conceptualize research as a process that consists of different stages such as defining research questions, analyzing data, and diffusing results to the broader public (Beck et al., 2022a; Newman et al., 2012; Shirk et al., 2012). Figure 2.1 visualizes this simple framework. Of course, the linear representation is a simplification – research processes can be non-linear, and researchers may iterate between stages. Moreover, not all projects involve all the activities depicted in Figure 2.1, and some projects may have additional stages. Still, this framework of the research process provides a useful guiding structure for our discussion of crowd involvement in chapters 4–11. We also indicate the relevant chapters (and, thus, stages of the research) when listing all examples in the Project Index (Chapter 16).

2.2 *WHO* THE CROWD IS: SIX CROWD CHARACTERISTICS

This book draws on a growing body of academic research that has studied the benefits and challenges of involving crowds in many different areas of science and innovation. We will also discuss a broad range of examples from different fields. Reflecting this broad and diverse foundation, we use a broad and inclusive definition of crowd: The crowd is a group of individuals who self-select to carry out tasks in a project in response to an open call (Afuah & Tucci, 2012; Beck et al., 2022b).[1]

[1] The term crowd can refer to the individuals who self-selected to participate (e.g., project participants in *CurieuzeNeuzen*) but also to all the individuals who saw the open call (e.g., all people who saw a *CurieuzeNeuzen* poster calling for participants). We will usually think of the crowd as those people who self-select to participate.

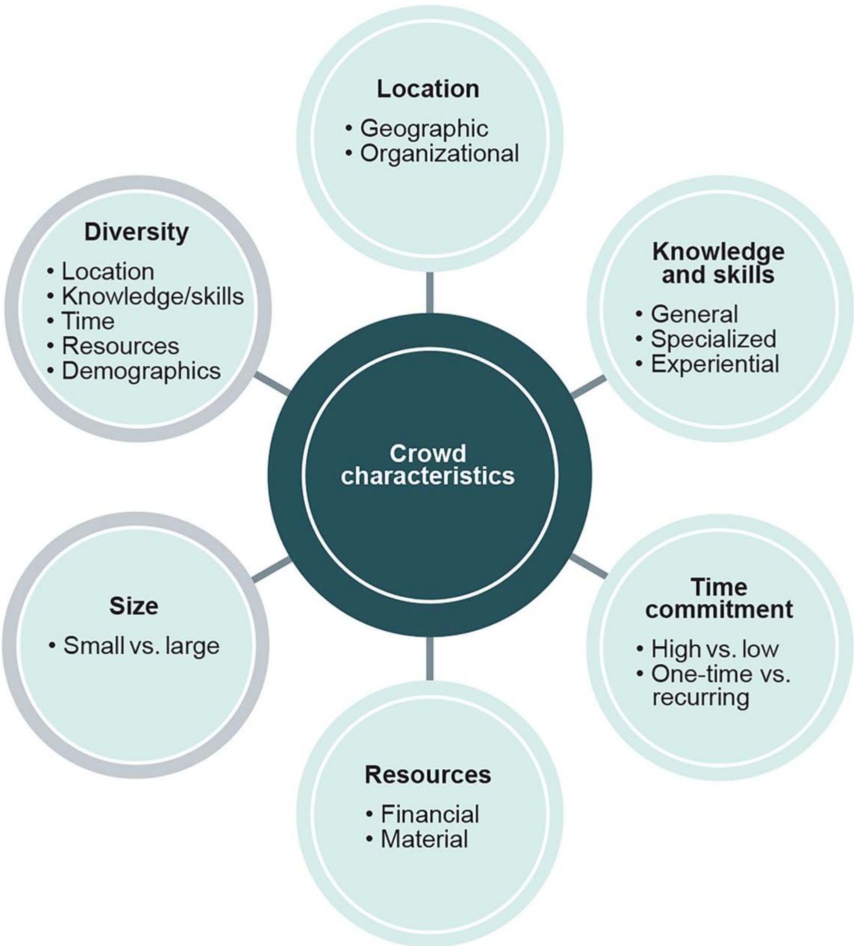
Note: Stylized conceptualization that abstracts from the complex and iterative nature of scientific research.

Figure 2.1 Stages of the research process

BOX 2.1 DEFINITION OF CROWD

The crowd is a group of individuals who self-select to carry out tasks in a project in response to an open call.

The crowds that we see in specific projects differ along several dimensions, often reflecting conscious choices that organizers made when setting up their projects. Our second framework highlights six characteristics of individual crowd members and of the overall crowd that can have important implications for the benefits and challenges of crowd involvement (summarized in Figure 2.2).



Note: Four characteristics describe individual crowd members, two describe the crowd as a whole (size and diversity).

Figure 2.2 Six key characteristics of crowd members and the crowd

Location of crowd members. The geographic location of crowd members typically does not matter in projects that operate fully online and involve tasks without connection to a particular place (e.g., *Zooniverse* projects). In other projects, however, geographic location is extremely important. Crowd contributors to the first *CurieuzeNeuzen* project, for example, needed to live in the Belgian region of Antwerp to set up devices to measure air quality. Projects that ask crowd members to monitor plants and animals may involve crowd members in selected locations (e.g., *Roadkill Austria*) or involve crowd members residing across the globe (e.g., *eBird*).

Another way to think about crowd members' location is with respect to their organizational affiliation. In most cases, crowd members are located outside of the project organizers' organization. For example, contributors who help *Zooniverse* projects with classifying images have no formal relationship with the *Zooniverse* platform or with the universities of the professional scientists who organize projects. In some cases, however, crowd members may also be located within the organization of the project organizers, such as when Harvard University scientists reached out to the broader public but also targeted Harvard faculty, staff, and alumni to crowdsource research questions for diabetes research (Guinan et al., 2013). So, while crowds are typically external, some projects also involve an internal crowd.

Knowledge and skills of crowd members. Crowd members may hold different types of knowledge and skills. This includes general knowledge and skills that most people possess, such as how to read and write simple text, judge simple visual characteristics of objects, walk around in nature, or count things. Crowd members may also have specialized knowledge and skills in particular domains that may result from formal training (e.g., crowd members with a PhD) or from regular reading and practice (e.g., doctors reading medical journals, hobbyists reading magazines, skills to practice a craft). Some participants can contribute "experiential knowledge", which is knowledge that results from extensive experience with particular problems (e.g., patients living with a particular disease) (Caron-Flinterman et al., 2005). Finally, some crowd members simply have certain special skills that others do not have. In the project *Foldit*, for example, players help determine protein structures by playing an online game, and the best players are those who have unique skills to imagine and manipulate objects in virtual space.

Time commitment of crowd members. Some crowd members have little time to contribute to projects. Most contributors in *Zooniverse* projects, for example, participate only for a few minutes (Sauermann & Franzoni, 2015). Other crowd members spend lots of time helping with large collaborative tasks – such as participants in *Epidemium* projects who help solve complex problems in cancer research. In addition to the volume of time spent by crowd members, the time dimension also captures the distribution of their efforts over time. In tasks such as image coding, for example, it typically does not matter whether a contributor spends 10 hours all at once (one-time) or smaller amounts of time regularly over multiple weeks. In projects that involve regular meetings or that ask crowd members to monitor changes in the environment, however, recurring participation over longer periods of time is important.

Resources of crowd members (other than time and knowledge). The primary contribution of crowd members is typically their time, knowledge, or experience. In many projects, however, crowd members also need other types of resources such as money (e.g., projects on the crowdfunding platform *Experiment.com*), transportation (e.g., biodiversity monitoring projects that require travel to particular locations), or physical equipment (e.g., computers to participate in online tasks, devices to take soil and air samples). As such, it is important to characterize crowd members with respect to their access to financial and other resources.

Size of the crowd. The crowd participating in a project can be relatively small (e.g., a few dozen who collaborate in *Epidemium* projects) or very large (hundreds of thousands in *Zooniverse* projects). Crowd size has important implications for the volume of contributions that the crowd can make, but also for the organizational structure that is needed to enable crowd involvement.

Diversity of the crowd. A final important dimension is the diversity of the crowd with respect to the individual-level characteristics we mentioned above (e.g., location, knowledge, time, resources) as well as any other potentially relevant characteristics such as gender, age, or political affiliation. Large crowds will typically also be quite diverse. In the *Zooniverse* project *Galaxy Zoo*, for example, the crowd includes people without a high school education as well as many PhDs, and participants are located all over the world (Raddick et al., 2013). But even small crowds can be diverse with respect to certain dimensions, and this is often on purpose. In *Epidemium* projects, for example, crowd members bring to the table complementary skills in areas such as statistics, medicine, and the social sciences. Although diversity is often useful, it can also create organizational challenges, e.g., if people located in different regions find it difficult to travel to joint meetings, or if people from different disciplinary backgrounds have a hard time finding a shared language to exchange ideas.

Table 2.1 uses the Six Crowd Characteristics Framework to illustrate how crowds differ in several example projects. The next sections will help us understand why different projects involve different crowds.

2.3 *WHAT* THE CROWD CONTRIBUTES: THE AKRD CROWD CONTRIBUTION MATRIX

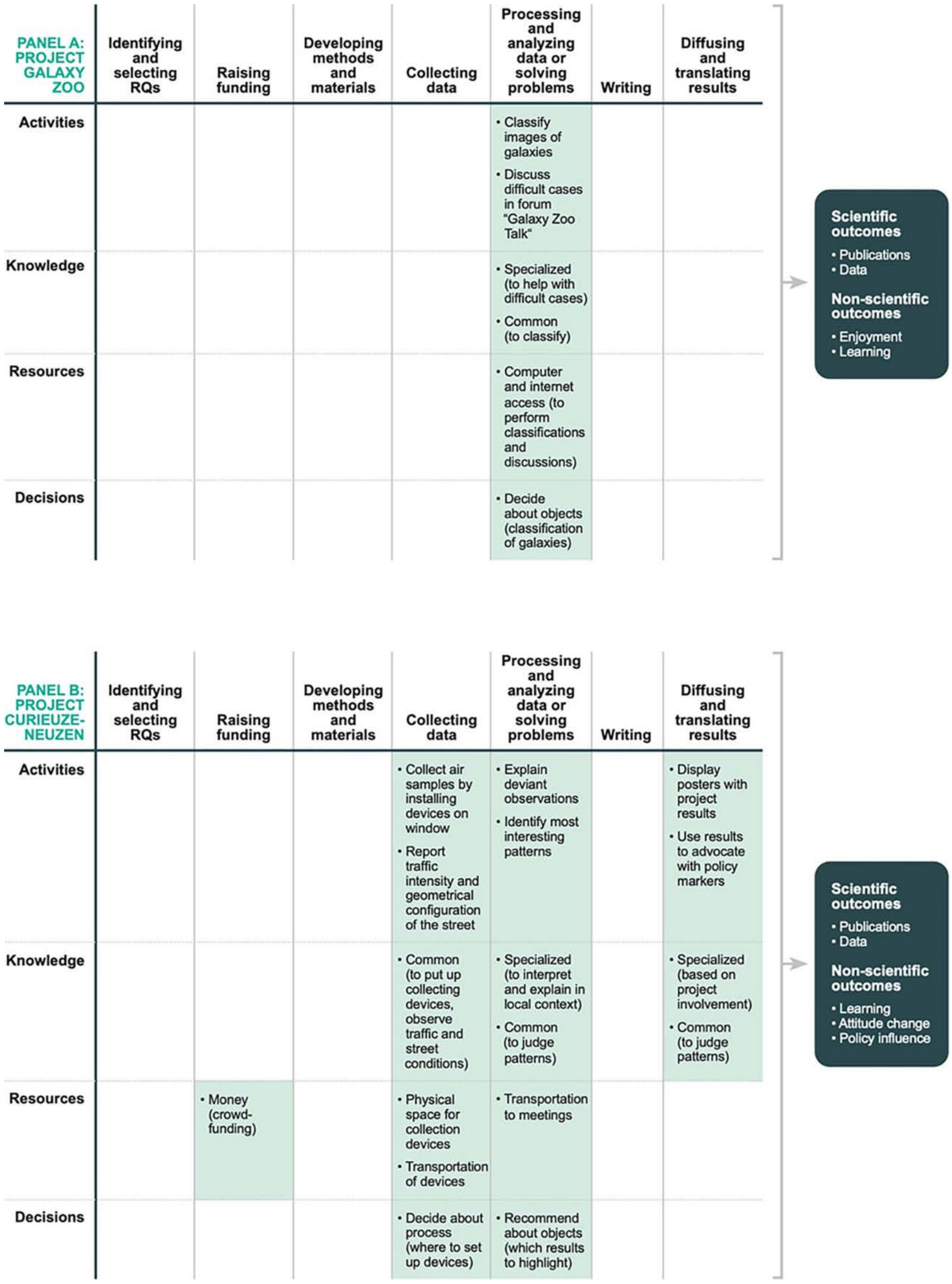
The third framework helps us understand what exactly crowd members contribute. Throughout this book, we will consider four general types of contributions: (1) the particular **A**ctivities crowd members carry out, (2) the **K**nowledge they contribute when performing these activities, (3) other **R**esources they contribute, and (4) the **D**ecisions they help make. Applied to each of the stages of the research process (Figure 2.1), this yields a Crowd Contribution Matrix that enables us to map the complete profile of crowd contributions in a research

Table 2.1 Crowds in example projects across different research fields

Project	Research field	Six Crowd Characteristics
Galaxy Zoo	Astronomy	People anywhere in the world; general knowledge to classify galaxies, specialized knowledge to deal with difficult cases; small or large amounts of time per person; access to computer and internet; large crowd; diverse in many dimensions (but diversity not necessary)
Tell Us! Mental Health	Medical science	People anywhere in the world; experiential knowledge as patients, caregivers, medical professionals; small amounts of time per person; access to computer and internet; medium-sized crowd; diverse with respect to experience with accidental injuries
Curieuze-Neuzen	Climate science	People in Antwerp; general knowledge to setup measurement devices; small or large amounts of time per person, recurring; access to physical measurement locations and transportation; medium-sized crowd; diversity with respect to locations within Antwerp
Epidemium ORL/IA	Medical science	People anywhere in the world; specialized knowledge related to data analysis, cancer research, graphics design, legal/economic/sociological issues, experiential knowledge as patients; medium to large amounts of time per person, recurring; access to computer and internet, specialized materials such as analysis tools; small crowd; diversity with respect to knowledge specializations
eBird	Biology	People anywhere in the world; specialized knowledge to observe and classify birds; small or large amounts of time per person; access to smartphone or computer and internet; large crowd; diverse with respect to geographic location and time of participation
Profs-Chercheurs	Education science	People in France; specialized knowledge and expertise as teachers; medium time per person, recurring; access to classrooms to perform experiments; small crowd; diversity with respect to relevant prior experience
Quantum Moves	Physics	People anywhere in the world; general knowledge to play a game; small or large amounts of time per person; access to computer and internet; large crowd; diverse in many dimensions (but diversity not necessary)
Glyph	Linguistics	People anywhere in the world; specialized knowledge and visual skills to identify patterns in scripts; small or large amounts of time per person; access to computer and internet; medium-sized crowd; diverse in many dimensions (but diversity not necessary)

project (Franzoni et al., 2022a). Figure 2.3 illustrates this using the examples of *Galaxy Zoo* (Panel A) and *CurieuzeNeuzen* (Panel B). Let us briefly discuss each of the AKRD contributions:

Activities. This dimension describes what the crowd is doing. At an aggregate level, information about activities is already captured by the process stages that form the backbone of the framework (e.g., developing research questions or collecting data). As such, entries for this dimension can convey more specific details. To illustrate, the primary task for *Galaxy Zoo* participants is to classify images of galaxies using a simple series of questions. Some crowd



Source: Adapted from Franzoni et al. (2022a).

Figure 2.3 AKRD Crowd Contribution Matrix for Galaxy Zoo (Panel A) and CurieuzeNeuzen (Panel B) members also discuss galaxies and help others with difficult cases in a forum. Both activities fit within the stage of processing and analyzing data. The project *CurieuzeNeuzen* involved crowd members in several different stages of the research process. Most importantly, participants physically collected air samples outside their home windows in the city of Antwerp and provided data on traffic intensity as well as the geometrical configuration of their streets. Crowd members also participated in a presentation of results and flagged results that stood out. Based on their understanding of the local conditions, residents from particular areas of the city verified results and contributed insights to explain unexpected or deviant findings. Participants also contributed to the diffusion of findings, e.g., by displaying posters with project results at their houses for neighbors and passersby. This example illustrates that the contributions of the crowd should match with the characteristics of the crowd (section 2.2): *CurieuzeNeuzen* recruited mostly in the city of Antwerp because performing data collection required contributors to be physically present in Antwerp. In contrast, *Galaxy Zoo* contributors work entirely online, which explains why this project can involve crowd members regardless of their physical location.

Knowledge. Although some activities are primarily physical in nature (e.g., collecting air samples in *CurieuzeNeuzen*), almost all activities require crowd members to contribute different types of knowledge. Indeed, knowledge is a key input examined by scholars studying science and innovation and also figures prominently in discussions of crowdsourcing (Afuah & Tucci, 2012). Within this dimension, we can describe concretely what knowledge crowd members bring to bear (e.g., knowledge of birds or experience with a particular disease). Sometimes, it is more instructive to characterize this knowledge at a more abstract level, e.g., to distinguish general, specialized, or experiential knowledge (see our discussion of the Six Crowd Characteristics in section 2.2).

Figure 2.3 shows the respective entries for our example projects. In *Galaxy Zoo*, most crowd members use common knowledge to judge basic characteristics of galaxies such as their shape. Some crowd members use specialized knowledge gained through experience in the project to manage discussions and to help others with difficult cases. In *CurieuzeNeuzen*, crowd members used common knowledge to set up measurement devices outside their windows and collect data. However, they used both common as well as specialized knowledge (in this case, their understanding of the local environment) when identifying interesting patterns in the data and coming up with explanations for unexpected results. They also used specialized knowledge regarding the project process and results when helping diffuse findings.

Resources other than effort and knowledge. Research also requires other types of resources such as money, materials, and equipment (Furman & Stern, 2011; Stephan, 2012). Contributions of such resources tend to be less salient in discussions of crowd science, but they are central to some projects such as

SETI@home, where citizens contribute primarily computing power. Similarly, a growing number of projects involve crowd members primarily as providers of financial resources – e.g., on the crowdfunding platform *Experiment.com* (Franzoni et al., 2024; Sauermann et al., 2019).

Even if such resources are not the crowd's primary contribution to a project, crowd members often need resources to perform research activities. For example, online projects typically require access to computers and the internet, while offline projects often require means of transportation to perform data collection or attend meetings (Newman et al., 2012). The lack of access to resources may prevent some individuals from contributing their effort and knowledge, increasing inequality and selection biases in project participation (Franzen et al., 2021).

Consider again the examples in Figure 2.3. In *Galaxy Zoo*, the primary resource required from contributors (other than their effort and knowledge) is a computer and internet access. In *CurieuzeNeuzen*, crowd members provided space in front of their windows to collect air samples and contributed their own transportation to pick up and drop off collection devices and attend project meetings. Crowd members also contributed a share of the project budget through crowdfunding (Irwin, 2018).

Decisions. The fourth dimension captures to what extent crowd members contribute by making decisions. We can describe decisions made by crowd members in specific detail or classify their level of involvement in decision-making more broadly as ranging from none to providing input and recommendations for lead investigators ("consultation") to having full control over particular aspects of the project (see Arnstein, 1969). Crowds can get involved in two phases of decision-making: Generating decision options (e.g., suggesting many different research questions or options for research designs) versus evaluating and choosing between available options (Beck et al., 2023). Generating decision options primarily requires knowledge and information. When choosing between options, however, decision-makers also bring in subjective preferences, i.e., what they care about and find important. Thus, projects that involve crowds in evaluating and choosing between options may not only benefit from crowd knowledge but will also be shaped by the preferences of the crowd.

Figure 2.3 shows that crowd members in *Galaxy Zoo* have little control over the project content or process. Participants in *CurieuzeNeuzen* were involved in a broader range of decisions such as where to locate collection devices (within guidelines set by the lead investigators) or which data patterns to highlight in reports.[2]

We also include in Figure 2.3 the key **Outcomes** that result from the various crowd contributions. The primary outcomes of *Galaxy Zoo* are scientific (e.g., peer-reviewed publications as well as data for future research use), although the project also provides enjoyment and learning for participants (Raddick et al., 2013). *CurieuzeNeuzen* resulted in publications and valuable data but also yielded important non-scientific outcomes such as citizens learning about their local environments, changes in citizens' traffic-related attitudes and behaviors, as well as influence on policy (Van Brussel & Huyse, 2018). Considering expected or desired outcomes is important because it pushes project organizers to clarify what they are trying to accomplish by involving the crowd and how they will measure project success (see section 1.2).

2.4 *WHY* CROWD INVOLVEMENT HAS BENEFITS: THE CROWD SCIENCE PARADIGMS

The frameworks introduced in prior sections help us describe the *when*, *who,* and *what* of crowd involvement. The final framework helps us to really understand *why* involving crowd members can help make a project more productive: the five Crowd Science Paradigms (see Beck et al., 2022b).

Crowd volume. One rationale for crowd involvement is that large crowds can support projects with a high volume of effort that can be distributed in space and time (Lyons & Zhang, 2019; Theobald et al., 2015). In projects focused on crowd volume, tasks tend to be standardized in nature, often requiring only common skills (Franzoni & Sauermann, 2014). The crowd volume paradigm is useful to understand large projects such as *eBird*, *iNaturalist*, or projects hosted on the *Zooniverse* platform. These projects primarily involve crowd members in collecting or processing data.

Research has documented the high volume of effort that crowds can supply but also highlights that contributions tend to be very uneven: A small share of highly motivated contributors tend to be responsible for a large share of the contributions (Sauermann & Franzoni, 2015). This point illustrates that the volume aspect of this paradigm refers to the volume of contributions and not necessarily the number of crowd members. Although the two are usually highly correlated, a large volume can result from many people who each

[2] Although the AKRD Crowd Contribution Matrix lists each of the four contributions separately, there may also be important connections. For example, different types of activities (dimension 1) tend to involve different types of decisions (dimension 4), and different types of decisions likely require different kinds of knowledge (dimension 2).

contribute relatively little but also from fewer crowd members who each contribute very intensively – and typically a mix of the two.

Broadcast search. A second paradigm highlights that broadcasting the call for contributions to a large and diverse crowd allows projects to find particular contributors or inputs that might otherwise be difficult to identify (Afuah & Tucci, 2012; Jeppesen & Lakhani, 2010). Broadcast search is particularly useful if a project requires highly specialized skills or rare resources: Those crowd members who have what is needed can self-select to participate and contribute their rare inputs. Similarly, broadcast search can allow projects to identify high-value "outlier" solutions to difficult problems (Felin & Zenger, 2014; Jeppesen & Lakhani, 2010). A prominent example is the 1989 Exxon Valdez oil spill clean-up. The platform *InnoCentive* (now *Wazoku Crowd*) broadcast a call for ideas in 2007, and the winning solution came from John Davis, who drew on his experience in the concrete industry to come up with a creative solution to prevent the freezing of oil in arctic waters (InnoCentive, 2007).

The broadcast search paradigm is useful when thinking about crowd involvement in scientific problem-solving, e.g., in protein folding or in space-related innovation contests at NASA (Lifshitz-Assaf, 2018). Broadcast search can also be a useful lens when thinking about access to rare resources other than knowledge, e.g., when a history project tries to find people who experienced a particular event, when medical researchers seek to identify patients with a rare disease, or when a project needs access to rare physical artifacts.

User crowd. The user crowd paradigm focuses on the value of experiential knowledge held by users in a particular problem domain (Von Hippel & Von Krogh, 2016). Because of their deep understanding of practical problems as well as existing solutions, users can often identify open questions and come up with novel ideas and effective solutions (Beck et al., 2022b; Poetz & Schreier, 2012).

Although the term "users" is less established in the context of science than in the context of innovation, there are many potentially relevant groups of users in science: They may include professional scientists in other fields (e.g., economists who use tools developed by statisticians) as well as practitioners who read cutting-edge research to apply it in practice (e.g., medical doctors). They can also be end-users such as patients who undergo some kind of treatment based on medical research, farmers who benefit from agricultural research, companies whose strategies and operations are informed by research in the social sciences, and policymakers who seek to make evidence-based decisions. Although the focus of the user crowd paradigm is on the unique knowledge that users can draw on, users may also have unique preferences that may be relevant, especially when they get involved in decision-making (see our discussion of AKRD Crowd Contributions in section 2.3).

Community production. The crowd volume, broadcast search, and user crowd paradigms focus on the contributions of individual crowd members who are not interacting. The community production paradigm highlights interactions and collaborative contributions. Research shows that joint efforts of crowd members with diverse knowledge and skills can lead to superior solutions, especially when problems are complex (Foss et al., 2016; Majchrzak & Malhotra, 2020; Singh & Fleming, 2010). The key benefit of interactions is that crowd members can share knowledge and ideas, stimulating creativity and weeding out inferior solutions. Interactions may also help participants discuss and resolve differences in preferences, e.g., regarding which goals a project should pursue or what trade-offs should be made between the advantages and disadvantages of different methods or technical solutions (Beck et al., 2023).

Community production can be powerful in problem-solving and in implementing complex projects. However, it can also be beneficial in the conceptual stages of research. Consider the example of online medical communities such as Patientslikeme.com or Cysticfibrosis.com, where members discuss their experiences, share existing solutions, and sometimes develop hypotheses regarding causes of diseases or potential new treatments. Similarly, the platform *Epidemium* facilitates collaborations among diverse crowd members who develop and implement novel research projects to fight cancer through big data analysis, integrating their knowledge but also preferences regarding various aspects of the project.

Crowd wisdom. The final paradigm focuses on the advantages that crowds have in making predictions or estimating values. For example, the average guess of crowd members regarding things such as the weight of an ox can be surprisingly accurate (Galton, 1907; Surowiecki, 2005). The key mechanism is that if judgments are at least somewhat independent, individuals' different biases and errors will tend to cancel each other out. The logic of this paradigm also applies to prediction markets that organizers can use to forecast outcomes as diverse as election results, foreign exchange rates, or the success of a clinical trial (Almenberg et al., 2009). Going beyond benefits from averaging, organizers can also reach out to crowds to obtain statistical measures of crowd opinions. In the project *Tell Us! Mental Health*, for example, asking crowd members to formulate research questions helped identify novel specific research questions via broadcast search, but clustering all submitted questions also gave organizers a sense of which general problem areas crowd members found particularly important to address.

Whereas the four paradigms discussed up to this point consider how crowds create objects (e.g., data, ideas, innovations, new products), the crowd wisdom paradigm is particularly useful in thinking about how crowds select objects. One application is the crowdfunding of innovative projects, which aggregates the judgments of many people with respect to project attributes such as the likelihood of technical success or the fit with consumer preferences (Butticè et al., 2017). Although crowd wisdom has initially focused on crowds' advantages in making accurate assessments of facts (e.g., the weight of an ox), aggregating crowd judgments can also be used to learn about the preferences of the broader public or specific subgroups (Müller-Trede et al., 2018). Crowd wisdom in making estimates or preference-based judgments may be useful at different stages of the research process, such as the selection of research problems, the estimation of important problem parameters, or the choice between alternative technical solutions.

Table 2.2 summarizes the underlying rationale for involving crowds in each of the five paradigms.

Table 2.2 Summary of Crowd Science Paradigms

Crowd Science Paradigm	Primary benefit of involving crowds in a research project
Crowd volume	A crowd of contributors supplies a high volume of effort or other inputs, potentially across different locations.
Broadcast search	Broadcasting a problem or call for inputs to the crowd helps identify individual outlier solutions or other rare inputs.
User crowd	Users have experiential knowledge or other use-related inputs that professional scientists lack.
Community production	Interactions among crowd members or between crowd members and researchers allow the recombination of complementary knowledge, preferences, and other inputs to address complex problems.
Crowd wisdom	Aggregating independent knowledge and preference inputs from many crowd members can mitigate individual-level errors and biases.

The five Crowd Science Paradigms highlight different rationales for involving crowds in research, but the different mechanisms may complement each other in practice. The project *Foldit*, for example, seeks to identify outlier solutions to protein-folding problems and relies on contributors who tend to have unusual skills in solving 3D puzzles (i.e., key features of broadcast search). However, even individuals with such rare skills do not have solutions ready and need to spend considerable time developing solutions (crowd volume), which involves not only much trial and error but also collaboration among contributors (community production).

Figure 2.4 visualizes the relevance of the five different Crowd Science Paradigms in *Foldit* using a Crowd Science Paradigm "Diamond" (Beck et al., 2024) and we will use similar Diamonds when analyzing project examples in subsequent chapters.[3] Identifying which paradigms are most relevant in a particular case is interesting for descriptive purposes but will also enable organizers to attract the right crowd and design the most suitable organizational infrastructure. We will illustrate these connections next, when discussing two tools that help organizers to get started.

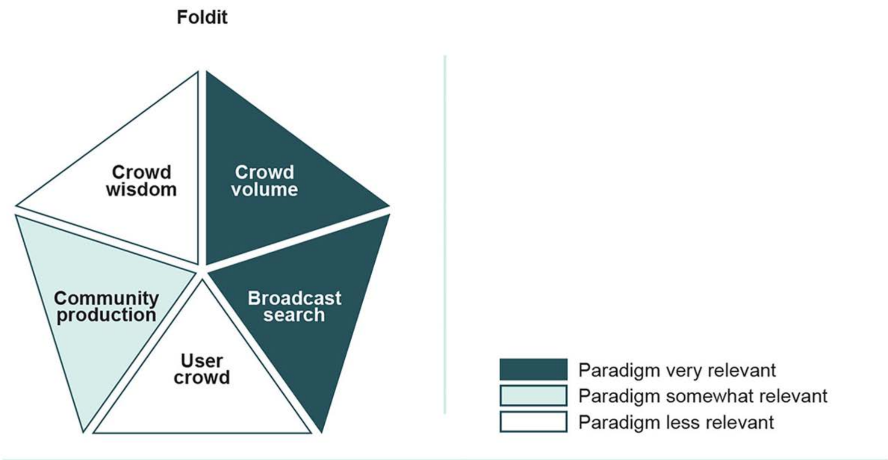


Figure 2.4 Crowd Science Paradigm Diamond showing the relevance of each of the five Crowd Science Paradigms in a particular project (example: Foldit)

[3] We adopt the terminology of Beck et al. (2024); Diamond here does not refer to a rhombus but rather more generally to an object with multiple edges and corners.

3. Tools for project design

The four frameworks outlined in Chapter 2 are very helpful for descriptive and analytical purposes. We now introduce two tools that can help you decide whether and how to involve crowds (note that we switch to "you" when discussing how readers can think more concretely about involving crowds in their research). The first tool entails four quadrants ("4Q Tool") with questions that help you analyze your overall goals, current research process, as well as current pains and gains that crowd involvement might address.[1] The second tool ("Crowd Science Design Canvas") guides you through important strategic design decisions, resulting in a better understanding of the potential benefits and challenges of crowd involvement, as well as a structured outline of what your crowd science project could look like. We will keep the following discussion rather general and will then illustrate the application of the tools using different fictional characters ("personas") in Chapters 4, 6, 7, and 9 for four of the stages of the research process. The website www.sciencewithcrowds.org includes customized templates for all stages discussed in this book.

3.1 4Q TOOL

Figure 3.1 shows the 4Q Tool with four quadrants. **Quadrant 1** helps you clarify the audience for your research, which may include scientific peers, the broader public, but also yourself. This quadrant also encourages you to think about the broader goals you are pursuing with your research, such as contributions to knowledge, career advancement, financial income, or broader societal impact (Cohen et al., 2020; Stephan, 2012). The answers to these questions are important because the potential benefits and challenges of crowd involvement partly depend on what a researcher is trying to accomplish (see section 1.2).

Quadrant 2 helps you describe how you are currently performing activities in a particular stage of the research process. For example, how do you currently come up with research questions? How do you currently generate data? In addition to asking about your current approach, Q2 also asks about other

[1] The analysis of "pains" and "gains" is also common in the analysis and design of entrepreneurial ventures. See https://www.strategyzer.com/canvas/value-proposition-canvas.

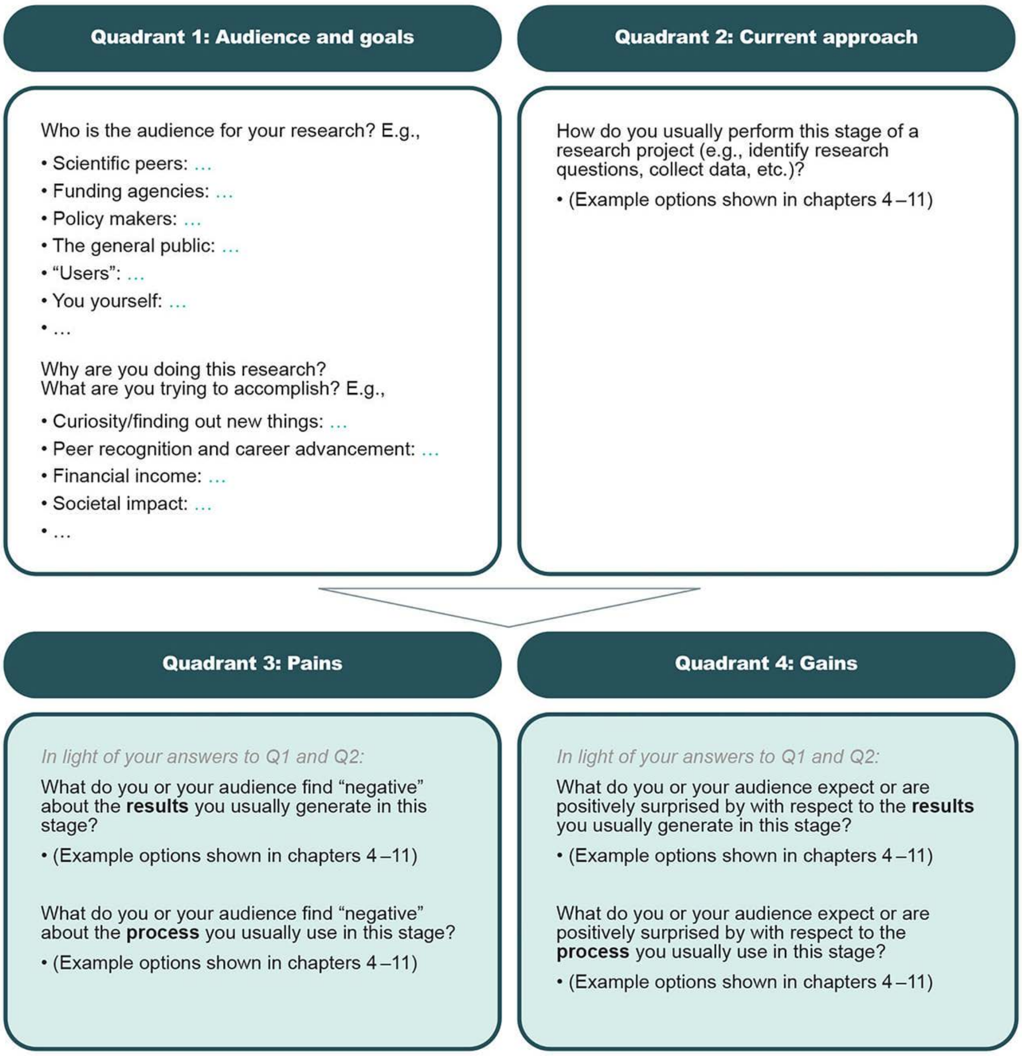


Figure 3.1 *4Q Tool to analyze the status quo in a particular stage of a research project*

common approaches in your field that you could use (without having to involve crowds). Understanding the current process is important to evaluate the potential benefits of involving crowds in a particular stage of the research.

Quadrant 3 asks about problems or "pains" with the current approach. What are the undesired risks, costs, or even negative emotions associated with the current approach? Such pains can relate to the scientific outcomes you generate in a particular stage. For example, journal reviewers may complain that your data sets are too small, while grant reviewers may reject your proposals because your research questions are not sufficiently relevant for society more broadly. But pains may also relate to the process you currently use.

Astrophysics PhD student Kevin Schawinski, for example, realized that it would take him too many sleepless nights to classify 900,000 images from the Sloan Digital Sky Survey for his dissertation (see Box 3.1). Understanding pains helps you think about whether and how involving crowds can relieve some of the pains. Kevin Schawinski went on to co-found *Galaxy Zoo*.

BOX 3.1 EFFORT REQUIRED IN SCIENCE

I classified 50,000 galaxies myself in a week, it was mind-numbing.

-Kevin Schawinski, co-founder of *Galaxy Zoo*, quoted in McGourty (2007).

Quadrant 4 helps you think about "gains": What does your audience expect, or what would they be surprised by? Do not try to get away with trivial answers such as "great research" but think more deeply about what exactly that means in your case. And again, such gains may relate to the outcomes you produce as well as the process that you use for doing so. For example, some funding agencies explicitly encourage researchers to involve crowd members in research processes. The better you understand potential gains, the easier it is to think about how crowd involvement can create such gains.

When working through the 4Q analysis, you may struggle to draw a clear line between pains (Q3) and gains (Q4). We do, too. For example, you could consider it a pain that your current research questions are not novel, or you could consider novelty to be a gain that you and your audience would appreciate and be surprised about. In the end, it is not that important whether a particular factor shows up in Q3 or Q4; as long as it shows up in either one of the quadrants, it will be considered in subsequent design choices. But asking about both pains and gains will encourage you to think more broadly about relevant issues, including some that you would not have considered when thinking about just one or the other.

The arrow linking the four quadrants in Figure 3.1 visualizes the flow of the analysis: Once you understand your audience and goals, as well as the current approach to performing a particular aspect of your research, you can identify pains and gains that the crowd may be able to address. But how do you get the information needed to answer the questions in Figure 3.1? Quadrant 1 requires a lot of personal reflection, e.g., regarding your own goals. But you should also draw on your understanding of the professional community and the broader environment in which you are operating. Junior researchers in particular will often find it useful to consult with mentors and advisors, e.g., to better understand relevant stakeholders such as funding agencies. Quadrant 2 asks you to reflect on your current approach to performing a particular stage of the process, but also other approaches that are readily available in your field. The former should be relatively easy. For the latter, you could rely on your expert knowledge but may also have to do some more digging or consult with colleagues and mentors. Answers to questions in Q3 and Q4 will draw on your own experiences, but you will also benefit from discussing this with colleagues, mentors, or representatives of the audiences that you have identified in Q1. This may include, among others, reviewers and editors at journals, officers at funding agencies, or members of other stakeholder groups.

3.2 CROWD SCIENCE DESIGN CANVAS

After having clarified pains and gains with the current approach using the 4Q Tool, you can now think more concretely about how crowds can help you in a particular stage of the research process, and what an effective project design could look like. The Crowd Science Design Canvas (Figure 3.2) will guide you through the key decisions using three segments:

Segment 1: Pain relievers and gain creators. The left part of this segment summarizes key pains and gains identified in your 4Q analysis to ensure that you keep them in mind when making design decisions. On the right side, you should write down how crowd involvement can address these pains ("pain relievers") or help create gains ("gain creators"). You may have initial ideas when starting your work on the Canvas, but these points will also emerge iteratively as you think about strategic design choices and implementation issues in other parts of the Canvas. Thus, you should return to segment 1 periodically to update the pain relievers and gain creators.

Segment 2: Strategic design choices. The core decisions relate to the frameworks we introduced earlier in this chapter:[2]

(1) Which Crowd Science Paradigms are most relevant in your case? For example, if your key pain is that your current approach to developing research questions results in incremental (rather than novel) research questions, you could design a crowd science project around several paradigms: Focusing on the broadcast search paradigm could help you identify novel questions that are not constrained by assumptions common in your field or that result from the integration

[2] The order in which we introduced the frameworks in Chapter 2 is useful to analyze existing projects. For project design, we recommend the reverse order – starting with the rationale for crowd involvement and then deriving implications for crowd contributions and crowd characteristics.

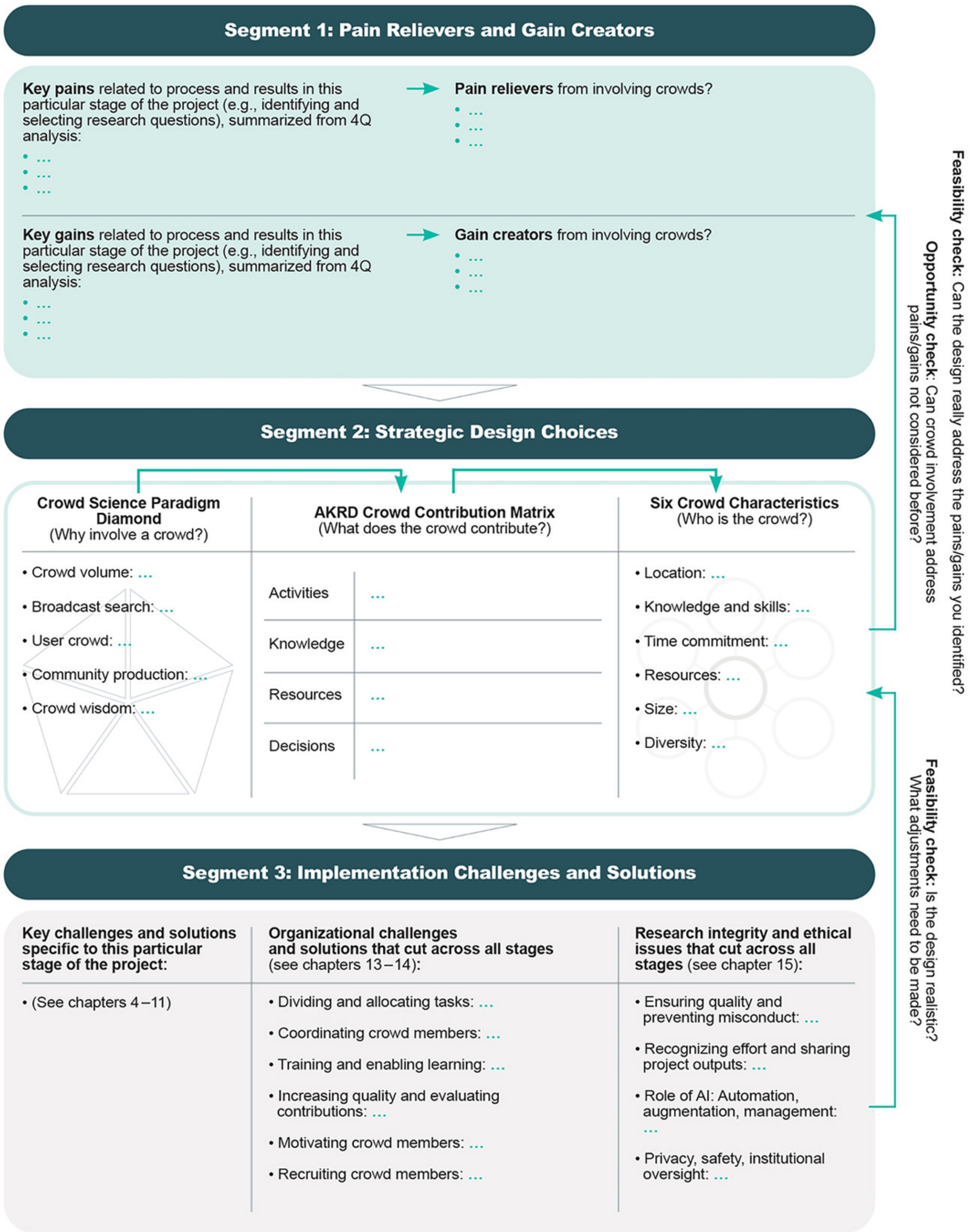


Figure 3.2 *Crowd Science Design Canvas for a particular stage of a research project*

of different fields. Focusing on the user crowd paradigm could help you identify research questions whose novelty comes from incorporating aspects that are more salient to users with experiential knowledge (e.g., a deeper understanding of underlying reasons for problems, awareness of constraints in the implementation of solutions). The decision regarding which paradigms to focus on should build on your understanding of the benefits of different paradigms discussed in section 2.4, as well as the various crowd science examples discussed in this book.

(2) Which AKRD contributions should crowd members make? Some answers will follow quite naturally from your decision on the most relevant Crowd Science Paradigms. For example, if you plan to leverage the community production paradigm and the user crowd paradigm to co-develop methods and materials with patients, then your crowd members will typically have to attend co-creation workshops, share experiential knowledge, and contribute the resources required to attend the workshops (e.g., travel, equipment for videoconferencing). But there are still many choices to be made, and your decisions should reflect your analysis of pains and gains: What specific contributions would reduce pains you have with the current approach or create new gains? To get ideas, you can revisit our general discussion of AKRD contributions in section 2.3 and may also find inspiration in the many case examples discussed throughout the book.

(3) What kind of crowd should you involve? Once you have decided on the relevant Crowd Science Paradigms and AKRD contributions, you can find out what type of crowd would be ideal to have. As discussed in section 2.2, this entails aspects such as the size of the crowd, geographic distribution, whether the crowd has experiential knowledge, etc. For example, if your main pain is that your data sets are too small and you have determined that you would like to leverage the crowd volume paradigm to ask crowd members to collect more observations in different countries, then you will probably need a large crowd that is geographically dispersed. Although the logical flow typically runs from Crowd Science Paradigms to AKRD Contributions and then to Six Crowd Characteristics, it will often be useful to iterate and refine decisions you have already made.

Segment 3: Implementation challenges and solutions. Although our focus in prior sections has been on the potential benefits from crowd involvement, organizers also need to cope with several challenges related to issues such as recruiting and motivating crowd members, coordinating crowd contributions, or ensuring the quality of crowd contributions. Not surprisingly, these challenges partly depend on what Crowd Science Paradigm you seek to leverage, what contributions crowd members should make, and what kind of crowd you plan to engage. Many of these challenges cut across stages of the research process, and we discuss them – as well as solutions – in Chapters 13–14. Some challenges are more specific to particular stages and will be discussed in the chapters focusing on those stages (i.e., Chapters 4–11). The third segment of the Canvas alerts you to potential challenges and encourages you to consider potential solutions.

Feasibility and opportunity checks. Our discussions of challenges throughout this book also suggest potential solutions, and we bring many examples of projects that have successfully navigated the challenges of involving crowds. However, some challenges may be too difficult to resolve in your particular case, or your ideal design may be too ambitious in terms of required time or resources. As such, you need to perform a feasibility check: Given the challenges and potential solutions, does the intended design seem realistic? If not, how could you modify your plans to overcome challenges or constraints? This reality check runs from the third segment of the Canvas back to the second.

Another check should run from the strategic design decisions (segment 2) to pain relievers and gain creators (segment 1): Is your intended design likely to address the pains you identified and generate the gains you were hoping for? Perhaps even more importantly, this check can serve to identify new opportunities you had not considered before: Are there additional gains that crowd involvement could generate, even though you had not considered them in your 4Q analysis? Are there additional pains that crowd involvement could address? If you identify new opportunities, add them to the first segment of the Canvas.

Note that the Crowd Science Design Canvas (draft) shown in Figure 3.2 is for just one particular stage of the research process. You may go through the same exercise for other stages that appear relevant to you. If you see opportunities to involve crowds in multiple stages, you should later look for synergies between stages and align key choices (for example, it is difficult to use a community production paradigm in one stage but crowd wisdom in another). But do not let this constrain your thinking yet – we will discuss interdependencies between stages in Chapter 12, and it is normal to return to a Canvas for updates and revisions. Indeed, you should consider the Canvas not only as a tool to map out an initial plan, but also to think through potential adjustments as new pains and gains arise, as you learn to work with crowds, and as organizational challenges and solutions emerge. Involving selected crowd members in co-designing a crowd science project can reduce the need for revisions and enable projects to better achieve their goals.

You now have a toolkit that includes four conceptual frameworks (Stages of the research process, Six Crowd Characteristics, AKRD Crowd Contribution Matrix, and five Crowd Science Paradigms) as well as two practical tools to analyze and design potential crowd involvement (4Q Tool and Crowd Science Design Canvas). We are ready to think about crowd involvement in each of the major stages of the research process in Chapters 4–11.

PART II

Involving crowds in different stages of the research process

4. Identifying and selecting research questions

Most research projects start with a research question (RQ) that describes the kind of knowledge researchers seek to generate to solve a particular problem. Such problems can be primarily basic and curiosity-driven, e.g., if a researcher wants to know more about the history of the universe. Problems can also relate to important practical concerns such as reducing poverty, improving health, preserving biodiversity, or ensuring clean water. And of course, problems can have both basic and applied elements (Stokes, 1997).[1]

Broad problem statements, such as "We need to understand the history of the universe" or "We need to cure cancer" are important in directing attention but they provide no guidance as to what might be done to solve those problems. Such statements are called "ill-structured" (Felin & Zenger, 2014; Simon, 1973). The corresponding research questions (e.g., "What is the history of the universe?", or "How can we cure cancer?") are similarly ill-structured and provide little guidance as to which elements of the problem should be investigated. In contrast, research questions are "well-structured" if they not only re-state general problems but also hint at potential underlying causes. For example, the question "What is the effect of regular physical exercise on the risk of cancer?" identifies a potential cause of cancer (lack of exercise) that can be systematically investigated. And, if it turns out that exercise is linked to a lower risk of cancer, it may help us solve the cancer problem.

Identifying an important problem and formulating a well-structured research question is a key activity in scientific research because it critically shapes subsequent stages in a project (Alvesson & Sandberg, 2011; Bryman, 2007). Moreover, researchers often have multiple research questions that they could try to answer, and the decision to choose one over the other can set them on very different paths. How can crowds help in this stage of the research process?

[1] Not all research projects start with a clear research question – some projects also start as unguided explorations of data or phenomena, and some research questions may evolve and change over the course of a project. Many aspects of the discussion in this chapter should still apply.

We will first look at several examples of crowd involvement in this stage, and we will use the AKRD Crowd Contribution Matrix to understand what exactly the crowd is contributing in each example. We will then draw on the Crowd Science Paradigms to discuss why and how involving crowd members in identifying and selecting research questions can be beneficial. We will also discuss challenges that often arise when crowds are involved in this stage of the research process. Finally, we introduce our first persona (Mehdi) to illustrate how researchers can use the 4Q Tool and the Crowd Science Design Canvas to think about whether and how to involve crowds in identifying and selecting research questions.

4.1 EXAMPLES

Epidemium ORL/IA. The *Epidemium* platform brings together crowd members with scientific and experiential knowledge related to cancer, data science expertise, as well as skills in other areas such as design, law, and ethics to collaboratively address challenges in cancer research (Benchoufi et al., 2017). Participants in *Epidemium* projects typically perform all stages of the research process and we will discuss *Epidemium* projects also in other chapters. One *Epidemium* project was the *ORL/IA* challenge, which focused on the diagnosis of ENT (ear, nose, and throat) cancer induced by human papillomavirus (HPV).[2] For the development of research questions, crowd members could participate in two facilitated launch events[3] and/or join using an online platform to create their own projects or to join others' projects (Figure 4.1). For about two weeks after the launch events, teams of self-selected crowd members worked collaboratively on the definition of their projects and to specify their research questions, using the platforms' online infrastructure and Slack discussion channels. Problem definitions and research questions were then reviewed by an expert before projects continued.[4]

The AKRD Crowd Contribution Matrix helps us map crowd contributions in this project in terms of activities, knowledge, other resources, and decisions (summarized in Table 4.1). Overall, 83 people participated in *Epidemium's* Season 3 launch events and 40 members signed up and joined the *Epidemium ORL/IA* challenge online. Jointly, they created three novel research projects

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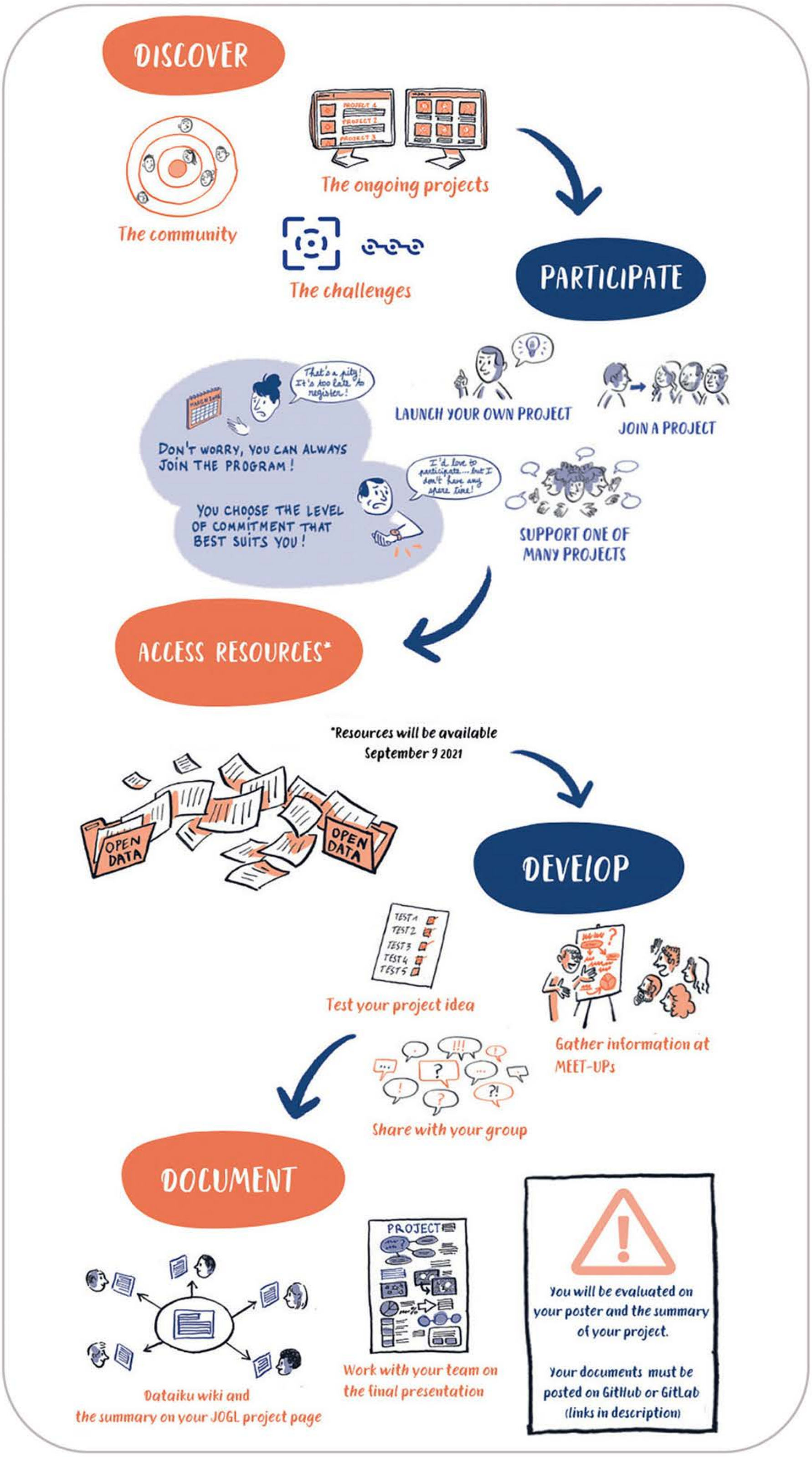
2 http://epidemium.org.

3 The *Epidemium* launch events in Seasons 1 and 2 were held as in-person events in Paris. Due to COVID-19, the Season 3 events took place as a hybrid meeting on September 9, 2021, followed by an online meeting on September 17. Videos of both meetings are available via *Epidemium*'s YouTube channel: https://www.youtube.com/channel/UCox7qtCL12TAzGf8xdRwN1A.

4 http://epidemium.org/how-it-work.html.



Source: http://epidemium.org.

Figure 4.1 Roadmap for Epidemium ORL/IA challenge

(PapAI, ORLIAn, and LittleBigCode).[5] Crowd members' main activity was to provide their own ideas related to advancing the diagnosis of ENT cancer induced by human papillomavirus (HPV). They contributed diverse scientific and experiential knowledge related to cancer, data science, and other relevant fields. Resources required to participate in the first stage included a computer (for online participation) or transportation (for those who participated in person in the hybrid launch event). The crowd created decision options (ideas for research questions) and decided collaboratively which questions to pursue and turn into a project. The *Epidemium* scientific committee and an ethics committee supported participants with advice regarding scientific relevance, methodological matters, and ethical issues.

*Tell Us! Accidental Injurie*s. The Austrian Ludwig Boltzmann Gesellschaft (LBG) and its Institute for Traumatology (i.e., accidental injuries of bones, tissues, and ligaments) were looking for new and promising research questions for their research groups. The institution explicitly sought to incorporate knowledge that does not originate from within the professional scientific discourse and to link research more closely to relevant societal challenges. As such, LBG decided to crowdsource research questions from patients, their caregivers, as well as medical professionals such as nurses, doctors, and therapists. Focusing on traumatology, they used two channels to reach out to the crowd. First, LBG initiated an online and offline campaign to attract participants with experience in the field of accidental injuries, including patients, caregivers, and medical practitioners (Figure 4.2). Second, LBG used the crowdsourcing platform Clickworker to invite individuals with personal or professional experience with accidental injuries to participate for a small monetary reward. Participants recruited via both channels were directed to the same custom-designed website, where they could suggest a research question that professional traumatology researchers might study. This resulted in 826 research questions submitted by crowd members from 39 different countries.[6] The submitted questions were then grouped into 14 main clusters by experts in traumatology and the social sciences. The organizers then selected a cluster around the relationships between aging and wound healing as the basis for a new research group (see Box 4.1).[7] This group received a 4 million EUR research grant from the Austrian National Foundation for Research, Technology and Development, as well as in-kind contributions from the Austrian Workers' Compensation Board.

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5 http://epidemium.org.

6 https://tell-us.online/_Resources/Persistent/f/c/c/b/fccb73883edcd513a8cae1f7891401441070e1e8/Tell_us_Report2019_en.pdf.

7 https://show.lbg.ac.at/?lang=en.

BOX 4.1 BENEFITS OF INVOLVING CROWDS IN DEVELOPING RESEARCH QUESTIONS

The biggest benefit we experienced by involving crowds in the development of research questions was to get a complementary view of the most striking medical needs in Trauma Care. The crowd answer "Effect of aging on certain aspects of healing" nicely coincided with our own previously set research goals and assures us that we are on the right track. To stratify and summarize the many different inputs on the crowd platform was one of the biggest challenges we experienced. Also, to think about how to give something back to the crowd.

-Heinz Redl, Professor of Experimental and Clinical Traumatology and co-organizer *of Tell Us! Accidental Injuries*, personal communication.

Source: Ludwig Boltzmann Gesellschaft, Open Innovation in Science Center.

Figure 4.2 Campaign poster for the project Tell Us! Accidental Injuries

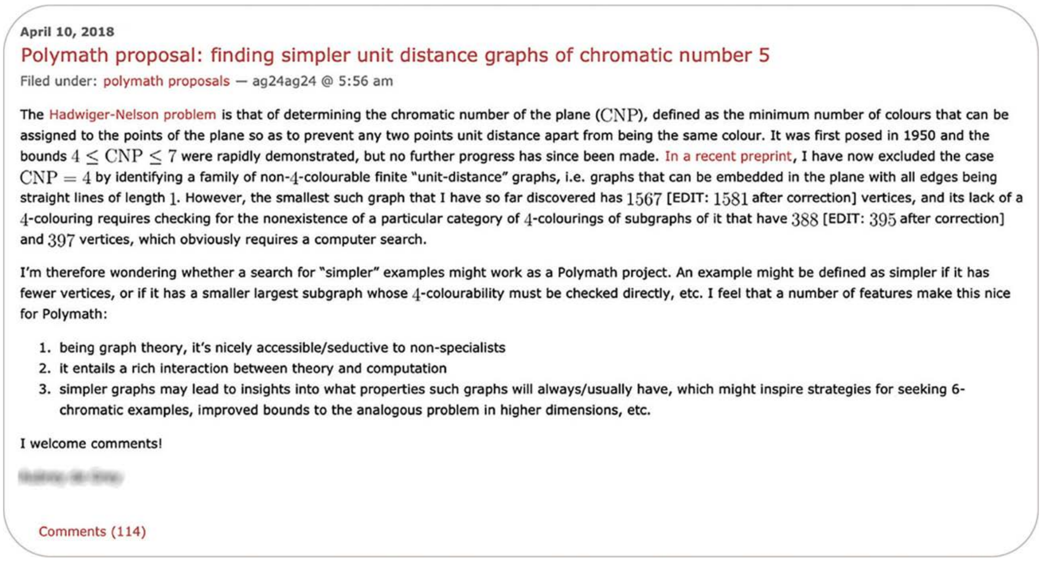
Applying the AKRD framework to analyze crowd contributions in this project (see Table 4.1), we see that the crowd's main activity was to generate and submit research questions via an online platform. Many of these questions incorporated experiential knowledge that crowd members had gained as patients or patient relatives (Beck et al., 2022b). Medical practitioners brought in their experience from diagnosing and treating patients, but they also seem to have aggregated experiential knowledge they had learned from their patients. *Tell Us! Accidental Injuries* did not require many other resource inputs, although a computer with internet access was required to participate. Crowd members were involved in decision-making by generating decision alternatives (i.e., potential research questions), but they were not involved in selecting the best research questions.

Polymath. The mathematician Timothy Gowers openly invited interested people to help solve a mathematical problem through an online collaboration. Participants who self-selected into this project included Fields Medalist and university professor Terry Tao, as well as PhD students, schoolteachers, and others with an interest in math. The first *Polymath* project was to develop a combinatorial proof to the density version of the Hales-Jewett theorem, which was ultimately published under the collective pseudonym D. H. J. Polymath (Polymath, 2012). Although Gowers defined the problem for the first *Polymath* project, crowd members actively participated in selecting problems to be solved in several subsequent *Polymath* projects. In some cases, problems were proposed by other lead investigators but ultimately also by general crowd members. Contributors then decided which problems to pursue through blog discussions and informal polls.[8]

Polymath participants contributed to several different stages of the research process, and we will return to this example again in later chapters. Focusing on the stage of identifying research questions, we see that the main activity performed by crowd members was to suggest problems to be solved in an online forum. Figure 4.3 shows an example and suggests that this activity required quite specialized knowledge – contributors have to speak "math" and have a sufficient understanding of how math problems are posed, and which problems might be most interesting given the state of the field. Other resources required included computer and internet access. Crowd members were involved in decision-making by generating decision alternatives, expressing their support for particular problems in discussions and informal polls, or even just going ahead and starting to work on a problem, hoping that others would join.

ExCiteS Kenya. The Extreme Citizen Science research group at University College London (UCL) has developed a range of projects that involve local communities in co-creating research projects with professional scientists. In one of these projects, scientists collaborated with herders and farmers in Kenya to study ecosystem change and preserve local ecological knowledge (ExCiteS, 2019). The UCL scientists invited local communities to share and discuss what problems they faced and collaboratively brainstorm how the available UCL

[8] https://gilkalai.wordpress.com/2021/01/29/possible-future-polymath-projects-2009-2021/.


April 10, 2018

Polymath proposal: finding simpler unit distance graphs of chromatic number 5

Filed under: polymath proposals — ag24ag24 @ 5:56 am

The Hadwiger-Nelson problem is that of determining the chromatic number of the plane (CNP), defined as the minimum number of colours that can be assigned to the points of the plane so as to prevent any two points unit distance apart from being the same colour. It was first posed in 1950 and the bounds $4 \leq \mathrm{CNP} \leq 7$ were rapidly demonstrated, but no further progress has since been made. In a recent preprint, I have now excluded the case $\mathrm{CNP} = 4$ by identifying a family of non-4-colourable finite "unit-distance" graphs, i.e. graphs that can be embedded in the plane with all edges being straight lines of length 1. However, the smallest such graph that I have so far discovered has 1567 [EDIT: 1581 after correction] vertices, and its lack of a 4-colouring requires checking for the nonexistence of a particular category of 4-colourings of subgraphs of it that have 388 [EDIT: 395 after correction] and 397 vertices, which obviously requires a computer search.

I'm therefore wondering whether a search for "simpler" examples might work as a Polymath project. An example might be defined as simpler if it has fewer vertices, or if it has a smaller largest subgraph whose 4-colourability must be checked directly, etc. I feel that a number of features make this nice for Polymath:

1. being graph theory, it's nicely accessible/seductive to non-specialists
2. it entails a rich interaction between theory and computation
3. simpler graphs may lead to insights into what properties such graphs will always/usually have, which might inspire strategies for seeking 6-chromatic examples, improved bounds to the analogous problem in higher dimensions, etc.

I welcome comments!

Comments (114)

Source: https://polymathprojects.org/category/polymath-proposals/help_outline.

Figure 4.3 *Polymath problem proposal generated by a crowd member*

technical infrastructure for data collection and monitoring might help communities study and address these problems. Among other contributions, the local participants used their knowledge about the local ecosystem to identify 134 plant species that needed to be monitored. Based on their understanding of the socio-political context, they also identified the need to develop mechanisms for sharing the data with each other and with regional partners to facilitate decision-making.

At the beginning of the process, participants' main activity consisted of joining meetings with the lead scientists to brainstorm and discuss possible research questions. Contributing to this discussion did not require expert scientific knowledge, but participants drew on their personal experience in the local ecosystem and their observations of species that might need monitoring. They had to commit time and travel to meetings in their villages, but all other required resources (pens, paper, electronic devices, etc.) were provided by the project team. Through their discussions within the whole team, participants generated alternative research questions and decided jointly with the ExCiteS scientists which questions would be pursued.

The project *A Healthier Southern Denmark* does not involve crowds in formulating research questions but in selecting which questions to pursue. In 2017, the regional government of Southern Denmark, together with the University of Southern Denmark (SDU), the university hospitals, and two media houses designed a process to invite citizens of the region of Southern Denmark to select health research proposals for funding.

Using SMS, crowd members can now vote every year on a small number of pre-screened research proposals developed by scientists at university hospitals. By doing so, citizens decide which of these proposals will receive funding.[9] The number of SMS votes per year ranged between 7,000 and 12,000. Each voting process involves a live TV show, where the winning research proposals are announced. In 2022, the crowd selected a project that investigates how the admission to an intensive care unit changes the lives of elderly patients and affects the quality of life among survivors.[10] The competing research projects proposed to study options for accelerating the diagnosis of acute vertigo, investigate why patients with anorexia are at increased risk of getting blood clots, identify the best treatment for peripheral arterial occlusive disease, and test whether cranberries are an effective preventive treatment against cystitis. In addition to helping set research agendas, this project also helps communicate science to a very large audience (Box 4.2).

BOX 4.2 INCREASING REACH BY INVOLVING CROWDS

We got huge societal impact. SDU research has through a dialogue been communicated to large groups of citizens. The reach of one project with Danmarks Radio (a media partner) was app. 560,000 people and 12,000 submitted votes.

-Anne Kathrine Overgaard and Thomas Kaarsted, organizers of *SDU Citizen Science*, personal communication.

In terms of the AKRD framework, the task for the crowd is quite simple: Vote for one of the proposed projects. This does not require any special knowledge, although some participants may have voted based on their knowledge about the pervasiveness or severity of different medical conditions. To vote using SMS, participants need access to cell phones. Crowd members are not involved in the generation of decision options (i.e., research questions) but they do decide which research question should be pursued.

9 https://www.tv2fyn.dk/ess.

10 https://faa.dk/fyn/projekt-om-livskvalitet-efter-indlaeggelse-vinder-et-sundere-syddanmark.

Table 4.1 AKRD Crowd Contributions for example projects (stage: identifying and selecting research questions)

	Epidemium ORL/IA	Tell Us! Accidental Injuries	Polymath	ExCiteS Kenya	A Healthier Southern Denmark
Activities	Propose and co-create idea for new research projects	Submit RQs via online platform	Propose problems in online forum	Brainstorm and discuss RQs with project team	Vote for research proposals
Knowledge	Diverse knowledge (scientific and experiential) in cancer, data science or other relevant areas	Experience as patient, relative, or medical practitioner	Advanced knowledge in mathematics	Local knowledge of the ecosystem	Common knowledge
Resources	Computer and internet connection; transportation to physical meetings	Computer and internet connection	Computer and internet connection	Transportation to physical project meetings	Phone to send SMS
Decisions	Generate decision options; evaluate and select	Generate decision options	Generate decision options; evaluate and select	Generate decision options; evaluate and select	Select which option to pursue

The five examples we covered illustrate how projects can involve crowds in identifying and selecting research questions. We also described quite specifically the crowd contributions using the AKRD Crowd Contribution Matrix. But what underlying mechanisms explain why and how scientists benefited from involving crowds? The Crowd Science Paradigms introduced in section 2.4 help us get closer to an answer, and we will use them in the next section to discuss the potential benefits of crowd involvement in this stage of the research in more detail, using the five cases and additional examples for illustration. For now, we summarize our assessment of the relevant crowd paradigms using the Crowd Science Paradigm Diamonds in Figure 4.4.

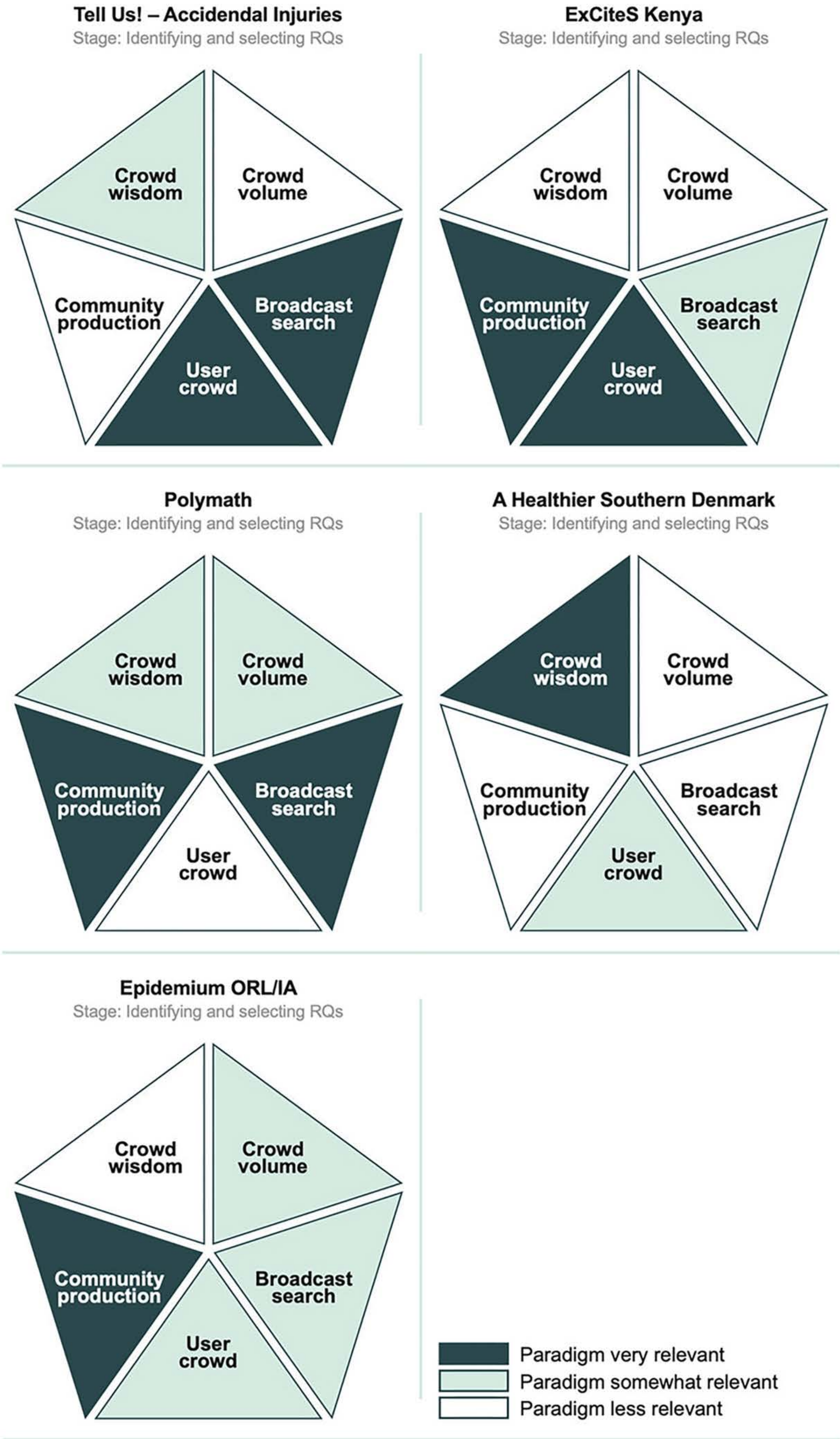


Figure 4.4 *Crowd Science Paradigm Diamonds for example projects (stage: identifying and selecting research questions)*

4.2 BENEFITS OF INVOLVING CROWDS IN IDENTIFYING AND SELECTING RESEARCH QUESTIONS

The five Crowd Science Paradigms help us think about why and how involving crowds can help in this stage of the research process.

The crowd volume paradigm focuses on the volume of inputs that can be contributed by large crowds, sometimes across a wide geographic space. The example cases we discussed are not primarily about generating many research questions – researchers ultimately only need a few really good ones. However, in some cases good questions result from people thinking very hard about problems and their underlying causes and investing considerable time in doing so. We see this feature in the projects *Polymath* and *Epidemium*, suggesting that the crowd volume paradigm is somewhat relevant for these two projects (see Figure 4.4).

The broadcast search paradigm highlights that crowd involvement may allow scientists to find "outlier" contributions. To the extent that we seek to find research questions that are important to a lot of people, looking for rare outlier questions may not seem like a smart strategy. However, recall that well-structured research questions do not only identify a problem but also include potential causes or solutions that can be investigated; novel ideas regarding such causes or solutions may be quite rare and creative. For example, while many people will agree that broken bones are an important problem, only a few crowd members may come up with outlier ideas regarding potential treatments. In that sense, the broadcast search paradigm seems relevant to several of the examples we discussed above, including *Tell Us! Accidental Injuries* and *Polymath*.

The user crowd paradigm emphasizes that crowd members can have deep knowledge in a problem domain, especially local or experiential knowledge that professional scientists may lack. This knowledge may point towards novel and important research questions. In *Tell Us! Accidental Injuries*, for example, patients, relatives, and medical practitioners used their experience in the problem domain of accidental injuries to generate the starting points for use-inspired research, reversing a "bench-to-bedside" to a "bedside-to-bench" research approach. Similarly, Kenyan farmers in the *ExCiteS Kenya* project contributed their knowledge of the local conditions and the most salient problems when co-creating the project with professional scientists from ExCiteS. Although anybody could vote in *A Healthier Southern Denmark*, the user crowd paradigm is also somewhat relevant in this project: The broader public includes many potential users of medical research whose problem-related knowledge and preferences likely influenced their votes.

The community production paradigm may also be a useful lens to understand the benefits of crowd involvement in this stage. In particular, collaborative brainstorming and discussions between crowd members and lead scientists in *ExCiteS Kenya* allowed the project to combine the expert knowledge of the latter with the experiential and local knowledge, as well as the preferences, of the former. In *Polymath* projects, interactions among crowd members helped them to better specify mathematical problems. Interactions and discussions also allowed participants in *Epidemium ORL/IA* to integrate diverse knowledge and preferences to develop and select feasible and important research questions.

The crowd wisdom paradigm highlights that integrating the estimates or preferences of many diverse crowd members may help overcome individual errors and biases. This paradigm seems most relevant for *A Healthier Southern Denmark*, where research questions had been pre-defined and screened by professionals, but crowd members voted which project should get funded. Tallying up the SMS votes of many people gives a good picture of overall preferences, and any mistakes (or intentional biases) in individuals' evaluations may cancel out as the crowd increases in size. Even though this example is mostly about aggregating preferences, projects may also rely on crowd wisdom with respect to knowledge. For example, a project organizer could ask the crowd to estimate the prevalence of different problems and then decide to focus on research questions addressing the problems that are estimated to be most common.

Does crowd involvement really yield *better* research questions? We tried to find out in a study that compared research questions generated by the crowd in two *Tell Us!* projects with research questions generated in the traditional scientific process (i.e., by teams of scientists) and published in conference proceedings. We asked professional scientists in the relevant fields to rate each question with respect to novelty, potential scientific impact, and potential practical impact (Beck et al., 2022b). We found that the average crowd-generated research question was rated lower than professional research questions. However, once we focused on the best of multiple submissions by individual crowd members, or on the best questions across all crowd members, crowd-generated questions outperformed professional ones on all dimensions. Selecting the best crowd generated questions did not necessarily create an unfair advantage because the professional research questions that make it into conference proceedings are typically also quite selected and result from iterative improvement processes.

4.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Organizers who seek to involve crowds in identifying and selecting research questions may face several challenges. Many of these challenges are relevant also in other stages – such as the challenge to attract enough contributors, to enable effective coordination among crowd members, and to evaluate the quality of a large volume of crowd contributions. We will discuss these cross-cutting challenges in Chapters 13–15. In the following, we focus on three challenges that are more specific to crowd involvement in this particular stage.

Knowledge of existing research. A good research question should be novel or should at least not have been answered before. As such, knowing what has already been done helps one come up with new research questions (e.g., if prior findings are contradictory) but also in selecting questions (e.g., dropping those that have already been answered). Professional scientists acquire knowledge about prior research during formal training but also through activities such as reading academic literature at the beginning of a new project, reviewing for journals and funding agencies, or attending professional conferences. Crowd members who are not professional scientists often do not have this knowledge, making it difficult for them to generate and select novel research questions. This challenge can be addressed in different ways.

First, some projects involve crowd members who are themselves professional scientists and will have knowledge of relevant existing research (Guinan et al., 2013). Relatedly, even some lay experts may have extensive knowledge in the domain from reading related literature, e.g., as patients or relatives who have a strong motivation to learn about new scientific developments related to a particular disease. Some people also follow the academic literature in specific areas out of curiosity and interest. In the project *Eterna*, for example, the main task for crowd members ("players") is to generate RNA structures that may have desirable properties, and some of these designs are then synthesized and tested in the organizers' lab at Stanford University. Although the primary scientific goal of the project is to identify promising new RNA designs (see Chapter 9), data from lab tests are also returned to players to see if they find anything interesting. A few years ago, a small group of players started to notice specific signatures of a particular type of RNA and discussed these observations on the discussion board. Drawing on their extensive experience as *Eterna* players but also avid readers of the relevant literature (Box 4.3), they realized that these patterns were unusual and had not been reported before. They started a side-project that investigated these patterns in more detail and ultimately resulted in a peer-reviewed publication (see Chapters 10 and 11). This example also demonstrates another useful mechanism to assemble the required prior knowledge – discussions among crowd members that allow them to pool their knowledge to get a more complete picture. Of course, this integration of knowledge and collective brainstorming can also involve the project organizers – in the true spirit of the community production paradigm.

BOX 4.3 EXPERT CITIZENS

I did no course work in biology but I have a PhD in computer science. I did not publish my dissertation … I am not sure anybody ever read it. I left academia and created a startup company after finishing my PhD. But I was always interested in chemistry, biology, physics … So I read a lot of papers.

-Roger Wellington-Oguri, *Eterna* player and co-initiator of project to investigate unusual RNA signatures, personal communication.

Another approach is to provide crowd members with tools and infrastructure that enable them to search for relevant prior research. One option is Google Scholar, but this tool is not easy to use for crowd members who are unfamiliar with field-specific scientific terminology and who may find it too difficult or time-consuming to review and digest long lists of search results. As an alternative, projects can provide access to tools that employ artificial intelligence to facilitate literature searches even for researchers outside of a particular field. Some of these tools also suggest links between domains that may stimulate users to think about creative new research questions (Beck et al., 2022c).

Generating well-structured research questions. Research questions tend to be particularly useful when they are well-structured: Highlighting important problems but also potential causes or solutions that can be investigated. Interestingly, results from the Beck et al. (2022b) study show that when crowd members are just asked to generate research questions, they often come up with ill-structured problem re-statements such as "How can we cure cancer?". This may reflect a lack of ideas on potential causes or solutions, but also that crowd members did not even think about causes or solutions, or that they believe a broad question is more helpful than a narrower, well-structured one.

If project organizers are looking for well-structured research questions, one approach is to co-create questions with crowd members in a discussion that seeks to identify both the problems and potential causes or solutions. Consider the cases reported in Beck et al. (2021), where social scientists collaborated with physicists at CERN to identify novel research questions on the organization of science. In one example, the original problem statement of a junior physicist was something like “Teams at CERN do not share as much information with each other as they should”. To better understand this problem, the social scientists then asked many questions about how collaborations work at CERN and what might be causing the problem. Eventually, the group generated a set of well-structured research questions such as “Does open governance within research teams (i.e., the involvement of both senior and junior members) lead to more openness and more collaboration with other teams?”. Of course, such co-creation is time-consuming and difficult to do with large crowds. An alternative that is easier to scale is to guide crowd members to generate well-structured questions by using templates. For example, asking crowd members to complete a statement such as “What is the effect of ___ on ____?” is more likely to yield a well-structured question than asking “What research question should scientists investigate?”.

Representativeness of participants. Whereas the identity of crowd members matters less in activities such as data collection, individuals’ personal background will influence what problems they identify, and individual preferences are a very important input in voting processes such as that implemented by *A Healthier Southern Denmark*. This raises the concern that the self-selection of crowd members into project participation may not result in a representative sample. Certain stakeholder groups may even try to hijack efforts to develop or select research questions in order to focus them on their particular needs and interests.

While self-selection may reflect personal interests in particular questions or topics, it may also reflect a different ability to bear the costs of participation. For example, we found in a recent study that crowd members with lower levels of income and education were less likely to support a particular research project when this involved personal costs (e.g., donating $1) than when it involved a costless vote (Franzoni et al., 2024). Thus, mechanisms of crowd involvement that are costly (in terms of money, but also time) can deter certain groups of individuals from participating, giving an advantage to research questions that are of interest to people with greater ability to bear those costs.

Of course, self-selection is also a defining feature of crowd science, and is particularly important in the broadcast search paradigm (we want to identify a few people with outlier ideas) as well as the user crowd paradigm (we want to attract people with relevant experiential knowledge). As such, organizers need to think carefully about the benefits of working with carefully selected crowds versus crowd members that are more representative of the broader population (see also section 14.2 on recruiting). If the goal is to come up with novel ideas or identify problems that may be hidden from plain sight, then it is often useful to reach out to people with deep user experience. If the goal is to find out which research questions address the most prevalent needs (i.e., research question selection), then getting preference inputs from a broad representative sample may be a better approach (Burda et al., 2023). This point leads us directly to the next section, where we will help readers think more concretely about whether and how to involve crowds in identifying and selecting research questions.

4.4 GETTING STARTED: DECIDING WHETHER AND HOW TO INVOLVE CROWDS IN IDENTIFYING AND SELECTING RESEARCH QUESTIONS

In "Getting started" sections, we help you think more concretely about whether and how crowd involvement could help you in a particular stage of the research process. To do so, we will use the 4Q Tool (section 3.1) and the Crowd Science Design Canvas (section 3.2). We illustrate the application of these tools in four of the book chapters using "personas", which are fictional characters whose made-up characteristics and problems allow us to think about key decisions more concretely. Our first persona is Mehdi, an assistant professor of neurosciences (Figure 4.5), whose fictional case will help us to think about crowd involvement in identifying and selecting research questions.

PERSONA: **MEHDI**

Position: **Assistant Professor in Neurosciences**
Organization: **Public University, Italy**

Background:
Mehdi's lab has developed a new method to characterize protein-protein interactions, which helps understand how cells function and how these functions are affected by different diseases. This, in turn, may help find windows for therapeutic interventions.

Mehdi's challenge:
His lab has validated the method in principle, but Mehdi now has to study how it performs in different disease areas and what conditions make it more or less effective. Which disease areas should he focus on and what specific questions should he study in those areas?

Figure 4.5 Persona for identifying and selecting research questions (Mehdi)

4.4.1 Status Quo Analysis Using the 4Q Tool

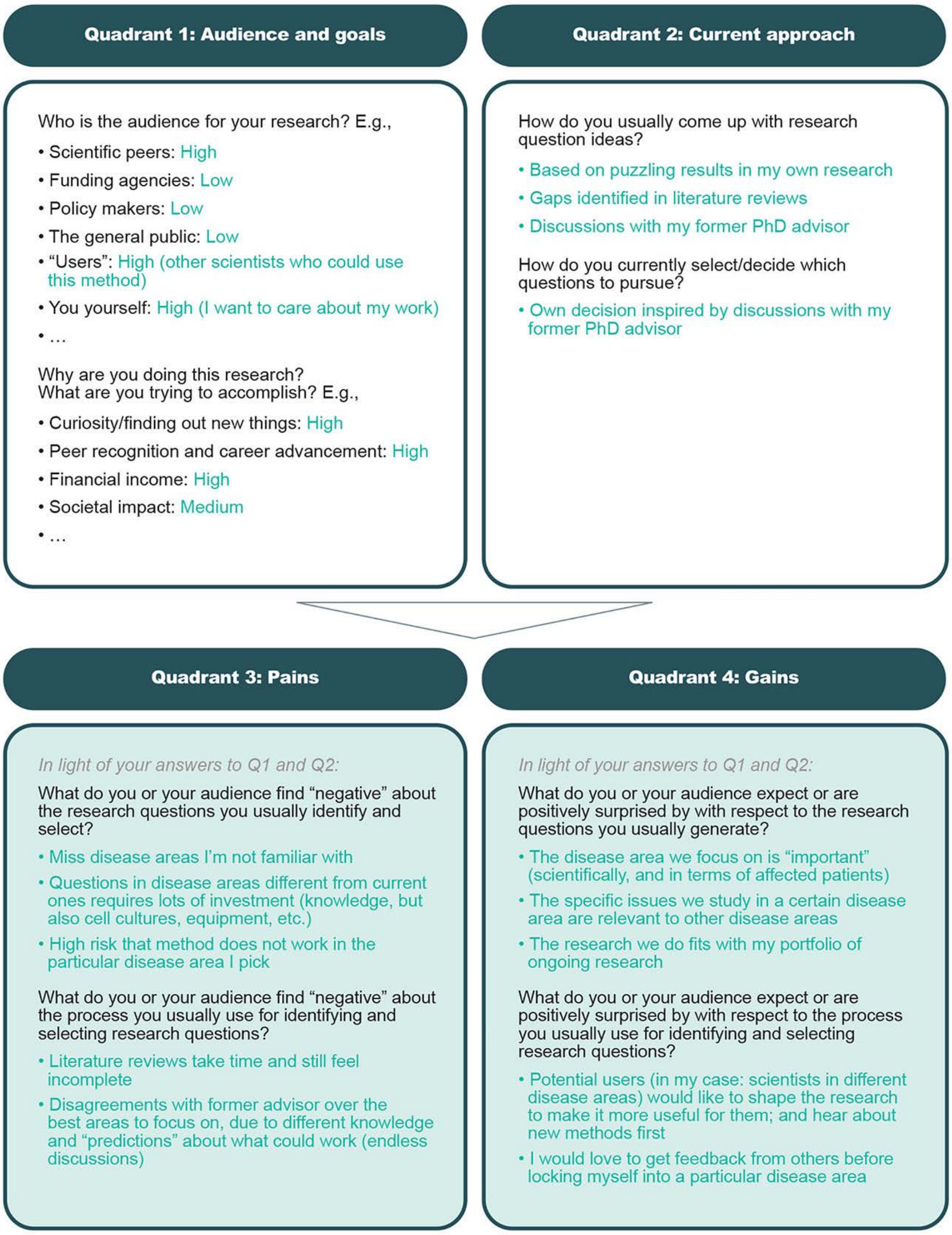
We discussed the 4Q Tool at an abstract level in section 3.1, and the website www.sciencewithcrowds.org includes a version with guiding questions for the stage of identifying and selecting research questions. Figure 4.6 shows the tool again with answers from our fictional persona Mehdi. We kept the answers brief to conserve space – you should think about your own answers very carefully to make sure you identify the most important pains and gains that crowd involvement may be able to address.

4.4.2 Developing a Project Using the Crowd Science Design Canvas

Figure 4.7 shows the Crowd Science Design Canvas customized for the stage of identifying and selecting research questions, as well as the key choices made by Mehdi (in green; revisions in purple; colour only in online version).

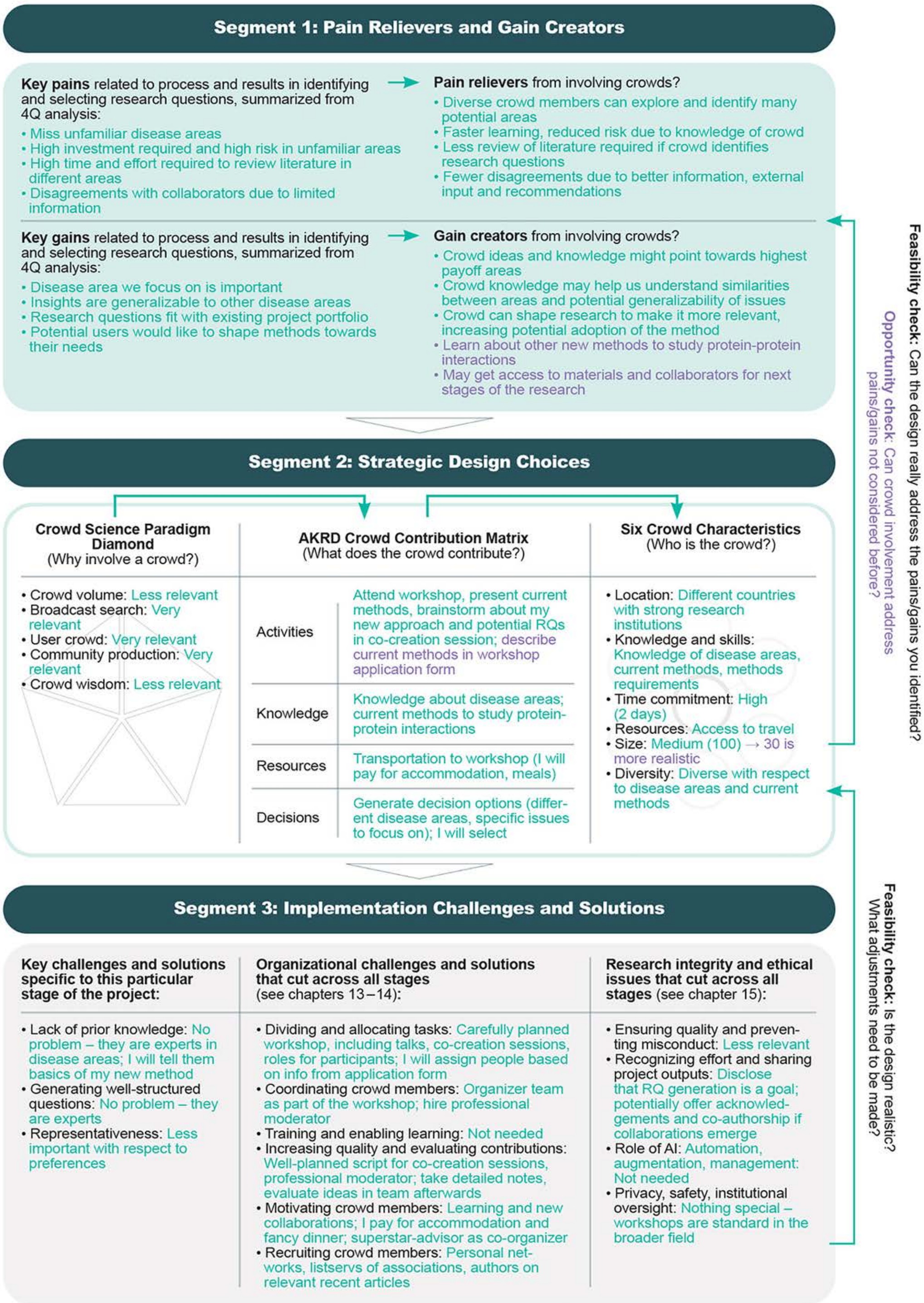
Segment 1 summarizes the pains and gains resulting from the 4Q analysis. The primary challenge Mehdi identifies is that the range of potential disease areas is vast, and it would require too much time and effort to explore them all and identify the most promising one. Mehdi is also concerned that he may pick the wrong area, investing lots of time only to find out that his method does not work well. As Mehdi is thinking about how to involve crowds, he focuses on the possibility of asking a diverse crowd of other professional researchers with expertise in different medical research areas. These scientists will know a lot about their respective areas and they may also be potential users of his method, perhaps allowing him to learn what they would expect from a new method and how he could validate it. He writes down his initial ideas on pain relievers and gain creators on the right side of segment 1. He will return to this part after having thought more carefully about the other two segments of the Canvas.

Segment 2 guides Mehdi through different strategic choices. Thinking about the benefits of the different Crowd Science Paradigms first, he believes that the user crowd paradigm is most helpful: He needs access to the knowledge and experience of other scientists who can potentially use his method in their medical research. They may better understand the challenges they are currently facing in their areas, and how much of an improvement his method might bring. But he also believes that potential users need to think hard about this and need to first better understand how his method works and what it is able to do. So, discussions and other mechanisms highlighted by the community production paradigm may be important. He realizes that some disease areas may be much more promising than others (broader scope, lower risk) and that different crowd members are familiar with different areas – broadcast search would help him identify those crowd members who sit in the most promising area(s). Although Mehdi recognizes that generating ideas will take effort and time, and that different people may have different biases when assessing the potential of different application areas, he believes that the crowd volume and crowd wisdom paradigms are less relevant for him.



Note: Mehdi's condensed answers in green; colour only in online version.

Figure 4.6 4Q Tool to analyze status quo with respect to identifying and selecting RQs



Note: Mehdi's condensed answers in green; revisions in purple; colour only in online version.

Figure 4.7 Crowd Science Design Canvas for identifying and selecting research questions

But what exactly should crowd members contribute? He primarily wants knowledge – about the methods they are currently using, specific requirements they have, but also potential uses they see for his newly developed method. He does not need any other resources from them, although thinking about resources makes him realize that it might be nice to get cell cultures and other materials from those researchers whose disease areas he ends up studying. Does he want to let the crowd members decide which areas to study? Not really… he is a bit worried that some crowd members may have their self-interest in mind (picking applications that matter to them but may not be optimal for his research), and he does not really want to give up control over a decision that may make (or break) this line of his work.

When thinking about the characteristics of his ideal crowd, Mehdi is quite sure that this should be a crowd composed of professional medical scientists – after all, those are the potential users of this method. Where crowd members are located does not really matter – although he believes that broadcast search is most successful if he casts a wide net by inviting people from different countries that have strong research institutions. Crowd members should have knowledge about potential application areas but also need to have enough background to understand what he is doing. Mehdi thinks that a larger crowd with background in different disease areas would be best because such a crowd is more likely to cover many potential applications, ensuring that he does not miss any particularly promising research questions. One hundred people sounds like a good number.

Segment 3. Moving to implementation challenges and solutions, Mehdi looks at the challenges specific to this stage and is relieved. He does not think he has to worry about crowd members' lack of prior knowledge – they will be experts in their fields and know what methods are currently being used to characterize protein-protein interactions. They also do not need much knowledge about what has been done with his method before – it is brand new, and he brings the required knowledge to the (community production) table. He is also not worried about the crowd's ability to structure research questions – professional scientists should know how to do that, and even if they don't, he can integrate everyone's knowledge in a community production setup. Mehdi is not worried much about representativeness in terms of preferences – he does not really try to learn about users' preferences in this case, and he also does not plan to involve crowd members in making final decisions, such that their preferences will be less relevant.

Mehdi spent a lot of time thinking about organizational challenges and solutions by reading Chapters 13 to 15 of this book. The most difficult challenges in his case seem related to recruiting, motivation, but also organizing a community production process among potential users of his new method: Why would other busy scientists help him with his research? And how can he best pick their brains? After discussing this with his former advisor and his postdoc, they come up with an idea: They will organize a "Florence workshop on new methods to study protein-protein interactions". He hopes that potential users will find this workshop relevant for their own research, motivating them to show up. Indeed, he remembers from the 4Q analysis that one of the gains his audience would appreciate is hearing about new methods first. The trouble is that his method has not been proven in particular application areas, so he cannot promise a new method quite yet. To make the workshop relevant, he decides to invite not only potential users of his method but also researchers who are working on alternative new methods to study protein-protein interactions. Although his advisor is a bit worried about competition down the road, at this early stage of the research, Mehdi really needs crowd members' knowledge inputs to help him develop and choose the most promising research questions. And he thinks that others will find it difficult to "steal" his early-stage method because his lab has developed unique capabilities that are hard to replicate. Perhaps more importantly, he recognizes another benefit of crowd involvement he had not considered: Harnessing the knowledge of not only users but also researchers who are working on alternative methods will help him to better judge the risks and benefits of his method and to pick the most promising application areas. Mehdi adds this benefit to segment 1 of the Canvas.

Mehdi realizes that a traditional workshop format may not work well for his purpose: People focus on presenting their own ideas and there is typically little time to get input from others. As such, Mehdi plans talks about new methods but also a special co-creation session, where he will present key aspects of his method, ask participants to challenge him about potential flaws, and collaborate to sketch out research questions in their particular disease areas. He will carefully script this session and hire a professional moderator who can manage the process. He hopes that potential users are incentivized to participate because they may ultimately get a method that helps them do their work – and they may get it faster by helping him. But to make sure they show up, he will use some of his funding to pay for participants' accommodation and organize a nice dinner in Florence. And he convinced his superstar-advisor to be one of the co-organizers. Mehdi's advisor will also use his personal network to spread the word about the workshop. To get a more diverse pool of participants, Mehdi will promote the workshop on the listservs of relevant professional associations, and he will ask his postdoc to identify potential participants by searching relevant recently published articles.

Mehdi believes that issues around research integrity and ethics are less relevant in his case because he will be working with other professional scientists, and because the workshop will not produce any data or results yet. But he should probably be upfront about why he is organizing the workshop – that one of his goals is to identify the most promising disease areas for his new method and to formulate more specific research questions for his future research. He will include this in the workshop call, which will also help prepare participants for the co-creation session. With this disclosure, it should also be no problem if he uses ideas that participants disclose during the workshop. And if someone has an amazing idea and offers to contribute other resources (such as materials) at a later stage, then Mehdi would appreciate a formal collaboration with shared co-authorship.

Feasibility and opportunity checks. Unfortunately, Mehdi's budget is limited and he also realizes that intensive discussions would be difficult with too many people. This feasibility check leads him to reduce the crowd size to 30. He believes he can still get diverse and potentially high value inputs by broadcasting his call for workshop participation widely but also deliberately targeting researchers in many different areas, including obvious and less obvious ones. Mehdi's postdoc has another good idea: They could include a field on the workshop application form that asks researchers to briefly describe how they are currently studying protein-protein interactions and why they are looking for a better approach. The responses to this question may help Mehdi to better select a diverse crowd – and they may already help him think about the best research questions going forward.

5. Raising funding

Research is costly. Although resource requirements differ across fields and types of projects, funding is required for all stages of the research, including things such as buying access to prior literature, purchasing materials or access to equipment, data collection, computing power to run statistical analyses, and even open access fees to publish research (Stephan, 2012). Perhaps most importantly, funding is required to pay the salaries of researchers and support staff.

Traditionally, some researchers receive their funding from home institutions, e.g., universities or research institutes. Others are financed primarily through grants. The grant mechanism in particular requires considerable time on the part of researchers who write grant applications, but also from peer evaluators and funding agencies who evaluate applications. Support from local grant offices is often essential to navigate the application process, as well as rules on accounting and reporting.

There is never enough funding for all the research ideas scientists come up with. The success rates vary widely, but applicants to agencies such as the NIH, NSF, or ERC are more likely to be rejected than accepted (with acceptance rates around 10–25 percent).[1]

There is evidence that funding may not always go to the projects or researchers that "should" get funded. One concern is that many grant mechanisms favor safe projects and discourage risk-taking, e.g., by asking for preliminary data or by putting too great an emphasis on the feasibility of projects (Franzoni et al., 2022b; Lane et al., 2022). This may well be in the interest of taxpayers who ultimately finance grants, but it may prevent science from making those risky leaps that are sometimes required to move the scientific frontier. A second concern is that existing mechanisms disadvantage junior researchers because those researchers have not had the chance to build a long list of high-impact publications that often serve as an important signal for evaluators. Although some funding agencies, such as NIH, have created dedicated

[1] https://erc.europa.eu/news-events/magazine/rewriting-rewarding-tips-repeat-applicants; https://report.nih.gov/nihdatabook/category/10; https://www.nsf.gov/homepagefundingandsupport.jsp

initiatives to support junior researchers, many junior scientists struggle to raise the funding required to do research and start their careers (Alberts et al., 2014).

Involving the crowd in research may help deal with funding challenges in two main ways. First, scientists who engage crowd members in different stages of the research process by providing appropriate non-financial rewards (see Chapter 14) are often able to get research inputs for less money, reducing the need for external funding. For example, crowd members contributing on the platform *Zooniverse* have saved projects millions of dollars compared to using traditional research assistants or *Amazon Mechanical Turk* (Sauermann & Franzoni, 2015). Similarly, crowd members who participate in activities such as co-creation workshops or collecting field data often cover parts of the related expenses themselves (the R in the AKRD Crowd Contributions Matrix). Second, and the focus of this section, crowd members can get involved in raising the money required to perform research. Let us start with four examples.

5.1 EXAMPLES

Gill Lab. A team of paleoecologists at the University of Maine needed funding to study how the ecosystem of the Falkland Islands has responded to past periods of climate change. To raise part of this funding, they started a crowdfunding campaign on the platform *Experiment.com*. Less than two months later, they had raised over 10,000 USD, which enabled them to travel to the Falkland Islands, hire a local driver, ship peat cores back to their lab in Maine, and process the samples. But the journey was not easy. Lead scientist Jacquelyn Gill and two graduate students spent a lot of time setting up the website, recording a video describing the research, and responding to comments and questions from visitors to the campaign page or from "backers" who had committed funding (Gill, 2014). They also discovered that crowdfunding success requires much energy to reach out to the broader public via social media and personal networks. Gill activated her over 6,000 Twitter (now X) followers and created @fakepenguinfacts stories to stimulate additional attention and excitement. But the effort paid off – the crowdfunding campaign enabled the team to perform the research in the Falkland Islands, ultimately resulting in a top-tier publication (Hamley et al., 2021). Moreover, it enabled the junior team to start building a track record that put them on the path to getting larger grants from public funding agencies (See Box 5.1).

BOX 5.1 CROWDFUNDING FOR AN EARLY-CAREER RESEARCHER

Grant by grant, things are getting bigger, and now I'm finally feeling like, as we start to submit our first round of papers, I can apply for a government grant to do this work.

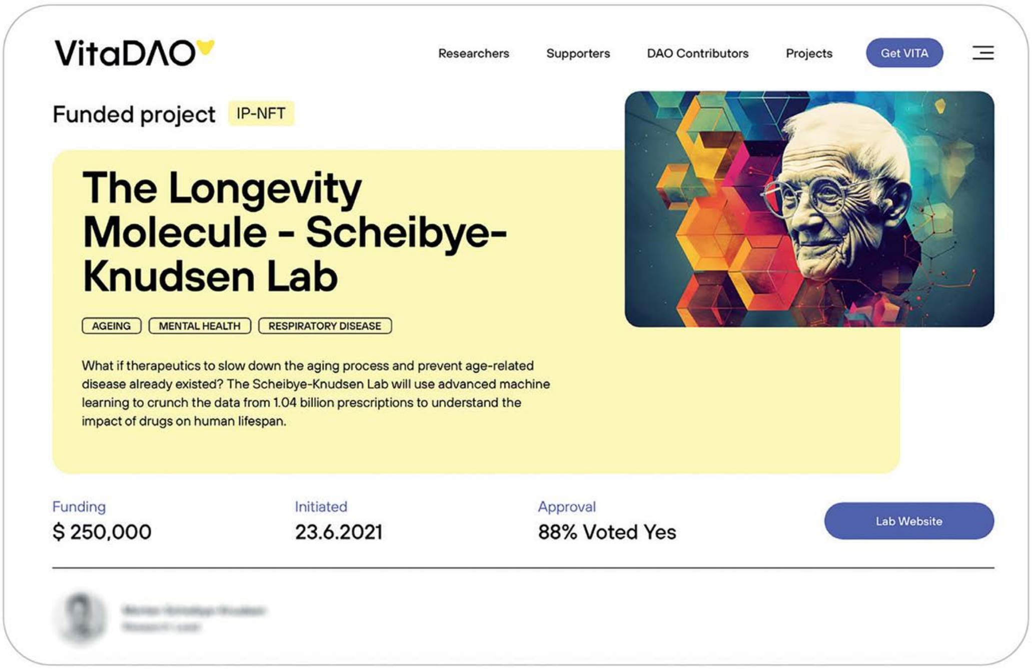
-Jacquelyn Gill, Professor of Paleoecology, quoted in Dolgin (2019).

CurieuzeNeuzen. Projects raising funding on the crowdfunding platform *Experiment.com* typically approach the crowd for funding only. In contrast, other projects involve crowd members primarily in other stages of the research process but also give them the option to donate money. Consider again the project *CurieuzeNeuzen*, which asked participants to participate by collecting air samples, interpreting data, and diffusing results. Some crowd members also contributed by donating physical money that could be used to fund various project expenses. Although this share of funding was only 10–20 percent of the total budget, it was a meaningful amount.[2]

Moores Lab. Audrey Moores is a professor of chemistry at McGill University in Canada. She and her team study sustainable materials and had the idea to turn the shells of the invasive green crab into plastic that is biodegradable in ocean waters. Professor Moores received funding for this project through the *Fathom Fund*, a unique funding mechanism that combines aspects of traditional grant mechanisms and crowdfunding.[3] In particular, the fund uses experts from its general funding board to evaluate whether a proposal is generally feasible, i.e., whether the methods can answer the research question. The experts do not evaluate whether the question is worth asking – that is left to the crowd, whose crowdfunding contributions ultimately decide whether a project will move forward. The *Fathom Fund* encourages scientists to engage with the general public but, as noted by the founders, the goal is not necessarily to move research towards great social relevance. Rather, the goal is to support scientists who are already working on relevant problems to get the support they often fail to get in the traditional funding system.[4]

[2] Personal communication with *CurieuzeNeuzen* organizers.
[3] https://meopar.ca/project-aims-to-turn-problematic-invasive-green-crabs-into-a-sustainable-solution/; https://www.nserc-crsng.gc.ca/Media-Media/ImpactStory-ArticlesPercutant_eng.asp?ID=1631.
[4] Personal communication with *Fathom Fund* organizers.

Scheibye-Knudsen Lab. Morten Scheibye-Knudsen is a professor at the University of Copenhagen, studying the cellular and organismal consequences of DNA damage – which has important consequences for age-related diseases. He raised 250,000 USD from *VitaDAO*, a decentralized autonomous organization of individuals interested in supporting research on longevity (Figure 5.1). Consisting of thousands of individuals, this community has now funded more than 20 large projects and is looking for moonshots that can make revolutionary contributions to science.[5] *VitaDAO,* as well as sister communities on the larger funding platform Molecule.xyz, use sophisticated technical infrastructure including Discord forums to discuss aging-related research and the research proposals applying for funding, blockchain to orchestrate and log their activities, as well as non-fungible tokens (NFTs) for fundraising purposes and to allow members to vote on proposals (Nature Biotechnology, 2023). Whereas the crowdfunding examples discussed earlier were donation-based, the NFTs used by *VitaDAO* can be traded. Given that the community holds some of the IP resulting from funded projects, the financial value of the NFTs partly reflects the expected or realized project success.[6]



Source: https://www.vitadao.com/projects/scheibye-knudsen-lab.

Figure 5.1 Scheibye-Knudsen project page on VitaDAO crowdfunding platform

5 https://www.vitadao.com/projects.
6 https://www.vitadao.com/blog-article/beginners-guide-to-vita-token.

Table 5.1 shows the crowd contributions in these examples, using the AKRD Crowd Contribution Matrix. Given that crowd contributions are primarily financial, the activities and knowledge requirements are very limited. Crowd members do not make decisions within the project, but their decisions (not) to donate money impact the viability of the project as a whole.

Table 5.1 AKRD Crowd Contributions for example projects (stage: acquiring funding)

	Gill Lab	Curieuze-Neuzen	Moores Lab	Scheibye-Knudsen Lab
Activities	Visit crowd-funding platform and donate money	Donate money	Visit crowd-funding platform and donate money	Contribute money via NFTs; discuss projects on Discord; vote on whether to fund
Knowledge	General knowledge	General knowledge	General knowledge	General knowledge; specialized knowledge in application areas
Resources	Money; computer and internet connection; credit card	Money	Money; computer and internet connection; credit card	Money; computer and internet connection; digital wallets
Decisions	Select whether project should go forward	Select whether project should go forward	Select whether project should go forward	Select which project should be funded

The four examples illustrate how projects can involve crowds to help raise funding. But what underlying mechanisms explain why and how scientists benefited from involving crowds? Figure 5.2 shows our assessment of the most relevant Crowd Science Paradigms in the example projects. We will explain our assessment in more detail when discussing the general benefits of involving crowds in raising funding in the next section.

5.2 BENEFITS OF INVOLVING CROWDS IN RAISING FUNDING

We studied projects on the crowdfunding platform *Experiment.com* and made a number of interesting findings (Sauermann et al., 2019). First, most projects raise only small amounts of funding, but there is a wide distribution, with one

Figure 5.2 *Crowd Science Paradigm Diamonds for example projects (stage: acquiring funding)*

project raising over 2 million USD to investigate a cure for Batten disease (a fatal genetic disorder). Second, the scientists asking for funding tend to be junior, including master's and PhD students, although there was also a significant number of associate and full professors (who tended to ask for larger amounts of funding). Third, most projects seek funding for equipment, travel, and other direct costs such as fees for study participants. Very few projects raise money for investigators' salaries, suggesting that salaries are paid from other sources.

Finally, the chances of funding success are roughly 50 percent – higher than at traditional funding agencies, but certainly not guaranteed either.

So, what are donors looking at when deciding whether to crowdfund a research project? In the Sauermann et al. (2019) study, we report correlations between funding success and a number of characteristics of the projects as well as the organizers. Among other factors, students and junior investigators are more likely to achieve their funding targets, and women have higher success rates than men. Moreover, prior publications by the investigators mentioned in the campaign did not predict funding success. Some of these patterns differ from what we know about funding in the traditional grant system, suggesting that crowd members may decide differently from typical peer reviewers.

We also found that projects that feature a video, show endorsements by other scientists, and provide updates about project progress are more likely to get funded. Although rewards are generally much less common than on other platforms, such as Kickstarter, some projects offer rewards such as photographs of animals observed in fieldwork, the naming of a shark, or visits to the investigators' lab. Such projects are also much more likely to receive funding. We note that these results are correlational, so it is not clear whether these project characteristics drive funding success or, perhaps, certain highly motivated scientists spend more effort in designing their projects while also doing more unobserved work to raise the funding they need (recall the *Gill Lab* example above). That being said, greater success of projects with features such as videos or rewards has also been reported in other crowdfunding research (Butticè et al., 2017; Vachelard et al., 2016).

Additional evidence on crowd members' decisions to support a research project comes from a recent study that asked over 2,000 citizens to evaluate four different research proposals with respect to their scientific merit, the capabilities of the team members, and potential social impact (Franzoni et al., 2024). Contrary to concerns raised by some professional scientists, the crowd does not ignore scientific merit or team capabilities – but it does seem to place greater weight on the potential social impact of a project than typical peer reviewers do. Perhaps even more interestingly, that study explores what crowd members thought about when judging social impact. The first criterion seems to be the magnitude of the problem that a project seeks to address, as reflected in the number of people (or animals, etc.) affected by the problem as well as the severity of the problem for those who are affected. Only a small share of the evaluators explicitly mentioned whether or not the project could actually provide a solution.

Taken together, crowdfunding is a viable way to raise funding for scientific research, although in most cases it appears to complement rather than substitute for traditional funding mechanisms. In particular, crowdfunding seems to be most suitable for smaller projects, projects that can demonstrate a tangible social benefit, or projects that do not fit the requirements of traditional funders (see Box 5.2). Recent developments such as Decentralized Autonomous Organizations (DAOs) are particularly exciting because they suggest the potential for larger project sizes while also involving more complex organizational setups to leverage different benefits of crowd involvement.

BOX 5.2 CROWDFUNDING TO BRIDGE THE "VALLEY OF DEATH"

Translational projects that bridge basic biology research and practical applications often fall into a funding gap. They are too applied for traditional academic grants yet too preliminary for venture capital, lacking immediate IP. Our goal is to support initiatives as they navigate this "valley of death".

-Benji Leibowitz, Director of Product, Molecule.xyz, personal communication.

We can now turn to our framework of Crowd Science Paradigms to better understand how and why engaging the crowd in raising funding may benefit researchers.

The crowd volume paradigm focuses on the benefits of generating a large volume of contributions from many contributors. In the stage of funding, the contribution of the crowd is money rather than time or effort. Yet, the idea that volume is important still applies. In particular, the average contribution to scientific crowdfunding campaigns tends to be quite small, but when a large number of individuals pitch in, the total amount of funding can be significant (Sauermann et al., 2019). This paradigm particularly applies to the *Gill Lab*, *Moores Lab,* and *Scheibye-Knudsen Lab* examples.

The broadcast search paradigm highlights that broadcasting a call for contributions to many people may enable a project to identify outliers, i.e., contributors with particularly effective solutions to problems or rare skills and knowledge. In the context of crowdfunding, the outliers that projects are looking for are people with a high ability and willingness to pay. Although most projects achieve their funding goals by collecting many small donations, some projects manage to find a few donors who are willing to fund a large chunk of the budget. For example, the project researching a cure for Batten disease received some very large donations from movie stars, while a project studying target-based discovery for coronavirus disease raised over 25,000 USD from fewer than 20 donors.[7] But even the donors who give smaller amounts are highly selected from among the many people who see a campaign but decide not to contribute. In that sense, the broadcast paradigm is relevant for both the *Gill Lab* and the *Moores Lab* projects, although perhaps less for the latter, where the *Fathom Fund* asked to see crowdfunding success more to get a sense of the public's preferences rather than to contribute the bulk of the funding.

The user crowd paradigm highlights that crowd members who are affected by a focal problem and are (potential) users of research may possess unique experiential knowledge. This knowledge, in turn, may be an important input into different stages of the research process. Of course, the primary contribution in the fundraising stage is money rather than knowledge. Nevertheless, potential users may be particularly responsive to calls for funding because they are more aware of existing problems or because they believe the research may also benefit them personally or others they care about (see also discussion of motivations in section 14.1). To illustrate, Figure 5.3 shows a section of the *Experiment.com* discussion forum for the project *Open Insulin*. This discussion includes, among others, supportive comments from a doctor who is acutely aware of the need for more cost-efficient insulin from his work with patients as well as a diabetes patient personally affected by the high cost of insulin. One can also read lively discussions of research proposals in the *VitaDAO* forums that are partly based on members' personal experiences. The user crowd paradigm seems less relevant for the *Gill Lab* and *Moores Lab* cases, but highly relevant for the *Scheibye-Knudsen Lab* and *CurieuzeNeuzen* – where financial contributions were primarily made by participants who had a personal interest in air quality data from their region.

The community production paradigm – highlighting knowledge exchange and interactions among contributors – seems less relevant in funding than in other stages. However, exchanges and comments on discussion boards, such as the one shown in Figure 5.3, or on *VitaDAO* forums, can allow crowd members to collectively make sense of a proposal, or to identify potential challenges and problems. To the extent that these exchanges then provide input in crowd members' decision-making, they are important. Of course, this may lead the crowd to provide funding but also to withhold it, such that it may not always yield benefits for the researchers who propose a project.

Finally, the crowd wisdom paradigm highlights how aggregating the opinions of the crowd can help organizers get more accurate estimates of facts or societal preferences. Similar to crowd voting on research questions (Chapter 4), this paradigm applies to crowdfunding in that aggregating the funding decisions of many people may provide insights into societal preferences. Indeed,

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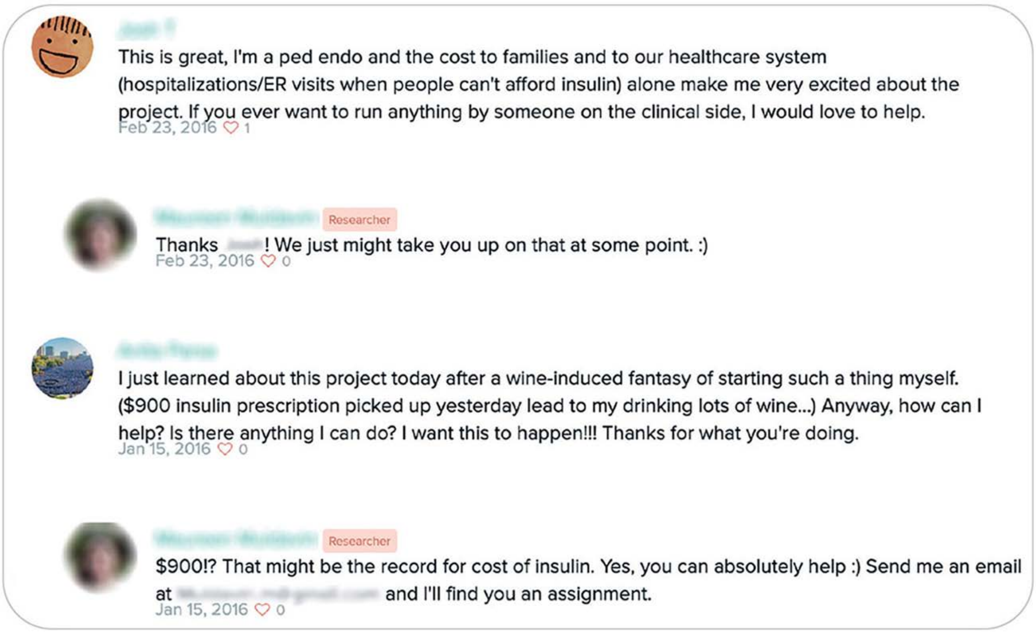
[7] https://experiment.com/projects/target-based-drug-discovery-for-coronavirus-disease-2019.



Source: https://experiment.com/projects/open-insulin

Figure 5.3 Discussion on Open Insulin campaign on Experiment.com

this is the rationale of the *Fathom Fund* (who supported the *Moores Lab* project) when it interprets crowdfunding success as evidence of potential societal impact. Voting is even more explicit in *VitaDAO*, although votes in that case likely reflect various aspects such as expected project success, societal relevance, as well as expected financial profit. As noted in our discussion of crowd voting on research questions, however, outcomes should always be interpreted in light of the degree to which the voters are representative of the relevant population. In the particular context of crowdfunding, representativeness may be low because of the financial costs that are imposed on individuals who want to express their support for a project (Franzoni et al., 2024).

Given that the primary goal of this stage is to raise funding, it may seem of little relevance whether this funding comes from users, or in the form of many small versus a few large donations. Yet, organizers can still benefit from thinking about the crowd paradigm that is most likely to apply to their project – or decide explicitly which crowd paradigm they seek to leverage. First, different paradigms require different outreach strategies, as discussed in more detail in section 14.2 on recruiting. Second, crowdfunding mechanisms may also result in non-financial inputs that can be useful for other aspects of a project. Consider again the *Experiment.com* discussion shown in Figure 5.3, demonstrating that contributors also offer non-financial support such as their own time and effort or access to specialized clinical knowledge. Non-financial support has also been reported in other crowdfunding contexts (Agrawal et al., 2014; Vachelard et al., 2016). Of course, whether crowdfunding backers are able and willing to support projects with non-financial inputs depends, in part, on the underlying crowd paradigm and which crowd was recruited.

To conclude our discussion of potential benefits, we also consider the perspective of crowd members. By deciding which projects to fund, they have a considerable impact on the direction of science, especially if their decisions are amplified by other funding bodies such as the *Fathom Fund*. This may be particularly important for individuals who have an interest in specific problems (see also section 14.1 on motivation). Indeed, we find in Franzoni et al. (2024) that people who have a personal interest in the problem studied by a project are more likely to support this project with their own funding (as well as funding recommendations to agencies). In addition to influencing the path of research, participation in crowdfunding can also provide people with unique insights into research through videos and lab notes shared by investigators, or through personal interactions that unfold in discussion forums or during lab visits.

5.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Raising money from the crowd involves several challenges. Some of these apply to all stages of the research process, including the challenge of motivating and recruiting crowd members. We will discuss these challenges in Chapters 13–15. In the following, we focus on three challenges that are more specific to crowd involvement in raising funding.

Establishing trust. Researchers seeking crowdfunding need to do a particularly good job of establishing trust with the audience. This is, of course, relevant for other stages as well, but it may be most relevant for crowdfunding because backers have little opportunity to try out the project, like they could in other stages by getting involved for a short amount of time to see how things are going. Relatedly, backers' investment tends to come at one point in time, and often prior to the research being performed, increasing the uncertainty for them. As such, it is not surprising that most successful campaigns start with contributions from friends and family, who already have an established relationship with the researcher (Agrawal et al., 2014). Similarly, it is often essential to draw on existing social networks. Researchers who are not comfortable with activating their friends, family, or social networks should think twice about embarking on a crowdfunding campaign (Li & Pryer, 2014).

Conveying the importance of the research being done. Financial backers who do not otherwise participate in a project will not generate participation-related benefits such as satisfying their curiosity, intellectual challenge, or building social networks with other participants, which are important rewards for crowd members in other stages of the research process (see section 14.1). Thus, most successful crowdfunding projects tend to address well-recognized problems such as biodiversity and health, but also salient social issues such as fake news. Recent research confirms that societal impact is one of the key criteria that lay evaluators use to decide whether to support a crowdfunding campaign (Franzoni et al., 2024). It may be more difficult to raise crowdfunding for basic research that has no immediate applications. However, organizers can try to convey how their results may have real applications down the road, even if only in the longer term. For example, the *Gill Lab* project addressed quite fundamental questions about long-term climate change and ecosystem change in the Falkland Islands but explained how this can help protect penguins, marine mammals, and other species today (see Box 5.3).

BOX 5.3 CONVEYING THE IMPORTANCE OF RESEARCH

To protect penguins, marine mammals, and other species, we need to better understand how the islands have responded to past periods of rapid climate change. Funds raised through this campaign will help us take peat cores, to establish a climate and ecological history for the Falkland Islands spanning the last 20,000 years.

-*Gill Lab* crowdfunding pitch (Groff & Hamley, 2014).

Knowledge to evaluate proposals. There are concerns that crowd members without a scientific background do not have the knowledge and expertise to judge whether proposals are scientifically valid and feasible (Del Savio, 2017). Although we show in Franzoni et al. (2024) that crowd evaluators pay serious attention to scientific merit and team capabilities, we cannot tell how accurate they are in assessing these criteria. The common observation that social media activity has a big impact on crowdfunding success suggests that funding decisions may also reflect herding and social contagion rather than careful evaluation of projects. Relatedly, there are concerns that self-interested actors may try to influence public opinion on certain topics and shape crowdfunding outcomes to support biased research agendas or research with low scientific merit. There is little empirical evidence on the importance of such mechanisms in crowdfunding science. However, these concerns could be mitigated by hybrid systems that combine crowd evaluations with evaluations made by scientific experts. Recall that the *Fathom Fund* pre-screens projects based on scientific merit and feasibility using a panel of expert scientists. *Experiment.com* also does an internal check to ensure that projects fulfill minimum requirements regarding clarity and feasibility. In a recent initiative developed jointly with the FootPrint Coalition, *Experiment.com* has developed a new rapid grants program that gives professional science leads with domain expertise a budget they can allocate to crowdfunding campaigns, providing both financial support but also a signal of scientific merit to other potential backers.[8]

Our website www.sciencewithcrowds.org includes stage-specific templates of the 4Q Tool and Crowd Science Design Canvas. These templates will help you explore whether and how crowd involvement in fundraising might be helpful in your project. To see how these templates are used, check out the examples using fictional characters ("personas") in Chapters 4, 6, 7, and 9. The website also points to additional resources that can help with implementation questions such as which crowdfunding platform to use and what funding goal to set.

8 https://experiment.com/grants/scienceengine.

6. Developing methods and materials

Every research study uses some kind of method to develop and test a theory, or to investigate a phenomenon of interest. Different fields favor different methods, and the choice of method also depends on factors such as the research question, the resources available, the audience for the study, and, even researchers' philosophical perspectives (Creswell, 2021). One important method that is used across many fields is experimentation, where researchers manipulate one or more variables and observe the resulting changes in outcomes to test hypotheses and identify causal relationships. In observational research, scientists use various instruments such as telescopes or microscopes to track particular natural phenomena or simply observe and record behavior or other characteristics of people, animals, or plants. Other important methods include mathematical or computational modeling, comparative studies, content analysis, meta-analysis, surveys, and the case study approach.

In order to implement these methods, researchers typically have to develop or acquire specific materials (Stephan, 2012). In experimental research, for example, scientists need to develop treatments that manipulate the variables of interest (e.g., a funny video that changes the mood of a human subject, or a heating device that changes the temperature of a chemical substance) as well as approaches to measure changes in the outcomes of interest. To perform observational research, researchers need to identify relevant data sources such as biological samples, rocks, and historical diaries, but also digital resources such as online databases or MRI scans. Researchers performing surveys or interviews need to develop questionnaires or interview protocols. In other cases, researchers need tools or measurement devices such as sensors, spectrometers, sound recorders, petri dishes, or shovels and brushes, but also computer programs and scripts for data analysis, modeling, or simulations.

Choosing or developing the right methods and materials is important in order to increase the quality of research findings. Not surprisingly, funders, peer reviewers, and readers often look at a study's methods when forming judgments about the validity and reliability of the results (Franzoni et al., 2024; Lamont, 2009). Strong methods can, thus, increase both the scientific and the societal impact of a study. Can crowds help in developing better methods and materials? Let us look at some examples.

6.1 EXAMPLES

Open Research Behind Closed Doors. The goal of this project, initiated by the Austrian Ludwig Boltzmann Institute of Human Rights, was to study the impact of COVID-19 measures on persons with psychosocial and intellectual disabilities who were detained in closed institutions as a result of their criminal behavior or exemption from criminal responsibility. A major challenge in conducting this kind of research is the lack of data and access for researchers to relevant institutions and vulnerable groups.[1] In order to collect and analyze valid and reliable data despite these difficulties, the researchers in this project involved a crowd of "experts by experience" to co-design the project methodology in online co-creation workshops and via interviews.[2] These crowd members included persons deprived of liberty with psychosocial and intellectual disabilities, their relatives, as well as people closely working with them such as lawyers or representatives of extramural care facilities. The outcomes of this study informed a set of recommendations concerning COVID-19 regulations as well as measures to better address future pandemics in closed institutions.

In the *TARGet Kids! Parent and Clinician Team (PACT)*, researchers from the Applied Research Group for Kids in Canada[3] involve a small crowd of parents as co-researchers in designing new clinical trials embedded in their cohort study.[4] These parents co-create family-centered interventions for keeping children healthy, develop recruitment and consent processes that are minimally burdensome, and produce study recruitment scripts that are easy to understand (see Box 6.1).

BOX 6.1 CROWD INVOLVEMENT IN *PACT*

PACT members are engaged in shaping the design of new clinical trials, including creating minimally burdensome recruitment and consent processes and shaping family-centred interventions for promoting healthy weights in children. Parents have been instrumental in creating verbal study recruitment scripts, shortened consent forms and family-facing study materials.

-Vanderhout et al. (2021).

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1 https://gmr.lbg.ac.at/wp-content/uploads/sites/12/2021/10/factsheet_en_final.pdf.

2 https://gmr.lbg.ac.at/open-research-behind-closed-doors-assessing-the-impact-of-covid-19-measures-on-persons-with-psychosocial-and-intellectual-disabilities-deprived-of-liberty/?lang=en.

3 https://www.targetkids.ca.

4 https://researchinvolvement.biomedcentral.com/articles/10.1186/s40900-021-00293-y.

As part of the *PACT*, parents also contribute to all other stages of the research process, ranging from the development of the research questions to knowledge translation. The first *PACT* project was the *Parent Trial*. In this project, parents were involved in developing a randomized control trial to prevent obesity in young children with increased risk factors. They were recruited through an open call for participation distributed in *TARGet Kids!* primary care practices and via a website and mailing lists. Interested and eligible parents (they had to have a child between 12 months and six years old as well as access to a computer and the internet) who provided informed consent received background information and training and were then invited to join an online co-creation workshop. The workshop generated important insights on barriers and facilitators regarding the *Parent Trial* and created solutions to improve and adapt the trial design with respect to recruitment, engagement, and the actual intervention.[5] Participants received small honoraria in the form of gift cards that depended on their level of engagement and that they could also donate to *TARGet Kids!*.[6]

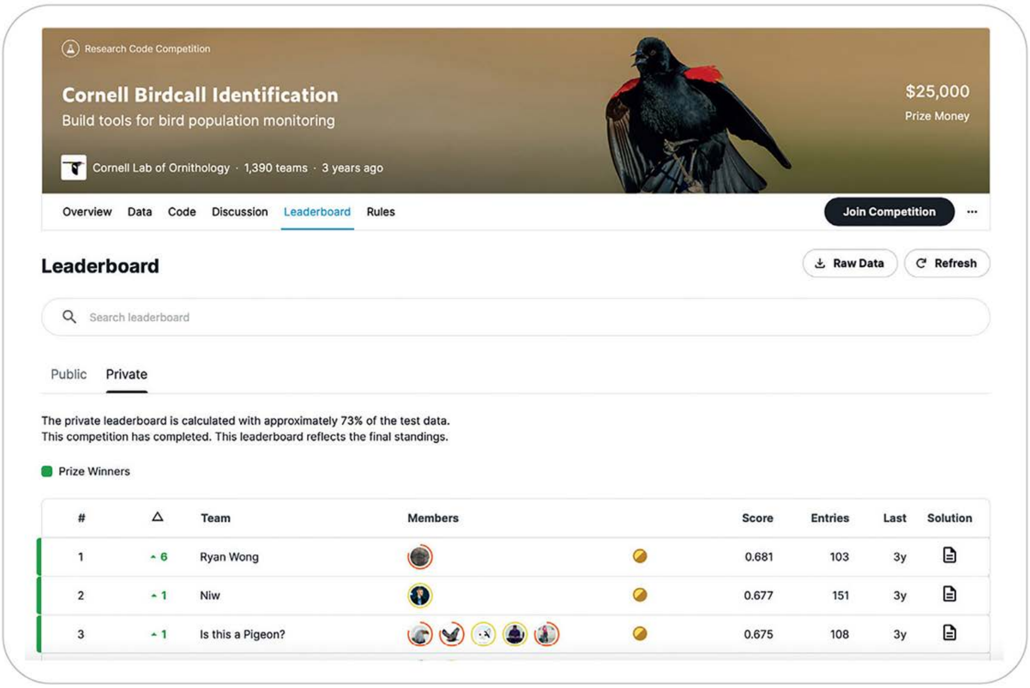
In the *Cornell Birdcall Identification* project, the Cornell Lab of Ornithology involved a crowd of data scientists to build tools for bird population monitoring. Since it is often easier to hear birds than to see them, the aim of this project was to develop machine listening algorithms that can accurately identify and classify bird vocalizations in complex soundscape recordings. The resulting data would then help researchers make inferences about an area's quality of life based on a changing bird population, including habitat quality, levels of pollution, and the effectiveness of restoration efforts. There were already projects underway to monitor bird populations by recording natural soundscapes, creating large, crowdsourced databases of recordings. However, the analysis of these recordings typically had to be done manually by domain experts, making it slow, incomplete, and costly. Automation using AI available at that time also proved difficult for long recordings, especially if multiple species were calling at the same time.[7] The project organizers involved a crowd to generate better algorithms by running a contest on the platform Kaggle. Participants received access to relevant sound recording databases; data access and use were governed by the Attribution-NonCommercial-ShareAlike license.[8] The three best solutions received a total of 25,000 USD in prizes (see Figure 6.1). The winners licensed their winning submissions and the underlying source code under an Open Source Initiative-approved license.

[5] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8130403/.

[6] https://www.targetkids.ca/_files/ugd/e40cf1_07d9d1a0aff441fb8bf79843ead5d364.pdf.

[7] https://www.kaggle.com/competitions/birdsong-recognition/overview.

[8] https://www.kaggle.com/competitions/birdsong-recognition/rules.



Source: https://www.kaggle.com/competitions/birdsong-recognition/leaderboard.

Figure 6.1 Leaderboard of the Cornell Birdcall Identification project

Table 6.1 summarizes the crowd involvement in developing materials and methods in our example projects. The projects leverage different types of crowd knowledge, ranging from experiential knowledge as a result of being affected by a certain condition or taking care of someone who is (e.g., *TARGet Kids! PACT* projects) to field-specific knowledge (e.g., related to algorithm development in the *Cornell Birdcall Identification* project). Resources required for participation ranged from having access to a computer and the internet to means to participate in physical co-creation meetings. The co-design approach in the *TARGet Kids! PACT* and *Open Research Behind Closed Doors* projects involved extensive crowd contributions to decision-making: Crowd members generated decision options (e.g., different interventions for preventing obesity in young children) and co-decided which of these options would be implemented. In the *Cornell Birdcall Identification* contest, crowd members generated different decision options (i.e., algorithms to analyze complex soundscape recordings), but they were not involved in selecting the best submissions.

Figure 6.2 shows our assessment of the most relevant Crowd Science Paradigms – helping us understand why exactly scientists benefited from involving crowds in this stage of the research process. We discuss this in more detail in the next section.

Table 6.1 AKRD Crowd Contributions for example projects (stage: developing methods and materials)

	Open Research Behind Closed Doors	TARGet Kids! PACT	Cornell Birdcall Identification
Activities	Co-design the project methodology	Co-design clinical trials	Develop tools to detect and classify complex soundscape recordings
Knowledge	Experiential knowledge as those affected, relatives or professional caregivers	Experiential knowledge as parents	Knowledge and skills related to data science, coding and the use of automated machine learning tools
Resources	Computer; telephone and/or internet connection	Computer and internet connection; transportation to co-creation meetings in the hospital; potentially childcare services during the co-creation meetings	Computer and internet connection; specific software tools
Decisions	Generate decision options; evaluate and select	Generate decision options; evaluate and select	Generate decision options

6.2 BENEFITS OF INVOLVING CROWDS IN DEVELOPING METHODS AND MATERIALS

The five Crowd Science Paradigms help us understand the potential benefits of involving crowd members in developing materials and methods.

The crowd volume paradigm seems less relevant for the cases we discussed in that the number of crowd members involved in co-designing materials and methods is usually a lot smaller than in other stages such as raising funding or collecting data. This partly reflects the interactive nature of co-creation processes and the required coordination. At the same time, the amount of effort required from individual crowd members tends to be very high: Participating in co-creation workshops, such as in the *TARGet Kids! PACT*, takes a lot of time. Developing new tools or methods is also often more time-consuming than what is required for a typical crowd contribution in data collection – note the number of different version entries individual crowd members came up with to develop a winning method in the *Cornell Birdcall Identification* project (Figure 6.1). Of course, this raises challenges in motivating crowd members to make larger investments of time (see Chapter 14).

The *Cornell Birdcall Identification* case also illustrates broadcast search. By broadcasting a methodological challenge to a large and diverse crowd of data scientists, the project was able to identify valuable outlier solutions for a novel research tool. To incentivize self-selection and effort to develop high-quality

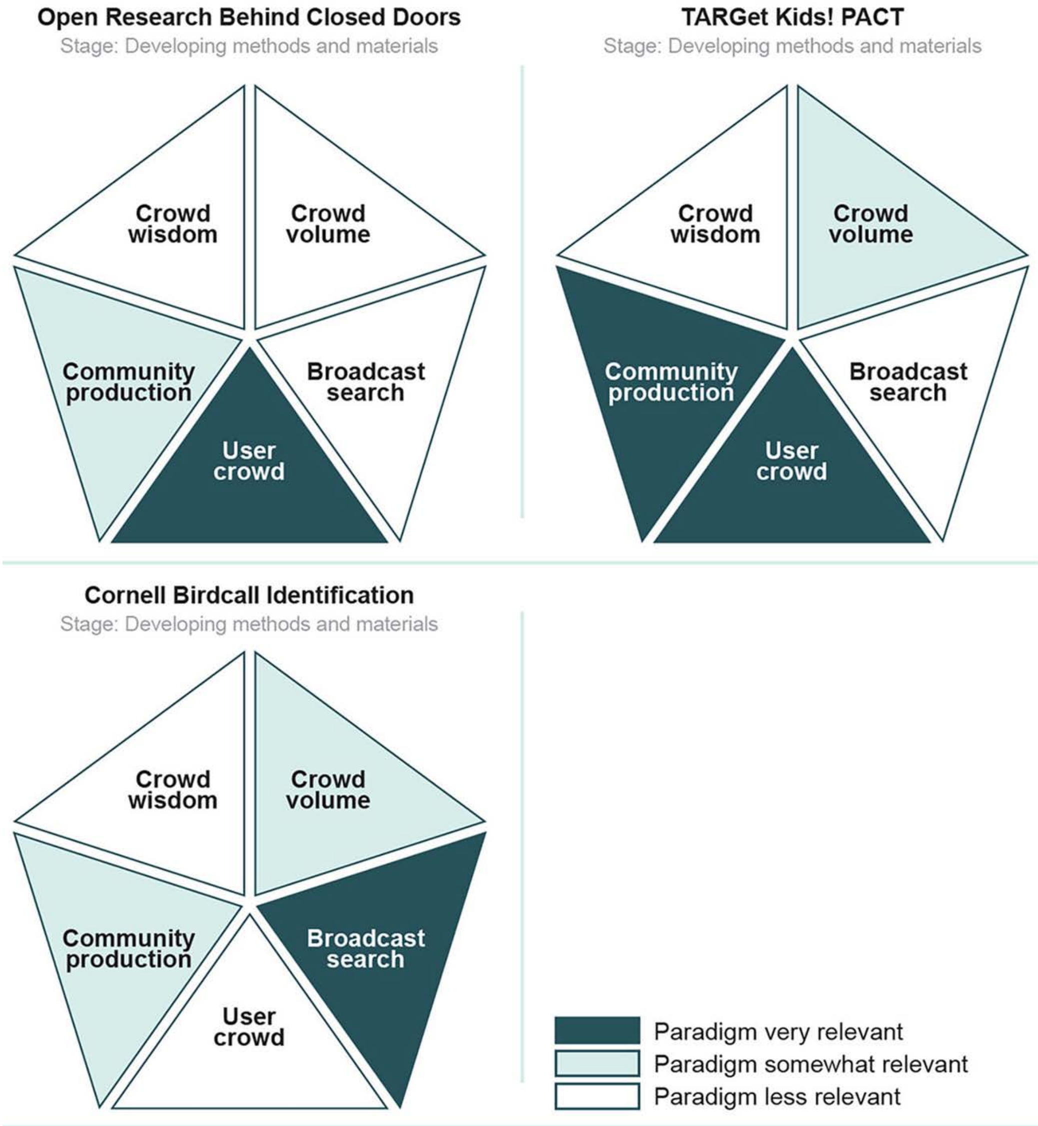


Figure 6.2 *Crowd Science Paradigm Diamonds for example projects (stage: developing methods and materials)*

solutions, many projects that seek to leverage broadcast search offer monetary prizes for the best solutions (Boudreau et al., 2011). Crowd members may also participate in challenges to develop new materials and methods for other reasons, such as learning, access to knowledge, gaining reputation, or participating and presenting their work at scientific conferences or expert workshops. In fact, many of the research competitions hosted on Kaggle offer only a small or even no monetary prize for the best solutions.[9]

The user crowd paradigm highlights that crowd members who are affected by a particular problem have access to local or experiential knowledge that professional scientists may lack (see Box 6.2). This paradigm is particularly relevant for *TARGet Kids! PACT* and *Open Research Behind Closed Doors*. As seen in these examples, experiential knowledge can inform better research designs, especially the development of more appropriate and feasible approaches to sampling and recruiting study participants. It also helps create healthcare interventions and data collection approaches that fit into family and healthcare routines, which can increase subjects' participation, minimize measurement errors, and improve overall resource efficiency. Particularly when the research involves humans, incorporating crowd members' experiential knowledge and preferences in the study design can also help prevent and address challenges with respect to privacy and data protection, as well as research ethics more generally. According to the logic of the user crowd paradigm, however, the crowd members who help to develop materials and methods should be representatives of those who participate in the main study (Hidalgo et al., 2021).

BOX 6.2 INVOLVING COMMUNITY MEMBERS IN DEVELOPING METHODS AND MATERIALS

Early engagement with individuals and community members that are the target group of a crowd science project can provide insights to challenges that will emerge in the project, questions and issues that need clarifying, and identifying mutual benefits from the project to community members. It can also help to ensure that design for data quality is done from the start. On the other hand, the researcher needs to be open about the amount of change that is possible and the constraints under which the project is taking place.

-Muki Haklay, Professor of Geographical Information Science and co-director of Extreme Citizen Science research group, personal communication.

The community production paradigm is also useful to understand the benefits of crowd involvement in several of the examples. *TARGet Kids! PACT*, for example, uses an interactive co-creation process to integrate diverse

9 https://www.kaggle.com/competitions?hostSegmentIdFilter=2.

experiential knowledge related to the problem context held by crowd members with professional scientists' knowledge concerning scientific research methods in a particular field. This enables projects to develop research designs that follow rigorous scientific standards while also being feasible and resulting in reliable data collection. In the *Cornell Bird Identification* challenge, crowd members competed individually, but they could also cooperate via the platform's forum by sharing initial ideas with others and receiving feedback. Interestingly, this led to productive "coopetition": Crowd members cooperated in some aspects of their work while they also competed with each other to win the prize for the best solution (Grimpe et al., 2023).

The crowd wisdom paradigm seems less relevant because estimating facts or learning about the preferences of a broader population matters less for the development of methods and materials. Crowd wisdom could still be relevant, however, if those crowd members who participate in co-development efforts are not representative of the broader population. In some cases, it might be useful, for example, to ask a broader set of parents to vote on which co-created intervention should be applied in a clinical trial, or to ask a broader set of crowd members who plan to be engaged in data collection which tool they would find easiest to use.

6.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Several general challenges that are also important when involving crowds in developing materials and methods are discussed in Chapters 13–15. In this section, we focus on three challenges that are more specific to involving crowds in this stage of the research process.

Knowledge on prior research and scientific methods. Developing methods and materials for a research study requires considerable knowledge about scientific methods in general and about the materials and methods that are valid in a particular field. Most crowd members will lack such knowledge. One approach to deal with this challenge is to provide training. Members of the *PACT*, for example, receive training in the form of online Patient-Oriented Research Curriculum in Child Health modules followed by a group meeting with a guest patient engagement expert (Vanderhout et al., 2021). They also have access to various academic resources and training programs as well as to tutorials and videos provided on the *TARGet Kids!* website.

Another approach is to decompose and decontextualize complex tasks to reduce the need for prior knowledge. In the *Cornell Birdcall Identification* project, for example, participants did not have to understand current methods for bird monitoring but focused on a more narrow and abstract methodological challenge: Developing a software tool to detect and classify complex soundscape recordings. Although they used project-specific inputs (e.g., a database of sound recordings), the task was of a more general nature and could be performed without deep knowledge of the context. We will see similar examples in Chapter 9 when discussing how to overcome challenges related to lack of prior knowledge in the stage of problem-solving.

Managing expectations with respect to time requirements. A challenge that is particularly critical when crowd members are involved in co-creating methods is time. Developing high-quality methods often takes time and iterative processes to review new ideas against the state-of-the-art, pre-test materials and methods, and experiment with different alternatives. The *Patient Involvement in Oncology (PATIO)* project organized by the Austrian Ludwig Boltzmann Institute for Applied Diagnostics, for example, involves patients suffering from prostate cancer and their spouses in developing minimally invasive, personalized approaches to diagnosing prostate cancer and improving patients' quality of life.[10] Despite the benefits of crowd involvement in this project, tensions between the time and rigor needed for scientific research and the expectations, as well as the capacity of patients who are on average 70 years old, continuously require dialogues to manage expectations (Beck et al., 2021). In addition to managing expectations, organizers can also try to develop opportunities for crowd members to get engaged at different levels of intensity (e.g., attending weekly meetings vs. giving input in a phone call).

Representativeness of participants. In some projects, a representative selection of participants is important to ensure that the methods that are developed "work" for the broader population that is relevant to a particular project. In the *TARGet Kids! PACT* project, for example, organizers recognized the need to involve a diverse group of crowd members in the co-development of methods and materials. This included ethnic minorities, households experiencing poverty, and fathers in addition to mothers. This representativeness is not ensured when, for example, certain groups of individuals cannot bear the (high) costs of participation or may have less interest in participating (see also Chapter 4). Organizers should think carefully about what kind of representation they need and develop mechanisms to engage those groups who may otherwise be less likely to contribute. In *TARGet Kids! PACT*, for example, the organizers initiated and facilitated fathers-only meetings and organized processes for mothers and fathers to take turns attending co-creation meetings (Vanderhout et al., 2021).

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[10] https://www.applied-diagnostics.at/patio/#initiative.

6.4 GETTING STARTED: DECIDING WHETHER AND HOW TO INVOLVE CROWDS IN DEVELOPING METHODS AND MATERIALS

The 4Q Tool and the Crowd Science Design Canvas help us think more concretely about opportunities to involve crowds in the development of methods and materials. Our fictional character for this chapter will be Linda – an accomplished medical scientist (Figure 6.3).

Figure 6.3 Persona for developing materials and methods (Linda)

6.4.1 Status Quo Analysis Using the 4Q Tool

We discussed the 4Q Tool at an abstract level in section 3.1, and the website www.sciencewithcrowds.org includes a template with guiding questions for the stage of developing methods and materials. Figure 6.4 shows the tool with Linda's condensed answers.

Quadrant 1: Audience and goals

Who is the audience for your research? E.g.,

- Scientific peers: Medium
- Funding agencies: High
- Policy makers: Medium
- The general public: Low
- "Users": High (people with SUD, caregivers)
- You yourself: Medium
- …

Why are you doing this research?
What are you trying to accomplish? E.g.,

- Curiosity/finding out new things: Medium
- Peer recognition and career advancement: Medium
- Financial income: Low
- Societal impact: High
- …

Quadrant 2: Current approach

How do you usually develop methods and materials for this research?

- We identify and select methods by:
  - Consulting peers who have used relevant methods and materials in the past
  - Review methods/materials used in publications on similar topics or the general methods literature
- We use existing tools provided by the university or available in the lab (e.g., survey software)
- Most obvious standard method we would use for this project: A survey using either a clinician-administered or a self-reported questionnaire among SUD patients in treatment, conducted in the clinical environment or via online tools

Quadrant 3: Pains

In light of your answers to Q1 and Q2:

What do you or your audience find "negative" about the methods and materials you usually use?

- Current methods do not reach a large and diverse population of people with SUD (especially those who are not patients in treatment). E.g., due to access issues, physical health conditions, cognitive impairments
- Low response rates to online surveys (due to jargon, lack of trust, privacy concerns, stigma and shame, …?)
- Typical surveys ask about what researchers have in mind – may miss what matters to people with SUD (especially those who do not show up in the hospital)
- Not clear that responses are reliable, especially responses from people with severe SUD

What do you or your audience find "negative" about the process you usually use for developing methods and materials?

- Lots of time spent on developing a full survey just to see that it fails in pre-tests
- Costly to go back and change things
- We seem to be re-using the same old approaches – need ideas on better ways to learn about preferences, needs, and substance use patterns

Quadrant 4: Gains

In light of your answers to Q1 and Q2:

What do you or your audience expect or are positively surprised by with respect to the methods and materials you usually use?

- Data come from a large and representative sample – people with diverse backgrounds can participate
- High response rate, few drop-outs
- Respondents give reliable answers – survey questions are easy to understand and answer; little room for error and (mis)interpretation
- In general: Methods have been validated, deliver reliable results, are well documented and replicable

What do you or your audience expect or are positively surprised by with respect to the process you usually use for developing methods and materials?

- The process stimulates thinking about the project goals, the audience, and the general set-up

Note: Linda's condensed answers in green; colour in online version.

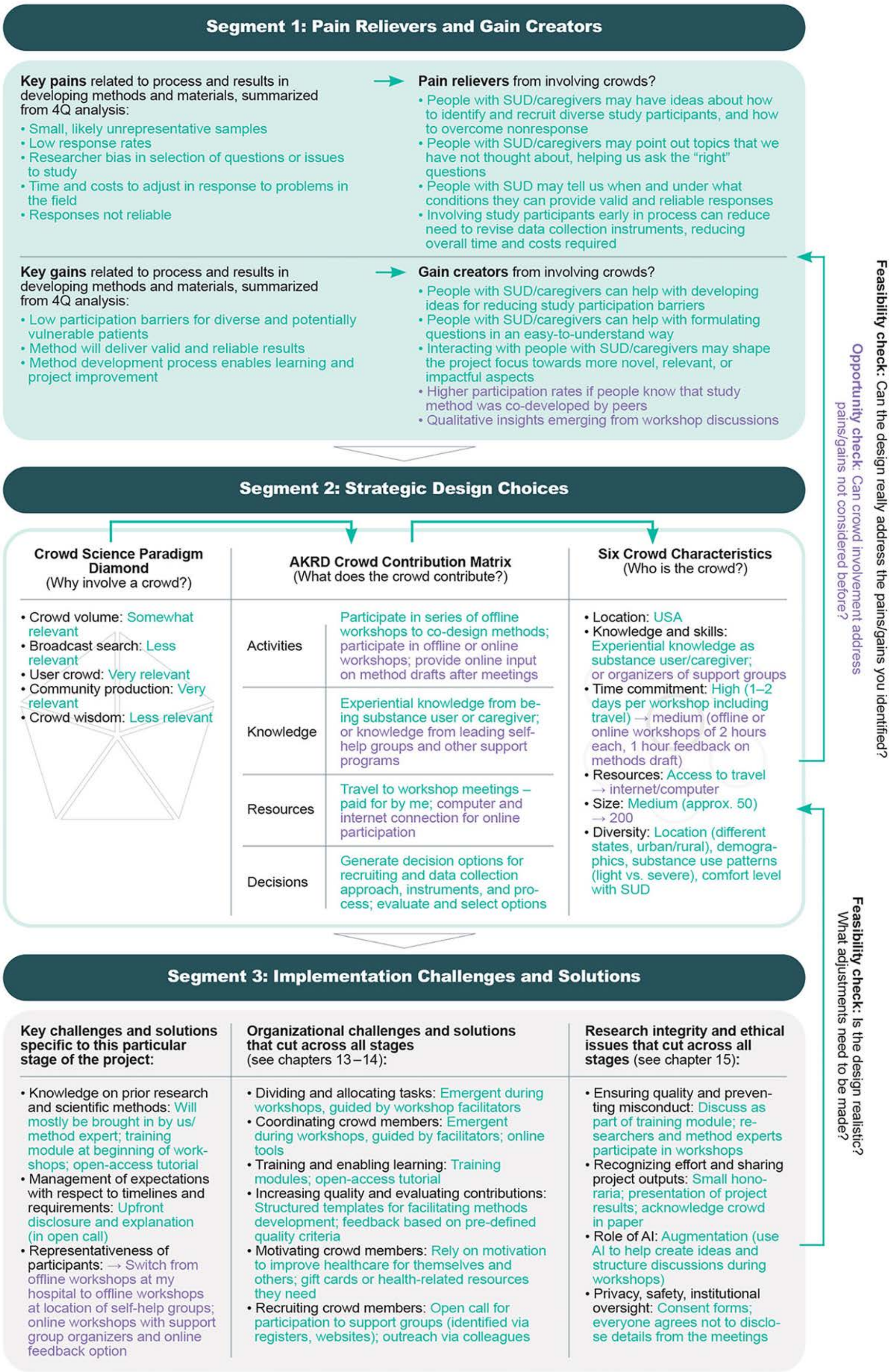
Figure 6.4 4Q Tool to analyze status quo with respect to developing methods and materials

6.4.2 Developing a Project Using the Crowd Science Design Canvas

Figure 6.5 shows the Crowd Science Design Canvas with Linda's entries (in green; revisions in purple; colour in online version). **Segment 1** summarizes the pains and gains resulting from Linda's 4Q analysis. The main problem Linda sees is that the conventional methods to get data on preferences, behaviors, and constraints related to digital technology use and substance use patterns in people with SUD give incomplete, biased, and potentially unreliable data. As Linda is thinking about how to involve crowds, she focuses on the possibility of involving people with SUD and their caregivers to help her design more effective data collection methods. She writes down initial ideas on potential pain relievers and gain creators from crowd involvement, which she will continuously adapt while working on segment 2.

Segment 2 guides Linda through different strategic choices. When thinking about Crowd Science Paradigms, she concludes that the user crowd aspect is indeed the key one for her: The (potential) users of digital SUD treatments and the respondents to her study are people with SUD as well as their caregivers, and she wants to access their unique experiences and understanding of the SUD problem. This experiential knowledge can help address several challenges with current methods, including how to reach more diverse study participants, how to lower barriers for participation, and how to develop questions that are clear and easy to answer. Perhaps most importantly, these groups can provide input on what questions she should ask in the first place – overcoming potential biases she may have harbored based on her own beliefs and experience with a very limited set of patients. But Linda does not think crowd members have recommendations ready to go – they may need to understand what she is trying to accomplish, what data collection tools are available, and what approaches are considered more scientifically rigorous than others. Similarly, Linda may have to dig deeper to understand why crowd members raise particular issues. As such, the community production paradigm is useful because it highlights the benefits of close collaboration between her team and crowd members. Linda does not think she needs a very large crowd – but the crowd volume paradigm still reminds her that she has to ask each contributor for a considerable amount of time to engage in a collaborative approach. She does not think that the crowd wisdom or broadcast search paradigms are relevant in her case.

The AKRD part of the Canvas leads Linda to think about what exactly crowd members should contribute. Given the importance of community production, she plans to organize co-creation workshops that bring together diverse crowd members and her team to discuss how to best collect valid and reliable data for this study, including the overall data collection approach, specific data collection instruments, as well as participant recruitment, data protection, and



Note: Linda's condensed answers in green; revisions in purple; colour in online version.

Figure 6.5 Crowd Science Design Canvas for developing methods and materials ethical issues. As implied by the user crowd paradigm, a key contribution will be certain types of knowledge that Linda does not have – knowledge resulting from the personal experience of substance users and their caretakers. Contributors will need to make their way to the co-creation workshops, which requires transportation. She plans to involve crowd members extensively in decision-making; she hopes that they will provide decision options by suggesting relevant topics and questions for data collection, but also approaches for recruiting participants or increasing response rates. Additionally, she plans to let participants co-decide on the methods as part of the general discussion and perhaps even through voting.

The Canvas also asks Linda to think about the characteristics of her ideal crowd. In terms of geography, Linda would want to collect ideas from people who live in different areas of the country to make sure the methods they develop work beyond any particular context. But she will limit the project to US participants, given that many relevant factors such as existing support systems and access to healthcare solutions are different abroad. The user crowd paradigm tells her that she needs to target crowd members who have relevant experiential knowledge about SUD. This includes people with SUD as well as professionals or family members who take care of them. The time commitment for participants will be relatively high – at least five hours for the workshop, plus time to prepare and travel. Crowd members need to have access to transportation, although Linda will pay for that. The ideal size of the crowd is relatively small – to enable deep discussions, and also recognizing the high costs for each person involved. And, of course, her budget for coffee and cookies is limited!

When thinking about crowd diversity, Linda realizes that she needs to include the perspectives of people from different socio-economic backgrounds and geographical areas (different US states, but also cities vs. rural areas) because different groups will face different challenges with existing SUD treatments, different access to digital tools, etc. She also needs to be careful to include people with different degrees of severity of SUD. And perhaps most importantly, she should include not only people who are comfortable talking about their SUDs but also people who are not because these people may benefit the most from digital healthcare solutions that help them understand and manage their disease.

Segment 3 of the Canvas leads Linda to think about implementation challenges and solutions. A first challenge specific to this stage of the research process is that participants may lack knowledge about how to develop an appropriate data collection approach, or about the pros and cons of different options. She is not too worried about this since participants will work in collaboration with her team. Still, Linda plans to give a short training at the beginning of every session and to provide participants with a good open-access tutorial she has found. Not everyone will have the time or energy to read it, but she hopes that some are motivated enough to do so. Another stage-specific challenge is to manage expectations regarding the time required to participate. Linda plans to do this by explaining the workshop setup and time requirements clearly when inviting participants. But Linda gets stuck when thinking about the challenge of ensuring the representativeness of participants: She realized early on that she needs diverse participants, especially given that non-representative data are one of the key pains she had identified in her 4Q analysis. She is now worried that the offline workshop format will systematically deter important groups of people, including those who are unwilling or unable to travel, people who have anxiety, and those who are not comfortable speaking about their substance use with strangers. This feasibility check leads her to make two major adjustments to her plans: First, she will not make people come to her hospital, but she or her team members will travel to a few different locations to meet with self-help groups or other support programs to lower their barriers for participation. Second, she will conduct online co-creation workshops with organizers or facilitators (rather than participants) of a larger number of such groups. She hopes that these people can share the experiential knowledge they have gained from interacting with a broad range of people with SUD as well as potentially their own (past) experience with SUD. She will also ask them to provide additional asynchronous feedback on draft materials after the meetings, which will also allow her to incorporate the knowledge from those who may not be able to participate in the workshops. Linda adjusts the parts of the Canvas she has already worked on (purple in Figure 6.5; colour in online version) and now concentrates on this new hybrid approach, which will also allow her to involve a larger crowd.

The second part of segment 3 of the Canvas covers organizational challenges. With respect to task division and allocation, Linda will map out different aspects of methods development (e.g., data collection approach, data collection instrument, study sample, outreach strategy, data protection) and plan which ones should be covered in which workshop. Individual participants' roles will have to emerge during the workshop. Linda realizes that she may need a professional facilitator to help her manage the process. For online workshops, she will also use collaboration tools such as Google Docs to gather and synthesize inputs. She will also explore whether artificial intelligence can help facilitate idea generation, or aggregate and structure inputs from the crowd.

Linda realizes that the quality of the methods and materials that are developed needs to be seen from two different perspectives. One is that of her professional peers who will focus on scientific rigor. The other audience is potential study participants, who need to find the study approach interesting and easy enough to participate in. Linda assumes that the respondents' perspective is well-represented given the composition of the crowd. To draw attention to scientific standards, Linda will involve an expert in collecting data on preferences and behaviors of humans who can give input into discussions and point out potential challenges; she will also provide participants with templates they can use to focus on more specific aspects of the methods design. In evaluating and selecting crowd contributions, Linda will consider the pros and cons that came up in discussions and will also ask the methods expert to evaluate options that contributors come up with. Especially when it comes to choices related to the perspective of study participants (e.g., response options or participation incentives), she may ask crowd members to vote (that may be difficult in offline workshops but should be feasible in online workshops or asynchronously after the workshops).

Linda believes that crowd members will be motivated by their desire to improve healthcare for themselves or others. Organizers of support groups may also be interested because digital health solutions can eventually facilitate their work. Linda additionally plans to offer small honoraria in the form of gift cards for support group organizers and members of their groups. They might also need other health-related resources that she can help with. To recruit crowd members (primarily organizers of self-help groups), she plans to collect contact information from registers or websites such as www.aa.org and ask her colleagues to reach out to relevant groups they may know. Although this approach should yield much broader coverage than focusing only on healthcare professionals and their patients, she recognizes that it will still miss people who are not affiliated with self-help groups or similar organizations. She briefly considers broad calls for contributions on LinkedIn and other social media but realizes that this raises many new challenges and that focusing on self-help groups will be difficult enough to pull off.

The final part of segment 3 reminds Linda to think about research integrity and ethical issues. She will cover research integrity at the beginning of the workshops, along with the training on data collection methods. The more important concern is privacy: She will design easy-to-understand consent forms for all workshop participants and will ask everyone to keep discussions confidential. Given the sensitivity of privacy and related issues in the health context, she will discuss her plans with her Institutional Review Board (see Chapter 15). To give back to participants, Linda will hold an online presentation discussing results from their study. She will also acknowledge workshop participants in the resulting publications and will describe in the paper how the crowd helped develop methods and materials.

Feasibility and opportunity checks. Linda already recognized earlier that it would be hard to get a diverse set of people to show up in person – her main adjustment was to hold offline workshops in different support group locations and to add online workshops for support group organizers. Although traveling will be a strain on her time and budget, it will be feasible, and at least a few offline workshops would give her much richer insights and allow her to establish more trusting relationships with participants than virtual meetings alone.

In the final check, Linda discovers two opportunities to address additional pains and gains. First, she realizes that co-creating the data collection strategy and method may help her increase response rates – both because the approach will appear better in the eyes of potential study participants and because people may be more likely to participate if they know that the approach was co-developed by their peers. Moreover, the support group organizers and members who have participated in the workshops may themselves promote the study to people with SDU or their relatives. A second opportunity is that the co-creation workshops will not only result in higher quality materials for the study but the discussions will also already reveal some of the substantive knowledge she tries to capture in her research: Insights into challenges that people with SDU face, what barriers might exist to the use of digital health solutions, and what features of such solutions could improve their adoption and effectiveness. She adds these points as gain creators in her Canvas.

7. Collecting data

Although some research is purely theoretical, most projects have empirical components, involving the collection of data and the subsequent analysis of data using statistical or other kinds of methods. Data can be observational, e.g., when social scientists observe the behavior of firms in different markets, when virologists track the spread of a new virus, or when astronomers capture data from galaxies using powerful telescopes. Other data are generated through experiments, e.g., when psychologists vary the composition of teams to study how this changes collaboration patterns, when chemists vary the inputs into a chemical reaction, or when medical scientists assign patients into treatment and control conditions to evaluate the effectiveness of a new drug. Researchers may generate and collect such data themselves (primary data), or they may re-use existing data and historical records (secondary data).

Some data that are collected or re-used need to be processed and transformed before they are analyzed. For example, images may have to be tagged, handwritten texts transcribed, or results from experiments checked to remove invalid observations. The boundaries between data collection, data processing, and data analysis are sometimes fuzzy. In this section, we discuss data collection, although some of the examples we give may also involve data processing. We will focus on data processing and analysis in Chapter 8.

Crowds can be extremely helpful with data collection because of the effort it takes to collect large amounts of data or because certain types of data can be collected better by leveraging the diverse capabilities, resources, or locations of crowd members. Indeed, this stage is the one that has so far seen the greatest use of crowd science mechanisms (see Chapter 1) and features some of the most high-profile projects and platforms. Let us look at some examples.

7.1 EXAMPLES

Mosquito Alert. The goal of this Spanish project is to study, monitor, and fight the spread of invasive mosquitoes capable of transmitting diseases such as dengue, Zika, or West Nile fever. The monitoring is carried out by crowd members who report the sighting of one of the relevant species, such as tiger mosquito or the yellow fever mosquito, using the project's app, along with a photo and the location of the observation. Given the difficulty of identifying different species of mosquitoes, sightings are validated by expert entomologists using the submitted information. The resulting data set is used for research but also displayed on public maps that help citizens and public health managers respond to dangerous mosquito outbreaks.[1]

The project *Aurorasaurus* is a collaboration between researchers from various institutions including New Mexico universities, NASA, and Penn State University. The project tracks Northern Lights across the world.[2] One way for crowd members to contribute is to report aurora sightings using a submission form, along with relevant information such as the color of the aurora and the level of activity. Users in the same location can also respond to recent reports made by others in order to verify them and collect additional data about an aurora. A second important task for crowd members is to inspect tweets that are continuously scraped by the project and to verify whether these tweets refer to actual sightings of an aurora. Both types of contribution add to a data set of aurora sightings that is then used for research in areas such as space science and physics. The project also produces real-time public maps that show interested parties aurora activity as well as the view line beyond which auroras are likely visible.

The *Solar Hydrogen Activity research Kit (SHArK)* project at the University of Wyoming involves serious experimental work on the part of the crowd members.[3] The scientific goal of this project is to discover metal oxide semiconductors that can split water into hydrogen and oxygen using sunlight. Given that there are millions of candidate compounds, the organizers developed inexpensive kits using components such as LEGO blocks, inkjet printers, and laser pointers. These kits have been distributed to schools and other organizations, but they can also be purchased on the project website. Crowd members can use these kits to test different compounds and upload their results to the project's shared database. The first promising p-type semiconductor was discovered in this project by an undergraduate student at Gonzaga University who subsequently appeared as a co-author on the publication describing the finding (Rowley et al., 2014).

Plastic Detective. Environmental scientists in Poland study the transition from a linear to a circular economy where products and materials are re-used. To get better data on consumption behaviors, they ask crowd members to watch other people around them and report their use of single-use plastic.[4] For each person they observe, crowd members complete a survey that includes

1 http://www.mosquitoalert.com/en/project/what-is-mosquito-alert/.

2 http://blog.aurorasaurus.org/?page_id=1050.

3 https://www.uwyo.edu/parkinson/shark_project.html.

4 https://uj.maps.arcgis.com/home/item.html?id=f23d1d18f7e84b1cbea1c425dc3f823f.

questions about the person (e.g., gender, age, relationship to the observer) and whether the crowd member has observed the other person doing activities such as drinking water from a bottle, grocery shopping, ordering take-away food, or using razors. Crowd members are then also asked to report to what extent the other person has used single-use plastic vs. alternative materials in performing these activities.

Weaving Techniques. Historians at the Museum for Natural History in Vienna had a prehistoric golden treasure in their hands, consisting of several bundles of interestingly shaped golden thread. They suspected that these bundles were decorations on textiles that have since disintegrated and disappeared. To better understand how such textiles with gold decorations were produced, they invited crowd members to participate in a workshop at the museum (Grömer & Saunderson, 2023). Crowd members were asked to experiment with different weaving techniques that also included gold threads (Figure 7.1). The textile-and-gold structures the crowd members came up with were data points that could then be compared to the bundles found in the treasure. Similarities between the structures provided hints as to which particular weaving techniques may have been used 3,000 years ago.

Source: Naturhistorisches Museum Wien.

Figure 7.1 Crowd members experimenting with ancient weaving techniques

Table 7.1 summarizes the crowd involvement in these five projects using the AKRD Crowd Contribution Matrix. We see that the example projects require different types of knowledge, ranging from just general skills to more specialized knowledge required to identify which mosquitoes belong to the species that should be tracked. Projects also require different kinds of resources – many projects require computers or smartphones to report data, projects that ask for observational data also require contributors to be physically mobile, and the project asking crowd members to run experiments at home requires access to the necessary equipment. Crowd members in the projects can typically decide where to make observations and, in the case of *SHArK*, what compounds to test.

Table 7.1 AKRD Crowd Contributions for example projects (stage: data collection)

	Mosquito Alert	Aurora-saurus	SHArK	Plastic Detective	Weaving Techniques
Activities	Take photos of target species mosquitoes; upload photos and additional information	Report sightings of auroras; verify tweets that may contain information about auroras	Run experiment on metal oxide semi-conductors and upload data	Observe others' use of single-use plastic and report using online survey tool	Experiment with weaving techniques to produce different textile-and-gold structures
Knowledge	Knowledge to identify target species	General knowledge	Basic knowledge of chemistry to perform the experiment	General knowledge	Skills in weaving
Resources	Transportation to observation locations; smartphone	Transportation to observation locations; computer/smartphone	SHArK test kit; computer and internet connection	Smartphone or computer	Transportation to participate in workshop
Decisions	Generate options (observation location and timing); select options	Generate options (observation location and timing); select options	Generate options (potential compounds); select options	Generate options (who and where to observe); select options	Generate options (weaving techniques); select options

The five examples illustrate how projects can involve crowds to help with data collection. We detailed the crowd contributions in terms of AKRD. But what underlying mechanisms explain why and how scientists benefited from involving crowds? Figure 7.2 shows our assessment of the most relevant Crowd Science Paradigms in the example projects. We will explain this assessment when discussing the general benefits of involving crowds in data collection in the next section.

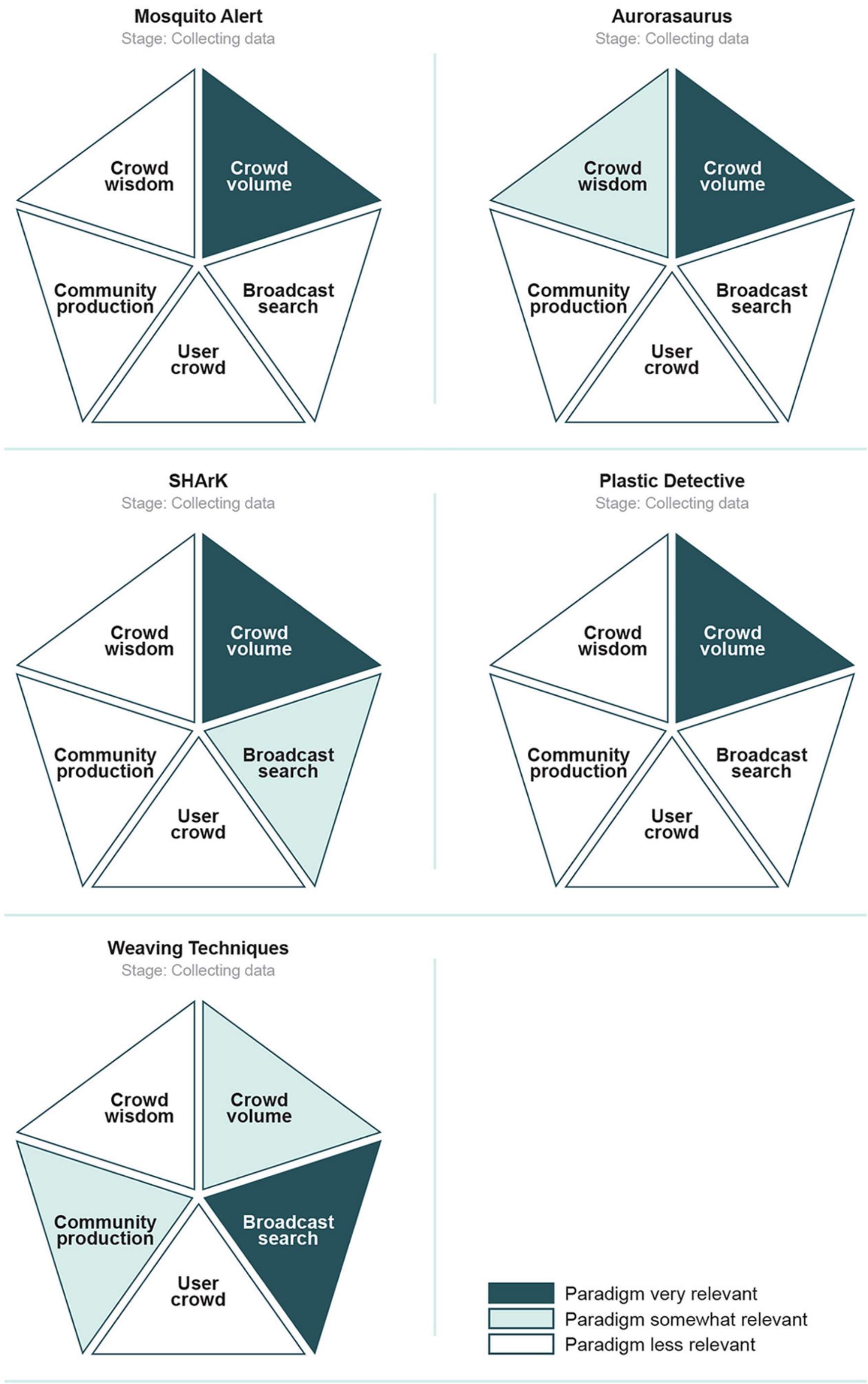


Figure 7.2 Crowd Science Paradigm Diamonds for example projects (stage: data collection)

7.2 BENEFITS OF INVOLVING CROWDS IN COLLECTING DATA

The widespread involvement of crowds in data collection reflects several advantages that play out particularly well in this stage of the research process.

Perhaps the most salient advantage is related to the crowd volume paradigm: Involving the crowd in data collection allows projects to cover a large geographical space and make observations more frequently than would be feasible for professional scientists alone. Consider again the project *Aurorasaurus*, which tracks auroras in different areas of the Earth and can dispatch observers relatively quickly to potential observation points. Or consider the project *eBird*, which every year crowdsources over 100 million bird observations across the globe, enabling it to generate extremely detailed and up-to-date data that can be used for research on topics such as biodiversity and climate change (Figure 7.3). Such effects of both scale and breadth of coverage can also materialize in virtual space: In the project *CSI-COP*, for example, a team of computer scientists and legal scholars asks participants to collect data on cookies and tracking technologies in apps on their personal devices.[5] In order to get comprehensive data on the tracking activities and GDPR compliance of a large number of organizations, the crowd in this project needs to be large but also diverse with respect to the use of different websites and apps.

The ability of crowds to collect large data sets that are comprehensive in both space and time has enabled significant progress in many fields, including the environmental sciences, biology, and astronomy (Poisson et al., 2020). Indeed, large crowd science projects such as *eBird* and *iNaturalist* are key contributors to the Global Biodiversity Information Facility, the official repository of data under the Convention on Biological Diversity.[6] Crowd science projects are particularly important in countries that have less developed national systems to collect scientific data (Ivanova & Shashkov, 2020).

The broadcast search paradigm can be relevant if researchers do not want to collect a large amount of data but rather some very specific data points that may be hard to get. Broadcast search might be very helpful, for example, to collect data on the population of white elephants.[7] Relatedly, broadcast search can help find crowd members who have rare knowledge or skills that are required to generate data. Consider again the project *Weaving Techniques*, where organizers broadcast the call for contributions widely to identify a relatively small number of crowd members who were able (and interested) to

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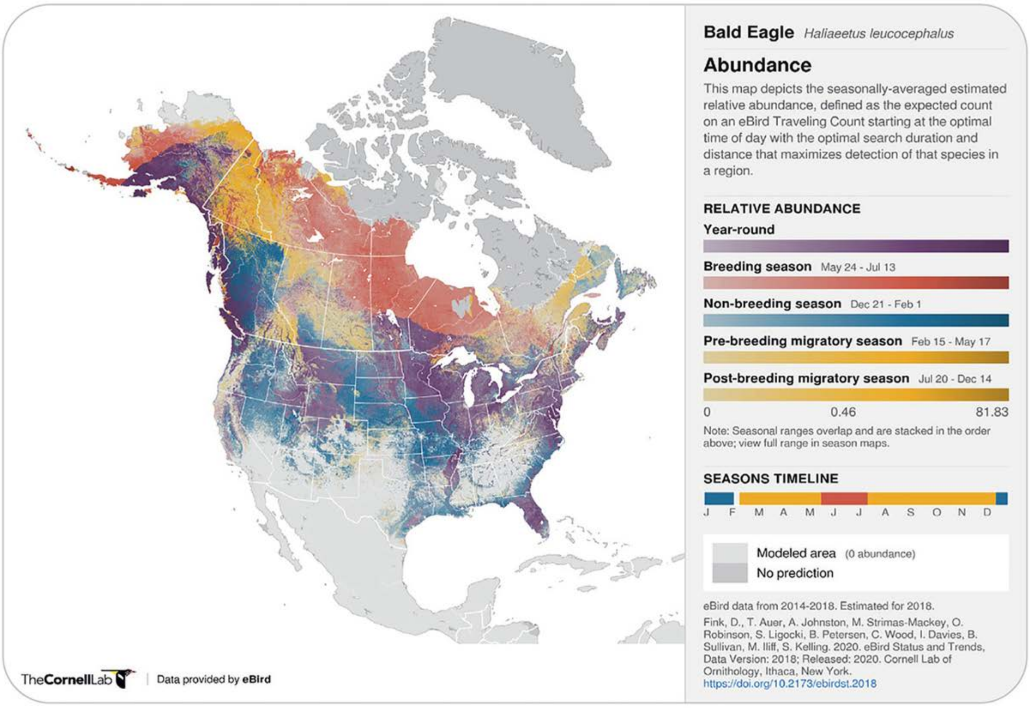
5 https://csi-cop.eu/about/.

6 https://support.ebird.org/en/support/solutions/articles/48001078113.

7 https://medium.com/exploring-the-world/the-white-elephant-a7d62eec3e96



Source: https://flyinglessons.us/2020/03/11/heres-a-springtime-gift-powerful-new-birding-tools-arrive-just-in-time-for-the-migration/.

Figure 7.3 Species map for Bald Eagle based on eBird data

participate in a workshop and experiment with different weaving techniques for gold threads. One participant, for example, was a specialist in fabrics used to decorate altars made in monasteries and therefore also very familiar with the use of gold threads. Data collection in the *SHArK* project also required physical experimentation, and broadcasting the call for contributions allowed the project to identify a few contributors who were smart or lucky enough to try particularly promising (outlier) compounds.

The user crowd paradigm highlights that involving crowds may be beneficial because it allows projects to access the relevant expertise of users such as patients or other affected parties. This paradigm seems less relevant in the examples discussed in the prior section. However, recall the *ExCiteS Kenya* project (Chapter 4), which involved members of the local community partly because these people had relevant knowledge that better enabled them to find and identify plants that needed observation, increasing the effectiveness and reliability of data collection. Relatedly, recruiting crowd members with relevant expertise may be the only viable way for researchers to get access to difficult-to-reach communities or settings. Consider the project *Profs-Chercheurs*, in which organizers at the Learning Planet Institute / University of Paris bring together teachers to study the value of different educational approaches in their classrooms. Interactions as part of the project enable educators to coordinate their experiments and to integrate observations to create a larger and more reliable data set on the impact of different educational approaches on students' learning outcomes.[8]

The community production paradigm is less relevant in data collection because crowd members typically operate independently from each other, with their individual contributions being pooled to form larger data sets. That being said, some elements of community production can be found in examples such as the *Weaving Techniques* project, where crowd members and organizers worked together in the same room, occasionally helping each other in performing experiments (i.e., weaving gold threads) and discussing the craft activities while live-microscoping the original archaeological artifact.

Many data collection efforts also benefit from the mechanisms highlighted by the crowd wisdom paradigm, namely that individual errors are canceled out as multiple crowd members make an estimate or an observation. In *eBird*, for example, some hotspot locations have multiple observers who may report slightly different observations, e.g., because they miss certain birds or because they are interested in some kinds of birds more than others. Similarly, multiple observers can report features of the same Northern Lights in *Aurorasaurus*. If a site has multiple observers and if observers' errors are not perfectly correlated, some of the errors will cancel out, resulting in more accurate data.

Taken together, involving crowds in data collection can help projects increase the size of data sets, the speed of data collection, and potentially even data quality. While the evidence is clear on scale and speed, the question of data quality remains debated – partly because quality depends on the particular kind of data that are generated and on the way in which crowd involvement is set up. We will return to these issues in the next section as well as in section 13.4 on cross-cutting challenges.

7.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Many of the challenges organizers face when involving crowds in data collection apply more generally across different stages of the research process (discussed in Chapters 13–15). Given this, we now focus on four challenges that are more specific to this particular stage.

8 https://www.profschercheurs.org/fr.

Resource requirements. The AKRD framework draws our attention to the resources that crowd members need in order to contribute, and data collection activities can be particularly prone to resource-related constraints. For example, some projects require access to transportation to travel to observation sites, as well as smartphones or other devices to record observations. Some projects also require participants to use specific tools and instruments such as camera traps for automated wildlife observation, jars to capture insects or water and air samples, Secchi disks to measure water transparency in oceans, robotic telescopes, excavation instruments, or devices to run chemical experiments (see *SHArK* project discussed above and Figure 7.4). Some of these tools are inexpensive, but others can cost thousands of dollars.[9] If contributors are expected to bear those costs on their own, this will severely limit not only the number of participants but also their diversity – with individuals from disadvantaged parts of society less likely to be able to afford participation. Some projects have tried to address this problem by coming up with low-cost tools and devices, often by creatively repurposing objects most people already have at home (e.g., LEGO blocks or kitchen utensils). Involving crowd members already in the design of methods and materials can help organizers identify such low-cost options (see Chapter 6). Other projects ask contributors to pay for the necessary tools and instruments but offer support for crowd members who are unable to do so (e.g., *SHArK*). Projects requiring the use of more expensive and specialized devices such as camera traps or GPS-enabled devices to record bat calls may also allow crowd members to rent such devices from organizers or through local libraries.[10]

Invasiveness of data collection. Some kinds of data collection may cause harm to landscapes, plants, animals, or even humans. For example, projects asking participants to visit fragile habitats may disturb local ecosystems, and projects asking participants to trap or tag animals may cause stress and physical damage to animals (Palmer et al., 2021). Some kinds of interactions with wildlife may be expressly forbidden by local laws, and some geographic areas may be under special environmental protection. But even activities that are not regulated may be problematic because of the power of the crowd in terms of numbers: While the sporadic removal of specimens may not be a problem, having many participants explore a particular area in search of certain types of plants or animals may lead to overcollection and the depletion of local populations, especially for less common species (Didham et al., 2020). Organizers should consider carefully how many data points they need to achieve research objectives and how data can be collected more efficiently to reduce negative

9 https://scistarter.org/panoptes.
10 https://scistarter.org/acoustic-bat-monitoring.

Source: http://www.secchidisk.org/.

Figure 7.4 *Instrument required to measure water transparency in the Secchi Disk project*

impacts (e.g., by asking participants to take pictures of insects rather than capture and kill them). Organizers should also develop training materials that help participants understand potential risks, and some projects have a "code of conduct" that clearly states which activities should be avoided.[11]

Data collection may also be invasive to humans or human communities. For example, crowd members who seek to collect observational data on others' leisure behaviors, consumption choices, or even sexual activity[12] may intrude upon privacy and create discomfort. Such concerns may be exacerbated if data are collected from vulnerable populations or communities (e.g., school children, indigenous communities). Project organizers should consult with affected individuals to discuss such concerns and what measures can be taken to minimize the invasiveness of data collection (see also Chapter 6 on involving crowds in developing methods and materials). Moreover, such risks (and benefits) of data collection with crowds should be discussed in the proposals that are submitted to Institutional Review Boards or other entities overseeing research on human subjects. Such proposals should also consider the risks that

[11] https://nestwatch.org/learn/how-to-nestwatch/code-of-conduct/.
[12] https://scistarter.org/kinsey-reporter.

crowd members themselves may face when helping collect data – be it physical harm (e.g., when observing animals in the wild, using dangerous tools) or psychological harm (e.g., recording roadkill or criminal behaviors). We will return to these issues in Chapter 15.

Expectations of openness. Projects that involve crowd members in data collection tend to share the resulting data using maps or other visualizations, and some disclose the full data sets. One potential reason is that crowd members – who give their personal time, effort, and other resources – see the data they produce as shared property that should not be kept secret (see Box 7.1).

BOX 7.1 ECSA PRINCIPLE #7

Principle #7: Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format. Data sharing may occur during or after the project, unless there are security or privacy concerns that prevent this.

-Ten Principles of Citizen Science (European Citizen Science Association, 2015).

Just as importantly, many crowd members have an intrinsic interest in the data they are collecting, e.g., they want to know where their favorite bird can be observed, if there is a mosquito threat in their area, or how clean the air is in their neighborhoods. Making data accessible is also likely to increase participation, which addresses a key challenge in making crowd science work (see Chapter 14). This means, however, that organizers need to think carefully about the infrastructure and tools they need to store, publish, or visualize data. Moreover, they should consider potential competitive implications, i.e., how comfortable they are if the data are also accessed by other researchers who may be working on similar research questions. In some cases, organizers balance different interests by disclosing aggregate data but keeping raw data private until their research using these data has been published. Other projects generate data that are so general that they can serve multiple scientific purposes, and competitive considerations are less relevant. Indeed, some large crowd science projects such as *eBird* are now recognized for advancing their fields by making large-scale data sets available to the broader research community. This recognition can be quite tangible – both in the form of citations but also in the form of large grants from agencies such as the NSF, the Sloan Foundation, or the European Union.

Data protection. Even though it is expected that data are eventually made public, some types of data may be sensitive and should not be shared publicly. For example, many projects in environmental monitoring do not disclose exact location data on observations of rare species in an effort to prevent poaching or other damage (Anhalt-Depies et al., 2019). Concerns about data protection are even more important when data are collected on humans, e.g., in the social and medical sciences. Organizers should minimize the amount of identifiable information that is collected by crowd participants and should develop appropriate data protection plans with their Institutional Review Boards or data protection units. Discussions of privacy and data protection, as well as research ethics more generally, should also be an explicit part of the onboarding of new crowd members to ensure that the respective measures are adhered to. And, of course, crowd members could even be involved in co-creating such plans, contributing their knowledge and values as individuals who are often quite similar to those who are being studied (Hidalgo et al., 2021).

With respect to both data collection and data protection, challenges can arise if crowd members are geographically dispersed: Projects that solicit data contributions from different parts of the world need to consider differences in the applicable legal and regulatory frameworks. Moreover, attention to cultural differences is important to anticipate potential harms that may arise from observations and data disclosure – behaviors and data that are innocuous in some regions may be highly controversial or even illegal in others.

7.4 GETTING STARTED: DECIDING WHETHER AND HOW TO INVOLVE CROWDS IN COLLECTING DATA

Let's use the 4Q Tool and the Crowd Science Design Canvas to think about involving crowds in data collection more concretely. This time, we will use the fictional character of Nari, a social scientist (Figure 7.5).

7.4.1 Status Quo Analysis Using the 4Q Tool

We discussed the 4Q Tool at an abstract level in section 3.1, and the website www.sciencewithcrowds.org includes a template with guiding questions for the stage of collecting data. Figure 7.6 shows the tool again, now with the answers from Nari.

7.4.2 Developing a Project Using the Crowd Science Design Canvas

Figure 7.7 shows the Crowd Science Design Canvas with Nari's entries (in green; revisions in purple; colour in online version). **Segment 1** summarizes the pains and gains resulting from her 4Q analysis. The primary issues here are the limited scale and coverage of existing data as well as the high costs and

PERSONA: **NARI**

Position: **Associate Professor in Innovation Studies**
Organization: **Business School, South Korea**

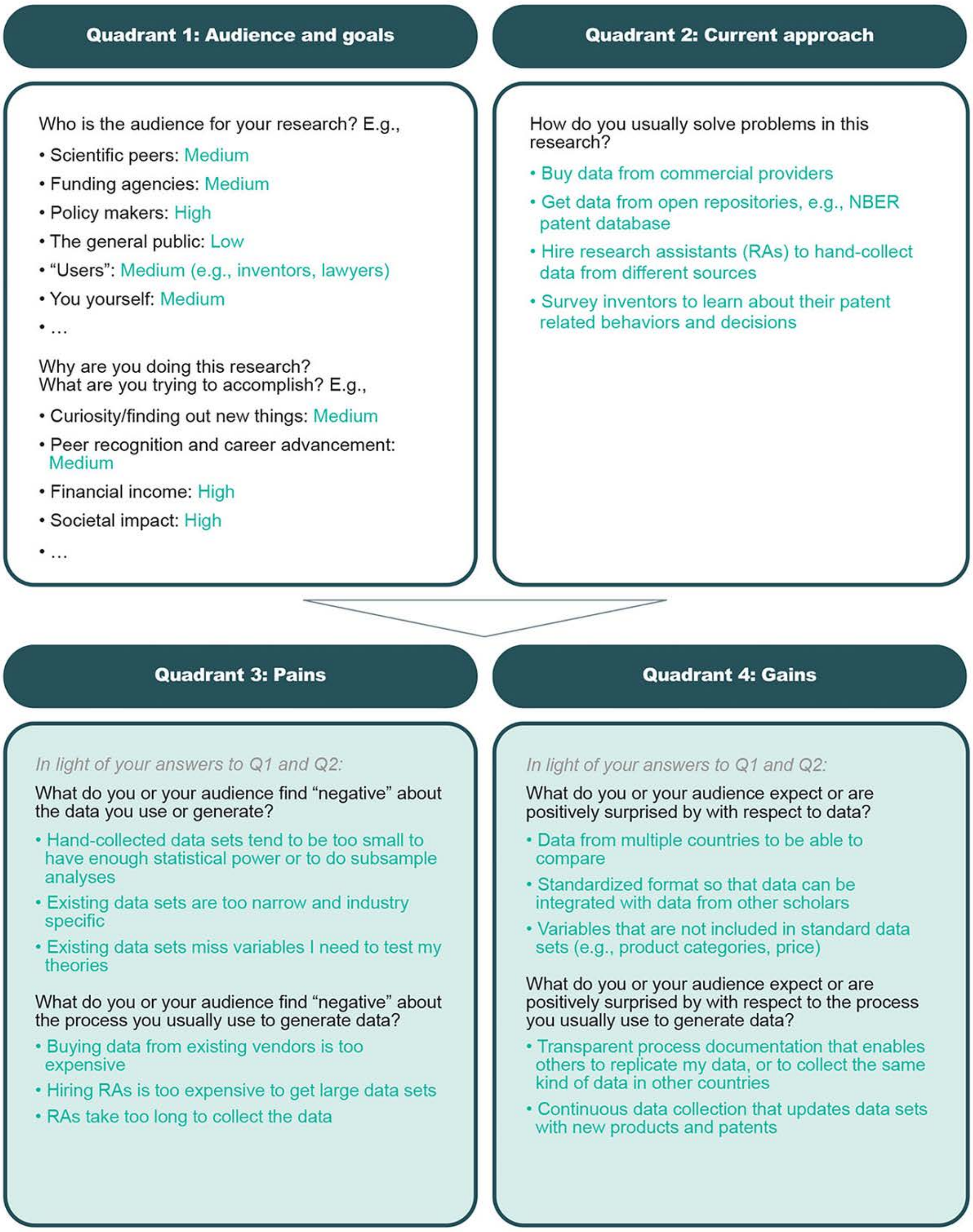
Background:
Nari studies intellectual property rights such as patents. Among others, she tries to understand the degree to which patents incentivize innovation by allowing innovators to appropriate financial returns vs. stifle innovation by preventing others from recombining ideas that are patented. This issue is a big open question in innovation research but also has important implications for science and innovation policies in different countries.

Nari's challenge:
She needs more and better data that tell her which commercialized products are protected by which specific patents. The currently available data are very limited in scope and size, and they are expensive – mostly coming from commercial data vendors who focus on specific industries such as pharmaceuticals. She could also hire research assistants to hand-collect data, but that would be expensive, take a lot of time, and they would likely miss large chunks of the product universe.

Figure 7.5 Persona for collecting data (Nari)

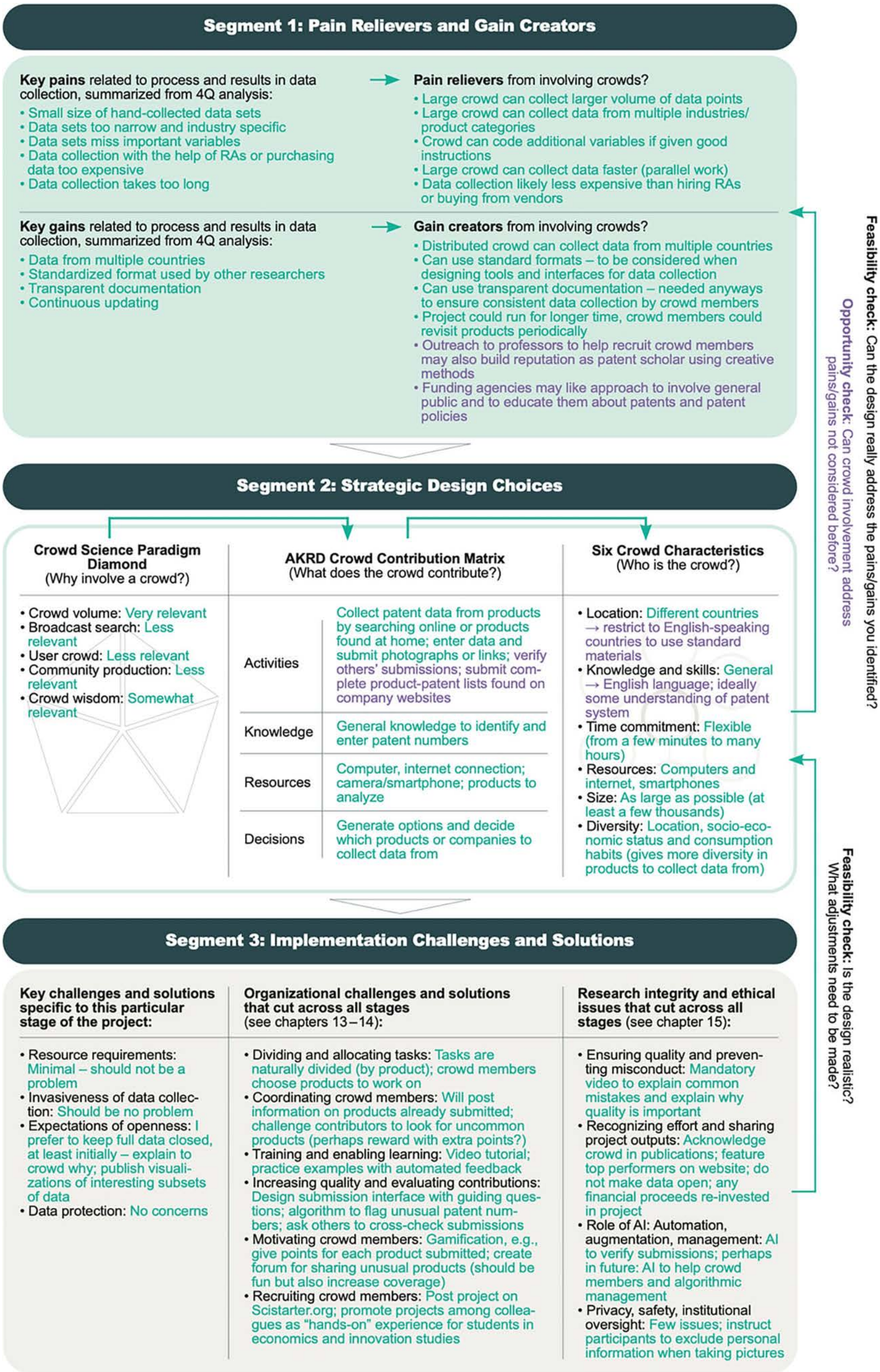
time required to collect or purchase data using conventional approaches. As Nari is thinking about how to involve crowds, she focuses on the possibility of asking people to help collect data on the patents that are behind different products they own or can find online. These data could be collected from the products themselves, such as electronic products that often list patents on the product itself. In other cases, patents are listed on product packaging, instruction manuals, or websites of manufacturers. Testing this approach by looking at products in her home, she was able to identify several product-patent links, and she found even more information online by looking up websites of products she used (Figure 7.8). She is writing down initial ideas on potential pain relievers and gain creators on the right side of segment 1. Nari then turns to segment 2 of the Canvas to figure out what this could really look like, cycling back to pain relievers and gain creators periodically.

Segment 2 guides Nari through different strategic choices. Thinking first about different Crowd Science Paradigms, Nari believes that the crowd volume paradigm will be most relevant: She needs data from a broad range of products and across a broad geographic space, and the more people participate, the broader and richer her data collection will be. Some elements of crowd wisdom may also be useful, e.g., if she gets data on the same products from multiple different people, to see whether the patents they identify overlap, or to overcome potential biases and errors that individual people may have. Nari believes that the the community production, broadcast search, and user crowd paradigms are less relevant.



Note: Nari's condensed answers in green; colour in online version.

Figure 7.6 4Q Tool to analyze status quo with respect to collecting data



Note: Nari's condensed answers in green; revisions in purple; colour in online version.

Figure 7.7 Crowd Science Design Canvas for data collection

Source: The authors.

Figure 7.8 Patent marking on a receiver

The next step is to think about what exactly crowd members should contribute (AKRD). Nari thinks that crowd members could use a web interface or even an app, similar to those employed by crowd science projects asking participants to collect biodiversity data. Participants could use entry fields to specify the product and producing company, pick product classifications from a dropdown list, and then enter relevant patent numbers found on the product or accompanying documentation. To allow verification, contributors should also upload a picture or supply a link to relevant product sheets. There is no special knowledge required, although Nari realizes she needs to train people to understand what patent numbers look like or how to classify products – she thinks she can design a simple training video to get them up to speed. In terms of resources, contributors will need a computer and perhaps a smartphone to use the app version and to take pictures. Participation in this project will be easier if people have products at home from which they can collect data. But people could also just look up products that they do not own online and enter the relevant data. Finally, crowd members could decide which products they want to look at, but they should then enter all the data requested on the entry sheet to ensure the data are complete. Nari does not really see any other major decisions in the data collection stage.

Nari thinks that her ideal crowd would consist of members of the public who either own various products or can look them up online. Given that broad international coverage would be a major gain, crowd members should be located in different countries. The time commitment does not have to be high – a few minutes should be enough to enter data from one or two products, but ideally crowd members stick around longer to become faster and perhaps also to learn where to find patent numbers and to be more systematic in data collection. Crowd members need access to the internet and computers or smartphones. The ideal size of the crowd is large – the more, the better. Crowd diversity also matters because a more diverse crowd should cover a broader product space: This includes diversity in geographic location, but also with respect to other factors such as age, gender, and income levels. After all, Nari's research seeks to understand the role of patents generally, not only in products used by rich people or by people of a certain gender.

Segment 3 of the Canvas helps Nari to think about implementation challenges and solutions. Looking first at challenges specific to the stage of data collection, she determines that crowd members would need computers but no other specialized equipment such as measurement devices. The data collection will also not be invasive (unless people storm local stores to analyze products on the shelves – but Nari does not think her crowd contributors would be *that* motivated). Data protection should also not be an issue – the data are not about people, and all the data she is asking crowd members to collect are already public. The one thing that worries her is the openness of data: Although Nari understands that crowd members might want the data to be open, she also sees considerable commercial potential in the data – after all, the high costs of buying even narrow data sets in areas such as pharmaceuticals are one of the main reasons she is looking for an alternative approach. Nari is also afraid that other innovation researchers who get access prematurely may write the very papers she is planning to write. So, she plans to publish visualizations of data that would be particularly interesting to crowd contributors and release more complete data only with a time delay to give herself some lead-time advantage to write papers. She realizes that the lack of full data disclosure means she will have to come up with really good ideas on how to motivate crowd members to help her.

Nari does not see problems with task division or task allocation since everyone has the same task: Take a product, find out what patents are behind it, enter the data online, and upload an image or other kind of record of the raw data. But the one issue that may need some thought is making sure that not everyone is collecting data from the same popular products (iPhones?!). To ensure broad coverage, she plans to publish a map that shows different product categories and the number of products entered in each, encouraging people to look for less common categories. She may also post lists of "most wanted" products or categories to give people ideas about things that are less covered.

Helping with this project does not require special knowledge, but Nari knows that she needs to train people to perform the task accurately. She plans to create a short video tutorial as well as practice product sheets from which people are asked to extract data. She already knows what contributors can find in those sheets, allowing her to give them automated feedback.

Nari realizes that ensuring quality is not trivial. What if people try to cheat by submitting fake products that do not even exist? Or simply make errors when recording patent numbers? She hopes that cheating will be discouraged by the requirement to also submit images of the products or links to product sheets. Moreover, Nari may have to add a second task for crowd members: Checking others' submissions to verify the products. Nari hopes that knowing about this verification mechanism will deter people from submitting incorrect data. This mechanism also partly addresses another point listed in the Canvas: How to evaluate and select contributions. To further address that point, she is working with a PhD student to develop an algorithm that can flag unusual patent numbers and analyze data from multiple submitters of the same product to see if they agree.

Nari plans to recruit contributors through platforms such as *Scistarter* because she wants to reach a broad range of people in many different places. However, she also wants to target people who know something about patents and may find the topic more interesting: She will promote the project among students in her field. Indeed, a few professor colleagues suggested that they could use the project to help their students learn about the topic of intellectual property. Therefore, she plans to develop some additional background material about patents and then promote the project as an in-class exercise that faculty members worldwide can use to give students hands-on experience working with patents. And she could share some interesting aggregated data, such as which types of products are more likely to be patented or which kinds of firms are more likely to use patents. But what about "regular" people? Although Nari loves patents, she realizes that most people find this topic obscure. She thinks that gamification might work: She could give people points for each submitted product or product-patent link. Although collaboration is not really required to do this task, crowd members may also find it fun to compete in teams: Which team can find the most products or the most product-patent links? She may also add a forum where crowd members can share and discuss cool or unusual products to create more excitement and stimulate coverage of less common products.

The final part of segment 3 makes Nari think about research integrity and ethical issues. She decides to add a training video on common mistakes that crowd members have to watch before they can start. This needs to be short – nobody loves watching such videos. She will also acknowledge crowd members in published papers that use the data, but she does not think co-authorship of the crowd is appropriate. She will recognize the top contributors each week on the project website. She does not want to share the full data publicly, but she also thinks that the crowd would care less about this than in the case of biodiversity or environmental data. She has no idea yet how good the data will be – but if the data are valuable and external parties are interested and are willing to pay, then she would commit to re-invest all the proceeds into the project itself, e.g., by developing better user interfaces or AI that automates some of the tedious tasks for crowd members. Speaking of AI: Some sub-tasks can probably be automated at some point (e.g., reading numbers on a product image), but most sub-tasks will require human crowd members (e.g., taking pictures of physical products in their homes, searching for product-patent lists online). Nari will keep up to date with the AI literature to see how algorithmic capabilities develop and where they could be used in the project. She could also imagine using some algorithmic management (e.g., to motivate crowd members who lose interest), but there are no pre-packaged tools for that yet, so she decides to first see what management problems she encounters. Nari does not see problems with respect to privacy or safety of crowd members – the tasks are standard online activities, and she will not collect sensitive data. But she will add in the instructions that if crowd members take pictures of products they own, they should not include anything that would reveal their identity or personal background.

Feasibility and opportunity checks. Are Nari's plans realistic? She is optimistic, but by going through some tests, she realizes that the task is not as easy as she had thought: People may face difficulties when trying to find patents on product websites. Patent numbers are also written in different formats and sources often do not specify in which country the patent is registered. She will have to develop more detailed tutorials and user interfaces, but this will only be feasible in one language. So, as much as she would love to cover many countries, she scales down her plans to focus on English-speaking countries. Nari also adjusts her crowd and recruiting strategy: Ideally, her crowd members have some understanding of patents and the patience to dig deeper into particular cases. So, she will keep her general outreach strategy but will put more emphasis on recruiting students who study related subjects. On a positive note, the feasibility check also makes her realize that contributors do not always have to go from individual products to associated patents: Some companies publish full lists of all their patents and products. Nari would still need crowd members to find such lists, but they could just upload the lists and Nari could read them automatically using AI. So, she adjusts the task for the crowd to either submit product-patent pairs, to verify others' submissions, or to submit complete product-patent lists.

In the final opportunity check, Nari realizes that developing this project might allow her to strengthen her reputation as a patent scholar and to demonstrate her skills in novel research methods (crowd science as well as AI). She also suspects that funding agencies may like her approach to involve crowds because this may help educate the public about intellectual property rights and patent policies. She adds these potential gain creators to segment 1 of the Canvas.

8. Processing and analyzing data

Data often have to be processed before they can be analyzed. This processing may involve activities such as transcribing handwritten records into digital records, classifying observations into relevant categories, identifying outlier observations, or cleaning out invalid data points. The subsequent data analysis can use a broad range of qualitative or quantitative techniques designed to identify patterns in the data, study correlations, or formally test hypotheses using experimental data.

The boundaries between data processing and analysis can be blurry, which is why we cover both aspects in one chapter. In the current project landscape, crowd members seem to be more commonly involved in data processing and the analysis of individual data elements (e.g., images) than in the analysis of full data sets. Before we think about the potential benefits and challenges of involving crowds in these activities, let us look at some examples.

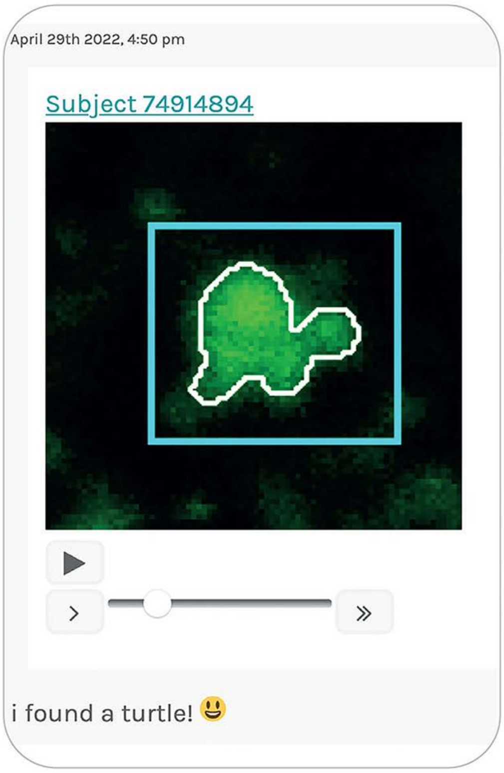
8.1 EXAMPLES

The UK/US-based project *Weather Rescue At Sea* seeks to extract climate data from the 1860s and 1870s from the logbooks of ships traveling through the Atlantic, Indian, and Pacific Ocean basins.[1] Following the standardization of logbook formats at an international maritime conference in 1854, the logbooks contain data points such as location, pressure, temperature, and windspeed. However, the tabular structure and the old handwriting make automatic transcription difficult. Thus, the project asks crowd members to transcribe the images manually. While working on this task, crowd members can also enjoy reading about unusual events on the ship that are recorded in separate sections of the logbook. Data from this project help create longer-term data series, allowing climate researchers to better understand climate change. They also help AI researchers improve algorithms for automatic transcription.

The Canadian project *Synaptic Protein Zoo* is building a database on synaptic proteins, which are molecules that control neurotransmitter release and

[1] https://www.zooniverse.org/projects/p-teleti/weather-rescue-at-sea/about/research.

reception.[2] Super-high-resolution microscopy provides images that can contain between 500 and 2,000 clusters of proteins that need to be differentiated from each other. This task can ultimately be done by AI, but humans are needed to generate a large amount of training data. As such, the project asks crowd members on the platform *Zooniverse* to help by drawing detailed outlines of visible clusters using a standard *Zooniverse* annotation tool (see Box 8.1). The emerging clusters can take all sorts of shapes – and crowd members can use the project's Talk discussion board to share particularly interesting pictures with each other (see Figure 8.1).



Source: https://www.zooniverse.org/projects/reber199/synaptic-protein-zoo/talk/4951/2427172.

Figure 8.1 Cluster identified in Synaptic Protein Zoo

2 https://www.zooniverse.org/projects/reber199/synaptic-protein-zoo/about/research.

BOX 8.1 CROWD INVOLVEMENT IN *SYNAPTIC PROTEIN ZOO*

By combining the human eye for pattern recognition with the energy for scientific discovery, I think Zooniverse participants can help us unlock the best segmentations of these neurons. I love this project because it allows one to look into the brain and to understand how it functions.

-Renée Hložek, Professor of Astronomy and Astrophysics and co-organizer of *Synaptic Protein Zoo*, quoted in Synaptic Protein Zoo (2024).

The project *Glyph* is led by a Max Planck Institute in Germany and seeks to describe the building blocks of the world's writing systems.[3] Doing so requires researchers to understand the visual properties of letters, which are composed of many different basic shapes such as circles, arches, or lines. Crowd participants are shown the letters of a particular script (e.g., the Latin alphabet) and asked to select all letters that share a common characteristic, such as top-to-bottom symmetry or the presence of a particular component shape. Importantly, these characteristics are not pre-defined by the organizers – contributors identify shared characteristics based on their own analysis of the letters presented to them. As such, crowd contributors help to both discover relevant classification criteria and analyze which letters (and scripts) share common properties. The results of this work help scientists to develop a classification system for scripts, predict letters that do not yet exist in a writing system, and understand how efficiently different scripts use their basic building blocks to create many letters while also ensuring that these letters are as distinct as possible.

NASA's project *Exoplanet Watch* asks crowd members to analyze telescope images and create light curves of exoplanets. These light curves allow researchers to better understand and describe planets outside our solar system. Crowd members can analyze images from their own telescopes or request data from robotic telescopes at partner institutions. They reduce the images using software tools provided by the project organizers and upload the completed light curves to the Exoplanet Database of the American Association of Variable Star Observers. Per the project's policy, all publications that use crowd members' light curves include these crowd members as co-authors.[4] Participants use a

3 https://glyph.shh.mpg.de/.
4 https://exoplanets.nasa.gov/exoplanet-watch/publications.

Slack channel to discuss their work, get help with problems, and share their passion for astronomy.

The *Epidemium ORL/IA* challenge focuses on studying human papillomavirus (HPV) -induced ear, nose, and throat (ENT) cancer. As discussed in section 4.1, crowd members participate by starting their own sub-projects or joining existing ones, and collaborate using the infrastructure of the *Epidemium* platform. The resulting teams then define the methods together, select the data they need to answer their research questions, and carry out the data analysis. To support this process, the platform organizers and challenge partners (or challenge owners) during Season 3 worked together to assemble and provide tabular and imagery data sets. This included microscopy image data of tumors and immune cells as well as clinical data on patient characteristics such as gender, age, tobacco consumption, or the therapeutic therapy implemented by doctors.[5] Crowd members analyze these data to better understand the relationship between the tumoral micro-environment and HPV quantity as well as the growth and spatial distribution of tumor cells, focusing on their sub-projects' specific research questions. Teams in the *Epidemium ORL/IA* sub-projects are relatively small, but many participants have specialist skills in areas such as data science and biology.[6] Facilitated by the platform, additional crowd members with complementary skills can join projects at any time during the process, including data analysis.

Table 8.1 summarizes crowd involvement in data processing and analysis in these example projects. We see that the projects require different types of knowledge, ranging from general skills to less common skills (e.g., reading old handwriting), to field-specific knowledge (e.g., astronomy and data science). The examples require only access to a computer, reflecting that the raw data collected by projects are processed in digital form. The main role of contributors in *Weather Rescue At Sea* and *Synaptic Protein Zoo* does not involve decisions (other than how to classify a particular image), although crowd members can decide whether to report interesting/unusual observations on the Talk discussion board. In *Glyph*, contributors can decide which of many possible shared characteristics of letters to focus on. Decision-making is most extensive in *Epidemium* projects as well as in *Exoplanet Watch,* where participants can decide which stars or exoplanets to investigate.

The five examples illustrate how projects can involve crowds to help process and analyze data. We also detailed the crowd contributions in terms of AKRD. But what underlying mechanisms explain why and how scientists benefited from involving crowds? Figure 8.2 shows our assessment of the most relevant Crowd Science Paradigms, and we will explain this assessment in the next section.

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5 http://epidemium.org.

6 http://epidemium.org.

Table 8.1 AKRD Crowd Contributions for example projects (stage: data processing and analysis)

	Weather Rescue At Sea	Synaptic Protein Zoo	Glyph	Exoplanet Watch	Epidemium ORL/IA
Activities	Transcribe weather data in ships' log-books from the 1860s and 1870s	Annotate super-high-resolution images of protein clusters	Identify commonalities between letters in different scripts	Reduce telescope images to create light curves of stars and exoplanets	Analyze the relationships between tumoral micro-environment and HPV quantity/ tumor cells
Knowledge	Skill in reading old handwriting	General skills	Visual skills to identify commonalities and differences between objects	Basic knowledge in astronomy, e.g., using coordinate systems	Specialist knowledge in data science, cancer, and other fields
Resources	Computer and internet connection	Computer and internet connection	Computer and internet connection	Computer and internet connection	Computer and internet connection; data analysis tools
Decisions	Select options (whether to highlight an observation in "Talk")	Select options (whether to highlight an observation in "Talk")	Generate options (characteristics to focus on); select options	Generate options (star or exoplanet to analyze); select options	Generate options (data, tools); select options

8.2 BENEFITS OF INVOLVING CROWDS IN DATA PROCESSING AND ANALYSIS

Projects involving crowd members in data processing are among the largest crowd science projects in existence – the platform *Zooniverse* alone now has a crowd of more than 2.7 million contributors.[7] The large scale of many projects suggests an important role of the crowd volume paradigm: A large number of contributors allows projects such as *Weather Rescue At Sea*, *Synaptic Protein Zoo*, or *Stall Catchers* to process large volumes of observations in a relatively short period of time (see Box 8.2). To make this benefit more tangible, we analyzed in a research study the number of contributors and the amount of time

[7] https://www.zooniverse.org/.

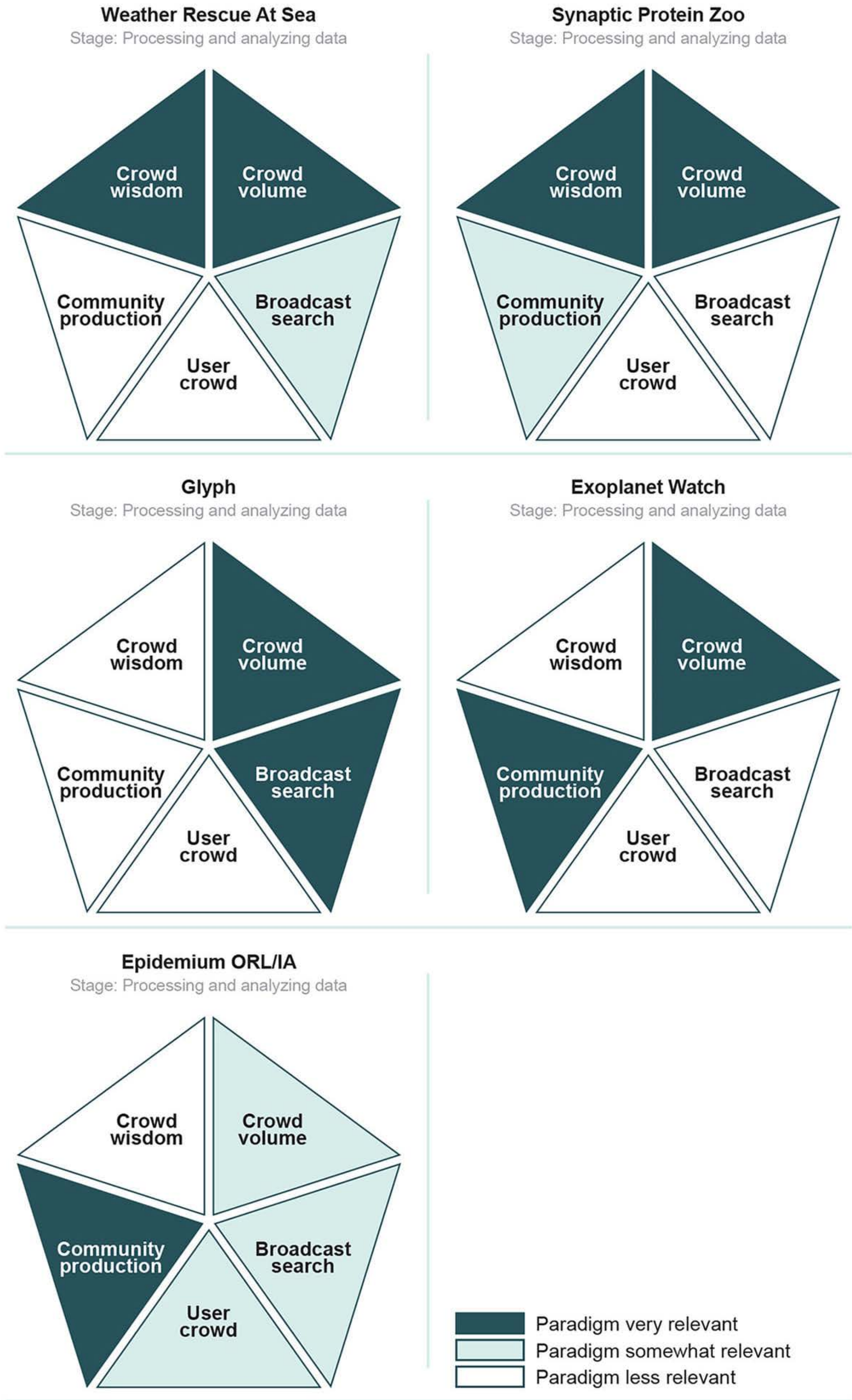

Figure 8.2 Crowd Science Paradigm Diamonds for example projects (stage: data processing and analysis)

contributed to seven early *Zooniverse* projects (Sauermann & Franzoni, 2015). We found that in the first 180 days alone, projects attracted tens of thousands of crowd members who contributed tens of thousands of hours of effort. Given that these contributions are generally unpaid, projects can perform large-scale research that may be impossible to finance when using paid research assistants or paid workers on platforms such as *Amazon Mechanical Turk*. We also found, however, that some projects generate a much larger volume of contributions than others – highlighting the need to actively recruit participants and to offer meaningful rewards that sustain crowd members' motivation (see Chapter 14).

BOX 8.2 CROWD INVOLVEMENT IN *STALL CATCHERS*

Working together, *Stall Catchers* can do in one hour what takes researchers one week in the lab! Anyone can do it!

-Quote from *Stall Catchers* website.

The example of *Epidemium ORL/IA* illustrates how broadcast search can allow projects to identify contributors who have specialized skills and knowledge, e.g., related to statistics and big data analysis. But some aspects of broadcast search are also visible in other examples we described, e.g., when *Weather Rescue At Sea* finds people who can read old handwriting or when *Glyph* finds people who are particularly good at seeing patterns in sequences of letters. Although we typically think of broadcast search with respect to skills, knowledge, or technical solutions (see section 2.4), the general idea of broadcast search can also apply to contributors' motives and interests: It may explain how some projects that tackle less popular topics find those crowd members who are willing to dedicate their time (see also Chapter 14). *Glyph* seems like a good example of self-selection based on interests.

The user crowd paradigm appears less relevant when it comes to processing large-scale data sets on objects such as galaxies or animals. Although such projects can require specialized skills and knowledge from contributors, this typically does not relate to a particular experience as users of research or as a party affected by particular problems. However, projects that involve crowds in the analysis of other types of data may also draw on relevant experiential knowledge. Consider *Epidemium* projects such as *ORL/IA*, which can benefit from the experience of patients or medical doctors when interpreting data or making sense of statistical relationships. *CurieuzeNeuzen* involved citizens in the collection of air quality data but also in the analysis and interpretation of the resulting data (see section 2.3). In the analysis part, residents' knowledge of the local conditions allowed them to verify results and to explain unexpected or deviant findings (Van Brussel & Huyse, 2018).

Projects that involve crowd members in more complex analysis tasks often enable discussions among crowd members, as well as between crowd members and professional scientists, pointing towards the importance of the community production paradigm. Interactions enable participants to share complementary knowledge and skills or to collectively make sense of what they see in the data. Such interactions are central to the success of *Epidemium* projects that bring together contributors with expertise in different areas such as health and data analytics. In *Exoplanet Watch*, participants also exchange ideas and observations with each other using a dedicated Slack channel. In *CurieuzeNeuzen*, discussions among participants and project leaders occurred during in-person project meetings and at public events. Even *Zooniverse* projects such as *Synaptic Protein Zoo* – which entail micro-tasks that are relatively simple to perform – have a Talk discussion forum that allows crowd members to ask for help, discuss interesting findings, or share strategies for better data analysis (see Figure 8.3). Indeed, some of the most well-known publications coming out of *Zooniverse* projects relate to the discovery of new astronomical objects that contributors found while processing images and that they then discussed on Talk pages (Cardamone et al., 2009; Lintott et al., 2009).

Data processing and analysis can also benefit from crowd wisdom. *Zooniverse* projects such as *Synaptic Protein Zoo* and *Weather Rescue At Sea*, for example, obtain multiple classifications for the same object from multiple crowd members. After multiple classifications have been made, the consensus points to the most accurate classification, even if individual crowd members make mistakes (Swanson et al., 2016; Willi et al., 2019) (see Box 8.3). As shown in a large body of research on crowd wisdom, this mechanism works best if individuals' errors are uncorrelated; it does not work well if crowd members share common biases and tend to make the same errors (Dickinson et al., 2010; Surowiecki, 2005). Shared errors are less likely if crowd members are diverse, suggesting a potential benefit not only from crowd size but also crowd diversity.

BOX 8.3 ERROR REDUCTION IN *WEATHER RESCUE AT SEA*

Question: I'm a new transcriber, what happens when I make errors, will it ruin the whole dataset?
Answer: Don't worry. We all make mistakes even the experienced transcribers do. With a bit of perseverance, handwriting will become clearer. Each image is classified by six different people. Once you and others classify all images, the research team will examine any disagreements in particular images. Then results will be run through a consensus step, to identify the "final version" of the data.

-Quote from *Weather Rescue At Sea* website.

January 17th 2019, 8:53 pm

Roughly the areas I've already covered in the legacysurvey viewer with 'high zoom level' is all of DES and most of SDSS + DECaLS + MzLS+BASS except;

- almost none of the SDSS 'arms' and arches sticking out of the main two SDSS globs
- the SDSS + DECaLS + MzLS+BASS area left of RA 245.8 of the main SDSS sky coverage. The sond biggest blob I've already done.

The actual trick to it lies in WISE images (IR)! Meaning using the W1-W2 and W3(dust) layer in th viewer. There is probably a sound scientific explanation for this, but for hunting Voorwerpjes it doesn't really matter so I simply assume hot dust (W3 filter) usually means things are 'stirred' and high W1-W2 often means an AGN (Seyfert), both good ingredients for a Voorwerp cocktail.

Why do I think this is a effective and efficient method? Firstly I found out that roughly 75% of all 'known' Voorwerpjes (+/- 30-ish) have these same characteristic colors in WISE images; a bright 'bubble' in the dust layer containing a distinct orange-brown AGN in the center (meaning high difference between WISE W1 and W2 filter).

Secondly I've already found quite some promising candidates using this method so I'm convinced this works, you can see them in the Voorwerpje thread.

Lastly using the WISE filters means you can search with an incredible zoom level which allows for processing of exceptionally large chunks of sky in a short amount of time. I've been using zoom level 10 to spot color cut candidates in WISE and then zoom in to check in optical. Also the Legacysurvey viewer allows for spacebar to flip between 2 layers and the keyboard arrows to more around; very very handy!

Below is an example to show how easy they are to spot; a bubble in the "WISE 12-micron dust map" layer at zoom level 10 and a distinct orange-brown core in the "unWISE W1/W2 NEO4" layer, and zooming in for optical at zoom level 16. Posting cutouts at zoom level 10 is quite useless so you'll just have to follow the link(s) to check and see.

http://legacysurvey.org/viewer?ra=15.2081&dec=-2.7014&zoom=10&layer=wssa
http://legacysurvey.org/viewer?ra=15.2068&dec=-2.7028&zoom=10&layer=unwise-neo4
http://legacysurvey.org/viewer?ra=15.2088&dec=-2.7052&zoom=16&layer=decals-dr7

Source: https://www.zooniverse.org/projects/zookeeper/galaxy-zoo/talk/1269/858076.

Figure 8.3 Galaxy Zoo contributor explaining strategy to find Vorweerps (a type of astronomical object) in Talk discussion forum

Although crowd wisdom is used routinely in classification tasks, it can also apply to other kinds of analyses. Consider a recent project that gave the same data set to different research groups, asking them to use the data to test the same two hypotheses regarding the effects of gender and professional status on verbosity during group meetings (Schweinsberg et al., 2021). The research groups performed different specific analyses and reported different results, including significant effects in the opposite direction for the same hypothesis.

These differences may have reflected errors by some teams, but more likely subjective choices that are inherent in many complex data analysis tasks (e.g., which variables to focus on, how to code measures, what variables to include in regressions). Having multiple investigators perform the same analysis may not necessarily yield a simple truth, but seeing the variability in results gives researchers a better sense of the strength of the conclusions that can be drawn from the data.

8.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Some challenges that apply to data processing and analysis also apply to data collection and are covered in Chapter 7 (e.g., data privacy, data disclosure). Other challenges apply across all stages and are covered in the cross-cutting Chapters 13–15. In this section, we focus on two challenges that are more specific to data processing and analysis.

Knowledge of tools and scientific methods. There are many examples of successful projects that involve crowd members in data processing and in analyzing individual data points (e.g., images, light curves, videos). However, there are fewer projects that involve crowd members in more complex analyses of data sets, e.g., using statistical techniques. One potential reason is that project organizers simply see less need to involve crowd members in such activities since these activities typically require less scale and volume than data collection or processing. Perhaps more importantly, however, complex analyses require considerable prior knowledge of tools and methods that crowd members without formal scientific training typically lack. Moreover, it is often not clear which tools and methods are most appropriate, given the research question, relevant norms in the relevant fields, as well as the goals of the project (Ottinger, 2010). An ambitious effort to also involve *Galaxy Zoo* participants in the analysis of data on galaxies (a project called *Galaxy Zoo Quench*) appears to have failed partly because crowd members felt a lack of knowledge (or guidance) regarding methodological choices. As stated by one participant: “I was unsure how to report my results, and on a more basic level was unsure about which descriptive and inferential stats were the most relevant to the project” (quoted in Crowston et al., 2019, p. 8).

One solution is to train crowd members and provide support throughout the analysis process. The Slack channel used by *Exoplanet Watch* to support crowd members in their work is a good example. However, this approach is very costly in terms of time and effort on the part of both project organizers and crowd members. Another approach is to involve a smaller number of (self-) selected crowd members who have the required knowledge and skills for a particular task, such as in *Epidemium* projects. The challenge is then to identify these highly skilled crowd members and to incentivize them to contribute their rare skills to the project rather than somewhere else (see Chapter 14). The most extreme solution to ensure that crowd members have the required skills is to limit participation to professional scientists and to incentivize them through co-authorship (Schweinsberg et al., 2021).

Need for coordination. Individual crowd members who process and analyze pieces of data (e.g., images, light curves) can operate quite independently as long as there are clear guidelines regarding what they are asked to do. Complex analyses of full data sets, however, require more coordination and discussion to decide what analyses should be performed, who performs them, and how results can be integrated. The "division of labor" between crowd members performing complex analyses is difficult to plan ex ante given uncertainty regarding what needs to be done, but also given uncertainty regarding which crowd members will participate, what their skills are, and how much time they are able to commit. Indeed, such challenges were very salient in the project *Galaxy Zoo Quench*, where a lack of leadership led to uncoordinated efforts such that "the volunteers did not reach a final decision about what should be done, so Phase 2 did not progress to having the desired final set of analyses and a scientific story" (Crowston et al., 2019, p. 8). We will discuss the challenge of coordination – and potential solutions – in more detail in Chapter 13 because it can apply to all stages of research. We highlight it here, however, because this challenge is particularly salient in complex data analyses.

The website www.sciencewithcrowds.org includes templates for the 4Q Tool and the Crowd Science Design Canvas with guiding questions for the stage of processing and analyzing data. These templates will help you explore whether and how crowd involvement in this stage might be helpful in your project. To see how these templates are used, check out our examples using fictional characters ("personas") in Chapters 4, 6, 7, and 9. The website also includes a list of additional resources, including selected platforms and tools you could use to involve crowds in data processing and analysis.

9. Solving problems

Problem-solving can be defined as finding a way to get from state A to a more desirable state B (Simon, 1973). Although many important problems seem obvious (e.g., we want to reduce the rate of cancer), it often takes additional effort to truly understand the underlying problems that need to be addressed (Schwenk & Thomas, 1983; Simon, 1973). For example, once we realize that cancer is caused by smoking, we can find a way to solve the cancer problem: Convince people to stop smoking. As such, an important part of problem-solving is problem definition and problem structuring, i.e., identifying relevant parameters or paths that can be used to move from state A to state B.

In some sense, all scientific research can contribute to problem-solving by closing gaps in our knowledge, and because a better understanding of natural or social facts and mechanisms can help us change things to achieve better outcomes. Recall that we already discussed "problems" in Chapter 4 when considering the involvement of crowds in identifying and selecting research questions. In this chapter, however, we focus on problem-solving in a narrower sense – as part of individual research projects. For example, epidemiologists may look for a better way to predict the spread of a particular virus. Cancer researchers may look for a drug compound to inhibit the growth of a specific type of cancer cell. Economists may look for an incentive mechanism that better rewards companies for reducing their carbon footprint. Mathematicians may look for a novel way to prove a theorem.

Problem-solving often requires prior knowledge. For example, researchers trying to design a new RNA-based vaccine need to be aware of existing RNA designs as well as the natural laws or rules that govern RNA. Such laws or rules constrain the solution space, e.g., what kinds of RNA designs are feasible and can work. Perhaps more importantly, problem-solving also requires creativity – the process of coming up with new solutions within a given solution space, often by recombining existing pieces of knowledge. For example, RNA designers may recombine elements from different existing RNA structures to create new RNA with certain desirable properties.

Finally, problem-solving often involves trial and error. Although researchers in some areas of science can compute optimal solutions, the solution space is often too complex to anticipate all possibilities or predict where the best solution is located. Thus, researchers often search by trying solutions, evaluating their performance, and then adjusting or trying a completely different approach. In doing so, humans naturally perform what is called “local search”: They experiment with solutions that they are familiar with and build on knowledge components that are easily accessible (March & Simon, 1958). This reduces the costs of search, but it also means that researchers may never explore those parts of the solution space that are more distant. How can crowds help solve problems?

9.1 EXAMPLES

The project *Eterna* asks crowd contributors to create RNA, tiny molecules composed of different bases (adenine, uracil, guanine, cytosine) that perform important functions in the cells of all living things. Designing new RNA molecules with particular structural properties can help scientists achieve important goals, such as creating stable mRNA vaccines against COVID-19 or developing diagnostic tests for tuberculosis. Unfortunately, the range of possibilities is immense and the ability of computers to design molecules remains limited. To address these challenges, the organizers have built a large community of human players who design new molecules in a gamified online environment. This environment provides the players with several tools they can use in their work, e.g., tools to switch base pairs or to compute the performance of designs with respect to key criteria (see Figure 9.1). Moreover, the environment specifies certain constraints that designs have to adhere to, e.g., with respect to the ratio of different bases. Players help each other in the process by discussing problems and potential solutions. Players can then also submit their best designs into a voting process, where the community decides which designs should be synthesized in a real lab to study their properties. *Eterna* players have developed novel RNA designs in response to several different scientific challenges (e.g., Andreasson et al., 2022).

We already introduced *Polymath* as a project that involves crowd members in the identification of problems that should be solved (Chapter 4). Participants also get involved in solving these (mathematical) problems, and they do so by exchanging ideas and developing mathematical proofs collaboratively on blogs. Although projects tend to be relatively small with respect to the number of participants (e.g., roughly 40 contributors to *Polymath* 1),[1] these numbers are quite large by the standards of mathematics (Wuchty et al., 2007). The *Polymath* blogs are public, allowing us to see the complex interplay between the contributions of different crowd members, who often correct each other or suggest alternative approaches to solve a particular part of the problem. When

[1] https://en.wikipedia.org/wiki/Polymath_Project.

Source: https://eternagame.org/news/8997813?sort=blog.

Figure 9.1 Section of Eterna interface with RNA design

the discussion becomes too complex or appears to be stuck, key contributors may move the project forward by summarizing intermediate results, identifying bottlenecks, or proposing alternative solution strategies.[2]

The goal of the *NASA Solar Flare Prediction* project was – you guessed it – to better predict solar flares. Solar flares are extremely dangerous to space missions, which explains why NASA scientists had worked on better methods to predict them for a long time. In 2009, they posted the challenge to develop better forecasting methods on open innovation platforms such as *InnoCentive*, offering an award of USD 30,000 for the best solution (Lifshitz-Assaf, 2018). More than 500 individuals had a look at this problem over the next three months, with 11 of them submitting solutions. The winning solution came from a semi-retired radio engineer from rural New Hampshire without any experience in heliophysics. He proposed an unconventional approach: Rather than using traditional satellite-based data, he created an algorithm that used radio-based data, significantly improving the accuracy of forecasts and making predictions much further in advance than was possible with existing approaches.

2 https://polymathprojects.org/2017/05/05/rotas-basis-conjecture-polymath-12-post-3/.

In *Quantum Moves*, crowd members help quantum physicists find the most efficient ways to move atoms from a specified initial state to a desired target state (Jensen et al., 2021). They do so by playing a game in which mouse movements simulate the movement of laser beams used in quantum labs to control and transfer atoms.[3] Although the first version of this game relied purely on human intuition to find the best solutions (Sørensen et al., 2016), version 2 provides players with an optimization algorithm that can help improve their initial solutions. The resulting "hybrid intelligence" system promises significant improvements upon existing approaches (see Box 9.1).

BOX 9.1 HYBRID INTELLIGENCE

Building interfaces that efficiently couple human intuition and computational power is one of the grand challenges of how humanity will prosper alongside AI. Quantum games have emerged as a fruitful testbed for involving citizens in research, allowing researchers to rethink their methodologies and for exploring innovative human-machine interaction.

-Jacob Sherson, Professor of Quantum Physics and founding director of the ScienceAtHome platform, personal communication.

Table 9.1 shows that our example projects require very different levels and types of knowledge from contributors – ranging from basic cognitive skills in *Quantum Moves* to highly specialized knowledge in *NASA Solar Flare Prediction* and *Polymath*. Resource requirements in these projects are limited to having access to computers and relevant software, although competitors in the *NASA Solar Flare Prediction* project could use different kinds of resources as long as the submitted solution conformed to the requirements defined by NASA. Crowd contributors had considerable decision power in the problem-solving stage of these projects – especially related to choosing between alternative paths toward the best solution.

Figure 9.2 shows our assessment of the most relevant Crowd Science Paradigms in the example projects. We will explain our assessment in more detail when discussing the general benefits of involving crowds in solving problems in the next section.

[3] https://www.scienceathome.org/games/quantum-moves-2/about-quantum-moves-2/.

Table 9.1 AKRD Crowd Contributions for example projects (stage: solving problems)

	Eterna	Polymath	NASA Solar Flare Prediction	Quantum Moves
Activities	Design RNA structures; vote which designs are most promising and should be tested in the lab	Solve mathematical problems collectively in a blog	Develop algorithm to predict solar storms based on different data inputs	Play a game to optimize the movement of atoms in a simulated quantum environment
Knowledge	Basic knowledge of RNA structures	Specialized knowledge in mathematics	Specialized knowledge in potentially relevant domains	General knowledge
Resources	Computer and internet connection	Computer and internet connection	Computer and internet connection; other resources depending on chosen approach	Computer and internet connection
Decisions	Generate options (structural design parameters and structures); select options	Generate options (solution steps); select options	Generate options (solution strategies); select options	Generate options (solution strategies, moves); select options

9.2 BENEFITS OF INVOLVING CROWDS IN SOLVING PROBLEMS

The examples above illustrate how crowds can contribute to problem-solving in science and suggest different relevant Crowd Science Paradigms. The most salient paradigm is broadcast search: Broadcasting a problem to a large number of diverse individuals can allow organizers to identify those crowd members who have pre-existing solutions or the unique knowledge required to come up with outlier solutions. In broadcast search, the most dramatic improvements are often achieved by crowd members who are distant from the organizers with respect to their prior knowledge and expertise, allowing them to search in very different regions of the solution space (Jeppesen & Lakhani, 2010). The winner of the *NASA Solar Flare Prediction* contest is one example: He had enough knowledge to understand the challenge but brought in pre-existing knowledge from an unusual domain, leading him to use radio vs. satellite-based data. Of course, the observation that outlier solutions come from distant individuals does not mean that all distant individuals will come up with valuable solutions – most participants (distant or not) tend to generate low-value

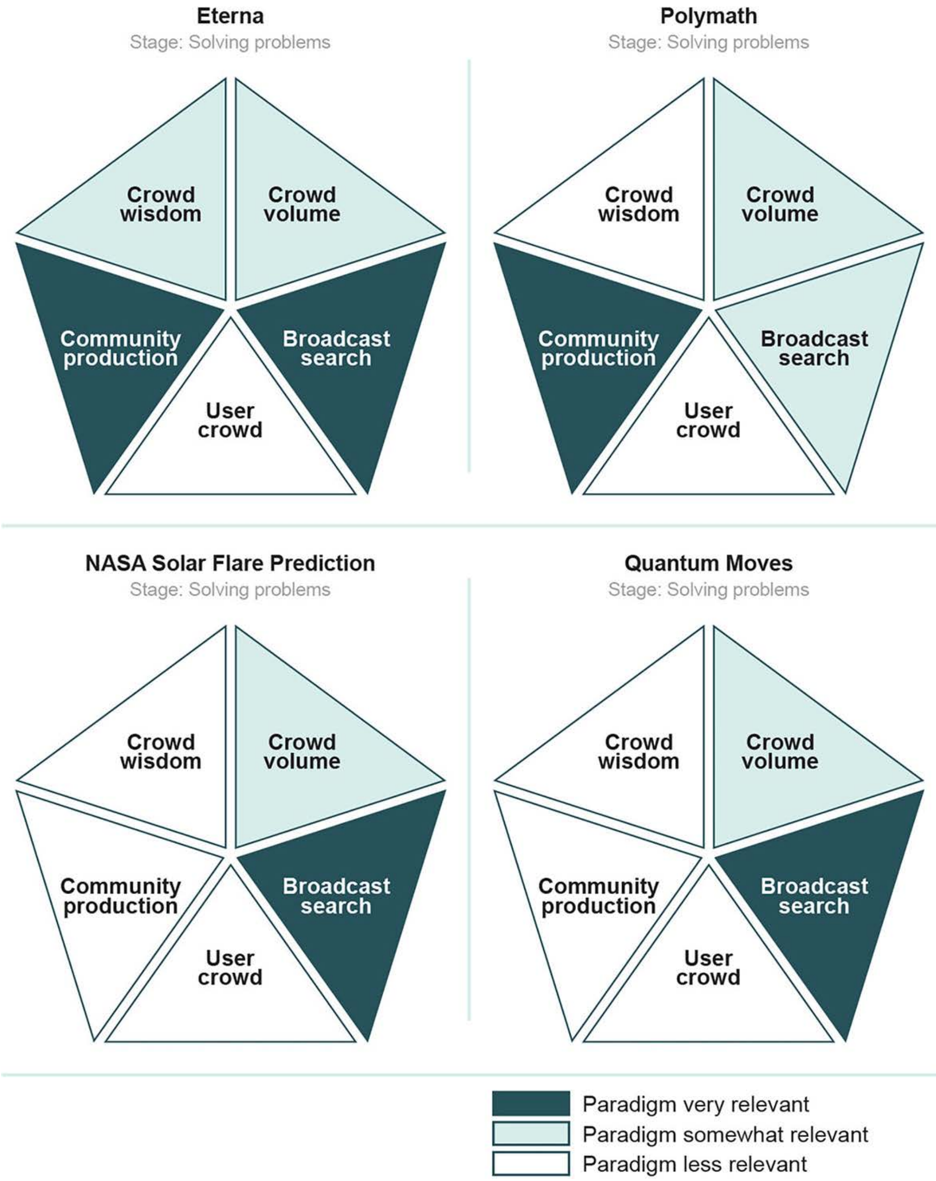

Figure 9.2 *Crowd Science Paradigm Diamonds for example projects (stage: solving problems)*

solutions, and organizers need to find efficient selection mechanisms to identify outlier solutions (see section 13.4). Broadcast search is also very important for *Eterna* and *Quantum Moves*, which seek to identify outlier designs and optimization solutions, respectively. It is somewhat less important in *Polymath* because problem-solving tends to be more collaborative rather than based on lots of independent attempts – although some individuals may still contribute outlier ideas for particular sub-problems.

All the examples we discussed also benefit to some extent from crowd volume: Developing solutions takes a lot of trial and error, and the quality of the best solution partly depends on how many people spend time experimenting with alternative approaches. For example, *Quantum Moves* has over 250,000 registered players, while *Eterna* has had over 60,000 players.[4]

The community production paradigm is useful to understand how projects such as *Polymath* come up with solutions to highly complex problems that may be too difficult for any individual person to solve. *Polymath* does not succeed primarily by identifying outlier solutions from distant individuals, or by having lots of people try different approaches. Rather, it uses a collaborative approach that enables contributors with different skills and knowledge to focus on different elements of the broader problem, share their knowledge, build on each other's ideas, and detect flaws in each other's thinking (Majchrzak & Malhotra, 2020). Community production is also very relevant in *Eterna*: Although solutions can be submitted by players working in isolation, many of the players who are highly involved interact and discuss strategies and solutions using chat or online forums (Krüger et al., 2023).

We introduced the project *Profs-Chercheurs* in Chapter 7 as an example of crowd involvement in data collection: Educators collect data about different approaches to improve learning outcomes. However, this case also involves an important problem-solving step: Crowd members (in this case, educators) have to first come up with a treatment they want to use to solve a particular problem in the classroom.[5] Focusing on the research challenge (problem) "How to help a disruptive student to control his outbursts of violence?", for example, an educator developed the solution "Establish a contract with the student" and then collected data on how well this solution worked.[6] This solution idea likely reflected the educator's prior experience in the classroom – including the observation that other solutions did not work and perhaps that engaging with students at eye level helped them feel more responsible and channel their emotions. This example illustrates the user crowd paradigm, which highlights the role of crowd members' prior experiential knowledge in a problem area. In the context of problem-solving, such knowledge can help crowd members pinpoint

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4 https://eternagame.org/publications.

5 We could also have discussed this as an example of research question or hypothesis generation rather than problem-solving. As noted before, these stages are closely related in that they require problem identification and thinking about (potential) causes or solutions. Whatever label we might use for this case, we will get to similar conclusions regarding the benefits (and challenges) of crowd involvement.

6 https://plateforme.profschercheurs.org/projects/mettre-en-place-un-contrat-positif-avec-lelev-1/summary.

deeper underlying problems (e.g., current methods to deal with disruptive students involve punishments, which lead to resistance rather than collaboration) but may also provide the raw material to come up with novel solutions.

This discussion of the role of user knowledge in *Profs-Chercheurs* seems to contradict our prior claim that outlier solutions often come from people outside the problem domain. Indeed, it would be interesting to see what solutions would be generated if we gave the challenge "How to deal with disruptive students" to people who are not educators or parents, and who potentially have experience in dealing with disruptive persons or objects in related contexts (Franke et al., 2014). More interestingly, however, this tension suggests the need to think carefully about the Crowd Science Paradigm that is most relevant in a particular context or what paradigms may need to be combined. Is it very important to have a deep understanding of the problem and to be aware of complex constraints on potential solutions (user crowd paradigm)? Or is it more important to take a fresh look at the problem and let go of implicit assumptions and approaches that have failed in the past (broadcast search paradigm)? Can we achieve a bit of both by letting people with different perspectives interact (community production paradigm?) or by applying the broadcast search paradigm and targeting a user crowd? We will return to such design decisions below.

The crowd wisdom paradigm appears less relevant for coming up with potential solutions to problems. However, it describes why it is sometimes useful to let crowd members evaluate problem solutions. Consider again the example of *Eterna*, where crowd members can vote on which designs should be tested in the next stage of a project. While an individual evaluator may focus on some important aspects but forget others, make errors in judgment, or have individual biases (voting for a friend), aggregating the votes of many crowd members is likely to yield more accurate assessments.

9.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

There is a sizeable body of literature on problem-solving in general, as well as on problem-solving using crowdsourcing mechanisms such as tournaments or communities (Bayus, 2013; Boudreau & Lakhani, 2013; Dahlander et al., 2019; Dahlander & O'Mahony, 2010; Lakhani et al., 2013; Poetz & Schreier, 2012). Interested readers are encouraged to look into that literature because many of the insights also apply to crowd involvement in scientific problem-solving. In this section, we focus on two challenges that are particularly relevant in the context of science.

Domain-specific knowledge. Solving scientific problems often requires considerable prior knowledge about the nature of the problem, potential underlying causes, as well as constraints that need to be observed when coming up with solutions. Most crowd members lack such knowledge.

One approach to dealing with this challenge is illustrated by *Polymath*: Projects can limit participation to just those people who have the required knowledge, either through screening of participants or by relying on self-selection. The downside is that this approach will reduce the number of participants and may also exclude people who lack domain-specific knowledge but have other knowledge that could help generate novel solutions.

A second option is to reduce the knowledge required by participants. Challenges hosted on the *Wazoku Crowd platform*, for example, are often written in plain English rather than field-specific jargon, and problems are described in an abstract way that disconnects them from likely irrelevant features of the particular context. For example, the problem "How can 5-hydroxymethyl-2-furancarboxylic acid be delivered into Gossypium in the temperate climate zone?" could be reframed more generally as "How can bioactive compounds be delivered to plant cells?".[7] A more abstract problem description eliminates the need for prior knowledge to understand field-specific jargon or irrelevant features of the context, but also encourages contributors to draw analogies to similar problems that may occur in other domains (Poetz et al., 2014). Of course, organizers need to be careful not to abstract too much – the solution to the seemingly more general problem still has to work for the specific case.

The projects *Eterna* and *Quantum Moves* enable participation by crowd members without much prior knowledge by using a different approach: They embed some of the required knowledge in the project infrastructure, directing contributors' thinking and actions automatically. For example, Eterna's design tool only includes the four bases adenine, uracil, guanine, and cytosine – preventing contributors from adding other molecules that scientists know cannot be part of RNA. *Eterna* also specifies rules regarding other aspects such as the frequency or ratio of certain bases in the RNA that should be developed. Similarly, players in *Quantum Moves* can only make certain kinds of moves that scientists specified as allowed, given their knowledge about how quantum labs operate. The downside of this approach is that constraints embedded into the infrastructure can be unnecessary or even wrong – preventing contributors from exploring potentially promising parts of the solution space. Perhaps more importantly, this approach works primarily to incorporate knowledge about constraints. It works less well to provide knowledge inputs that can serve for creative recombination. The pool of potentially relevant knowledge is often too

[7] See Wei et al. (2022) and https://environment.community.wazoku.com/challenge/ad180a0d0d8949e0a585745759556214?searchIndex=7.

large, and project organizers also do not yet know which pieces of knowledge will be required to solve the problem (if they did, they would be well on their way to a solution).

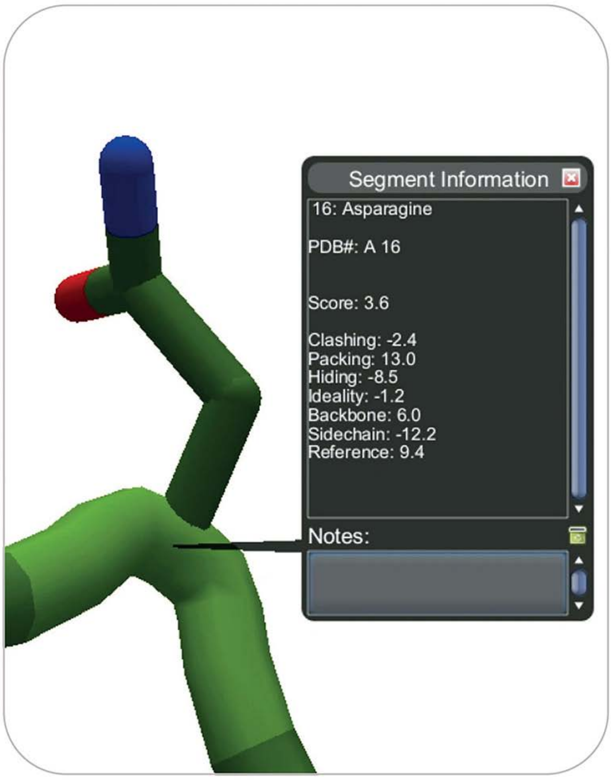
A final approach to address the lack of domain-specific knowledge is to train participants, e.g., using tutorials or workshops. *Eterna*, for example, organizes an annual conference that includes sessions on RNA research, new player tools offered by the platform, as well as other topics such as research ethics.[8] However, training crowd members is difficult, especially when the required knowledge is deep (e.g., Polymath) or when the scope of potentially relevant knowledge is very broad, making it difficult to predict what pieces crowd members will need. Rather than deciding ex ante what contributors will need, projects can also put in place mechanisms that enable them to find relevant knowledge on an as-needed basis. For example, projects can provide access to databases with prior literature or data, as well as to experts that can help with technical questions. Projects may also provide AI-based tools that allow crowd members to efficiently search the vast body of existing knowledge in a particular domain (Extance, 2018). Rather than serving just as better search engines, such tools can be designed to encourage creativity-enhancing approaches such as analogical reasoning or bridging between disconnected scientific domains (Beck et al., 2022c; Kittur et al., 2019).

Defining quality and providing feedback. Organizers need to specify how the quality of a solution will be evaluated or measured (see also section 13.4). This is not trivial since there may be multiple relevant quality dimensions. In the *NASA Solar Flare Prediction* challenge, for example, relevant dimensions included the time-window of predictions (the further in advance, the better), but also the accuracy and the confidence interval of predictions. Including some relevant dimensions but forgetting about others risks that crowd members come up with suboptimal or even infeasible solutions. In other cases, stating a very specific performance metric may restrict the solution space too much, preventing crowd members from coming up with solutions that are valuable in unexpected ways.

Moreover, it is often useful to provide feedback on the quality of solutions throughout the process so that crowd members can improve upon initial ideas. In a recent *Eterna* project, for example, an algorithm instantaneously predicted the likely degradation of an RNA structure, providing feedback on a core performance metric to players (Wayment-Steele et al., 2022). Similarly, players in the game Foldit receive instantaneous feedback regarding how well their designs perform with respect to key metrics (see Figure 9.3). Feedback can also be very important for crowds solving problems in a collaborative approach. Recall from our earlier discussion that expert contributors in *Polymath* at

8 https://eternagame.org/eternacon/2022.

times step in to summarize what the project has already accomplished, what hurdles remain, and what approaches may be most promising to move forward.



Source: https://foldit.fandom.com/wiki/Score_part.

Figure 9.3 Instant feedback on solution quality in Foldit

9.4 GETTING STARTED: DECIDING WHETHER AND HOW TO INVOLVE CROWDS IN SOLVING PROBLEMS

You have already met our persona for this chapter when we discussed how to involve crowds in developing methods and materials (section 6.4). Let's see what Linda is up to now (Figure 9.4).

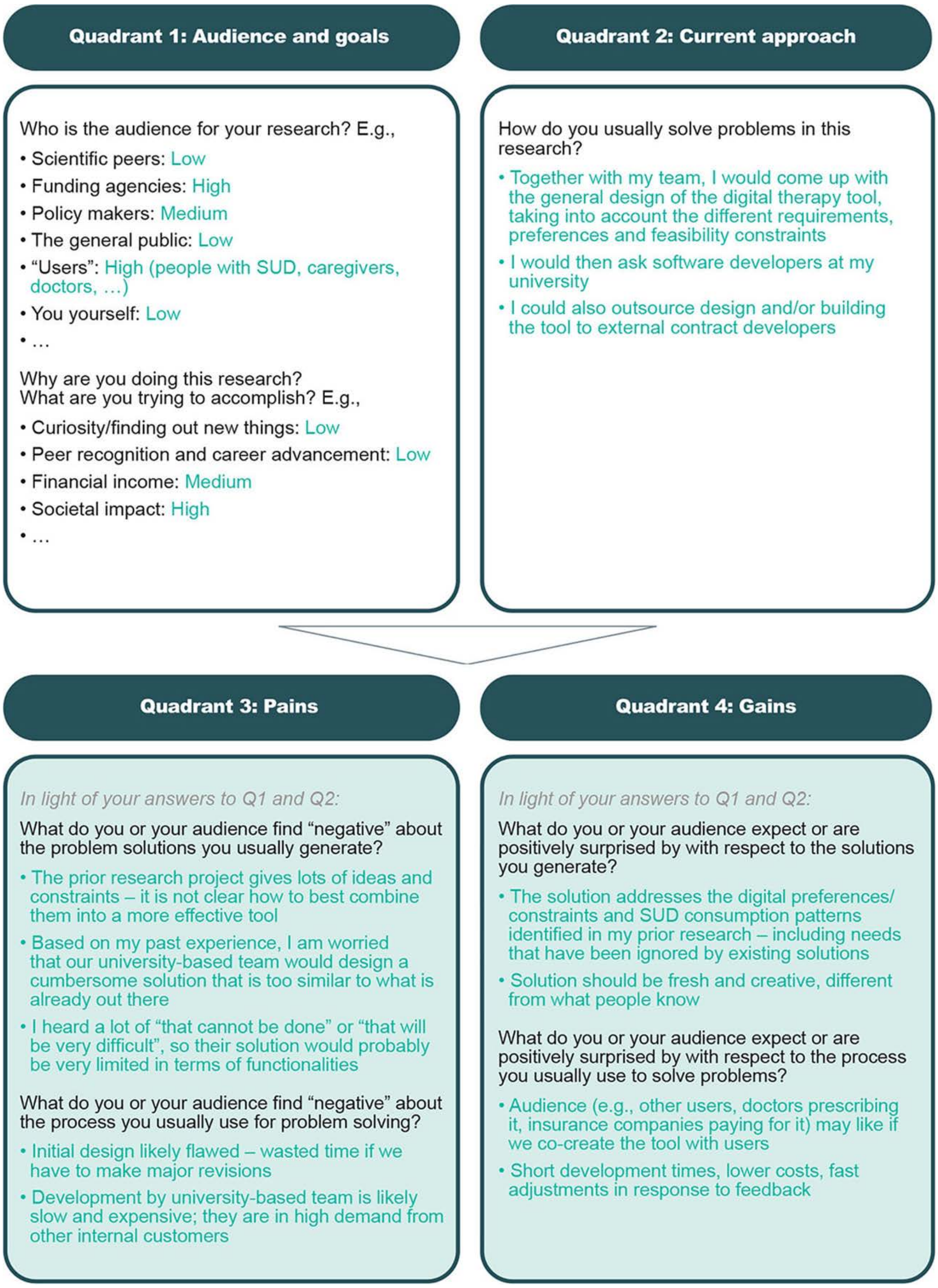
9.4.1 Status Quo Analysis Using the 4Q Tool

In section 3.1, we discussed the 4Q Tool at an abstract level, and our website www.sciencewithcrowds.org includes a template with guiding questions for the stage of solving problems. Figure 9.5 shows the tool with the condensed answers for Linda and her second project.

Figure 9.4 Persona for solving problems (Linda)

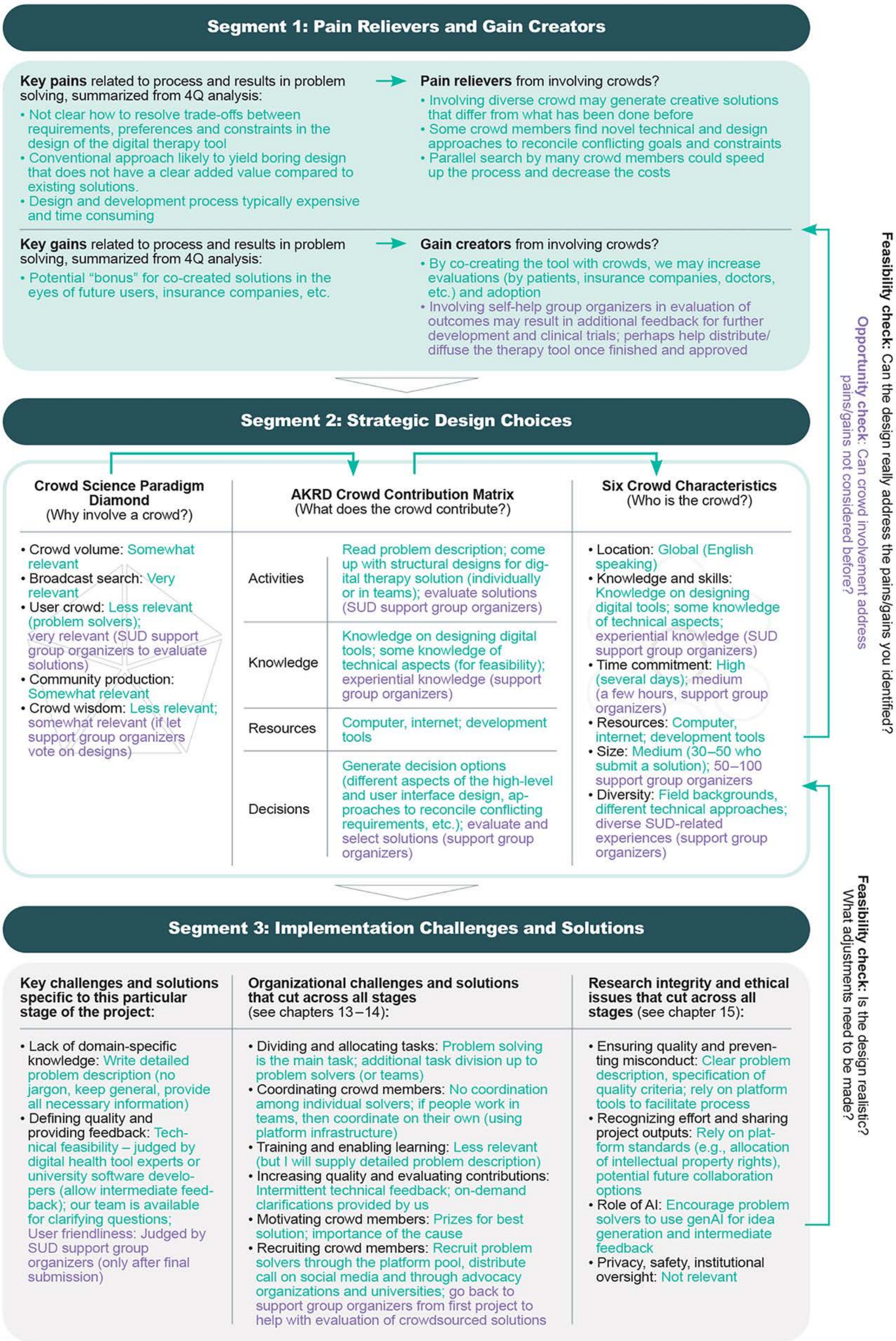
9.4.2 Developing a Project Using the Crowd Science Design Canvas

Figure 9.6 shows the Crowd Science Design Canvas with Linda's entries in green (and revisions in purple; colours in online version). **Segment 1** summarizes the pains and gains resulting from the 4Q analysis. The primary challenge Linda identifies is that it is not clear how the various requirements and constraints for the digital therapy tool can best be combined into a coherent design. She does not think that she will be creative enough, and she also did not have a great experience with the software developers at her university (they are good at programming but not at design). As Linda is thinking about how to involve crowds, she focuses on the possibility of running an ideation contest, where she asks crowd members to come up with creative, effective, and feasible structural designs (software architecture and user interface) for the tool, taking into account relevant patterns identified in her prior research. She is writing down initial ideas on potential pain relievers and gain creators on the right side of segment 1. Linda then turns to segment 2 to consider what this kind of crowd involvement could look like, returning to segment 1 as needed to update the pain relievers and gain creators.



Note: Linda's condensed answers in green; colours in online version.

Figure 9.5 4Q Tool to analyze status quo with respect to solving problems



Note: Linda's condensed answers in green; revisions in purple; colours in online version.

Figure 9.6 Crowd Science Design Canvas for problem-solving

Segment 2 guides Linda through different strategic choices. Thinking about the relevance of the different Crowd Science Paradigms, she believes that broadcast search might be the most helpful: She needs creative ideas on what a digital therapy tool could look like and how the different requirements, preferences, and constraints identified in her prior research can be accommodated. Experts in the digital health area would likely anchor on existing solutions, but Linda thinks that a fresh look from people outside the area may generate something new and more effective. This design problem is not simple, so it will take participants considerable time to develop solutions – suggesting that the crowd volume paradigm will also be somewhat relevant. She thinks that people can solve this challenge individually, but if they want to work in teams, then this might help them come up with even better solutions or help each other. Thus, community production may also be relevant. Linda has gained novel insights into user requirements from her first study, so she does not think the user crowd paradigm is relevant here – but she needs to make sure that she gives enough of the relevant background knowledge to crowd members working on the problem. She does not think that the crowd wisdom paradigm is important in her case.

The AKRD part of the Canvas helps Linda to clarify what crowd members should contribute: They should read her problem description and submit design proposals, and they will need knowledge about how to design digital tools and how to resolve technical trade-offs and constraints. Linda will not ask crowd members to build or program the tool – she primarily wants detailed ideas on what the tool can look like in terms of the software architecture (high-level design) and the user interface design. Later implementation can be done with the same or different people (including the university programmers). Crowd members will need computers and internet, but they can also use additional specialized software or tools they find helpful. Crowd members should develop design proposals, but they will not make decisions – Linda and her team will decide which solutions are the most promising.

When thinking about the characteristics of her ideal crowd, Linda believes that the right people for this task could sit anywhere – location is not important, as long as they speak English. Crowd members should have some experience in the design of digital tools. She expects it will take each person at least several days to work through this problem, so the time commitment is quite high. While she may need to reach a large crowd to activate self-selection among those who can provide good solutions (broadcast search), she does not think that the number of people who will eventually submit a solution needs to be huge. She expects between 30 and 50 submissions, but participants should ideally be diverse to increase the chance that they look at the problem from different perspectives. Concretely, Linda thinks that it would be good to attract people from areas such as healthcare, but perhaps also education, gaming, and citizen science apps.

Segment 3. Linda looks at the challenges specific to the stage of problem-solving. She is reminded that some participants may have relevant background knowledge about SUD and digital health tools – but many may not. Linda wants to enable broad participation to maximize the potential for outlier solutions, but she also wants to minimize the number of low/no-fit submissions to reduce the effort required to evaluate solutions. So, she decides to develop a detailed problem description that summarizes current approaches in digital health as well as general requirements for digital healthcare tools. This document will also explain the relevant requirements, preferences, and constraints for a more effective digital SUD therapy tool that she has identified in her prior research study. In doing so, she will minimize jargon and try to keep the discussion general enough to make this information easy to digest for people with different backgrounds. Linda then thinks about how to define and evaluate performance. She realizes that she has at least two dimensions of performance, both of which are somewhat subjective. First, the solutions need to be technically feasible and the approaches to reconcile conflicting goals or constraints need to make sense. She will either hire experts to judge this or ask her university software developers to help. Second, the design should make sense to potential users, i.e., people with substance use disorder. Can she judge that herself? As she is thinking about this question, many faces pop up in her head: the organizers of self-help groups she has worked with so intensively during her first project. She realizes that she could use this other crowd to help her with the evaluation of problem solutions (design proposals of digital SUD therapy tools). She goes back to earlier parts of the Canvas and makes the respective changes (in purple; colours in online version). She will explain the two performance dimensions to problem-solvers in the problem description, and she will also give participants the option to submit an initial draft for feedback from technical experts or reach out to her or her team for clarifications of requirements.

Linda now turns to general organizational challenges. Problem-solvers will receive her problem description but are then free to structure the job in any way they want; she will not decide on task division or allocation. Problem-solvers who want to work in teams will need to organize that themselves, but she will make sure that the crowdsourcing platform she uses enables cooperation and team submissions. She already thought about quality evaluations earlier – but is now reminded again that the quality of solutions will depend a lot on how well her problem description is written. So, she will have to spend significant time on this and ask for support from platform staff with relevant experience.

Motivation of crowd members is another big challenge: She needs smart people with valuable skills, and she needs several days of their time. Consistent with what she has read about problem-solving contests, she will give out significant financial prizes. She will also tell the participants that they are working for a good cause: Substance use disorder is a big problem and helping solve it will have benefits for patients and broader society. Suitable crowdsourcing platforms will have a pre-existing crowd looking for interesting challenges. Linda will additionally promote the contest through her social network and advocacy organizations, and she will ask local technical and design universities to share the contest with their students. Switching attention to the other crowd of SUD support group organizers (needed for the evaluation of solutions), she hopes they will be motivated to help because digital solutions can also make their own work easier. And she has already done the recruiting as part of her first project, so she will just reach out again to the same people. Many of them participated in the online presentation of the study results and expressed interest in staying further involved, so she is optimistic that this will work out.

The final part of segment 3 reminds Linda to consider research integrity and ethics. Problem-solving contest platforms already have many mechanisms in place that help address these issues (e.g., spaces to securely exchange problem information and solutions, escrow accounts to ensure payments are made, standards regarding ownership of intellectual property). Linda will schedule a meeting with platform staff to discuss what the options are and what they recommend. She does not think AI can take crowd members' tasks away, but she realizes that AI may be useful for problem-solvers to brainstorm or generate intermediate feedback on their ideas. She will test this and encourage problem-solvers in the problem description to take advantage of available AI tools. When thinking about the SUD support group organizers as the crowd for evaluations, she does not see major problems – except that some might have a conflict of interest: Even though Linda thinks that the digital therapy solution would help them, some organizers might think it takes away their jobs. She will discuss this with some of the organizers she particularly trusts and then see if she needs to come up with a solution.

Feasibility and opportunity checks. Linda's plans are still a bit rough – she needs to sit down with staff from a crowdsourcing platform to learn more about some of the detailed choices she has for organizing the contest (e.g., how to involve individuals vs. teams, reward levels, and intellectual property rights). Another open question is how detailed and technical the design has to be in order to judge its feasibility, and how such a design can then be implemented by programmers. She will set up a meeting with her university software developers to discuss these questions and then adjust her problem description and solution requirements accordingly. But she already recognizes one additional opportunity she had not considered before: By involving SUD support group organizers in the evaluation of designs, she can probably generate additional feedback that is useful for further development of the solution. Those crowd members may also help her later on when it comes to running the digital therapy tool through a clinical trial or promoting the final version. She adds these additional gain creators to segment 1 of the Canvas.

10. Writing

In the writing stage, researchers package information into a paper that can be submitted to conferences and journals or disseminated directly (e.g., via websites). Different research approaches yield different kinds of papers, ranging from conceptual papers that have lots of theory and no data, to empirical papers that succinctly report empirical patterns or tests of a hypothesis. Papers also typically motivate the study, review relevant prior research, and discuss the implications of their findings as well as opportunities for future research. Readers (and editors) increasingly expect additional disclosures such as plain language summaries, details about materials and instruments, as well as files with replication data. The norms regarding what a good paper should look like differ across fields and even across journals within a field. As such, an important challenge for researchers is to decide which journal or conference they should submit to, which reflects considerations such as the topic, the quality and importance of the study, as well as outlet-specific tastes regarding methods. Researchers may also look at the names of editorial board members and recent authors to see whether the community behind the journal or conference is a good fit.

There is a clear connection between writing and other stages of the research process: The outputs of other stages (e.g., conceptual arguments, analysis results) serve as inputs into the writing process. Of course, this process can be iterative. For example, writing up results can reveal inconsistencies that call for additional analyses, and writing up opportunities for future research may lead researchers to return to the data to see if they can already address some of these questions in the current project. There are also many interdependencies between the different elements of a paper, e.g., the introduction needs to prefigure the results, the discussion of the analysis needs to be aligned with the discussion of methods and materials, and the conclusion needs to build upon the main results of the paper as well as its limitations. Notwithstanding important differences across fields and types of papers, it is fair to say that writing can be one of the most complex and challenging stages of the research process. Are crowds up to the challenge?

10.1 EXAMPLES

The organizers of the annual *Exoplanet Research Workshop* guide crowd participants through the process of analyzing data on exoplanets and writing up results for submission to peer-reviewed journals (e.g., Yang et al., 2022).[1] The data and analysis tools are taken from the project *Exoplanet Watch* (see Chapter 8). The crowd in this case consists of pre-college students with a strong interest in astronomy who participate in a series of meetings over several weeks. Papers are written in teams that coordinate using online tools such as Slack, and that can plug into the support infrastructure of the *Exoplanet Watch* project for questions related to data and analysis. The topics of papers are relatively well-defined by the organizers: In 2022, for example, participants analyzed transits of the exoplanet Qatar-1b, with different teams focusing on different sets of transits. Members of the organizing team explain the process of writing a research paper in online sessions and YouTube videos (see Figure 10.1). They have also developed a template that teams can use to write a standard "observe-measure-report" paper, following the conventions in their field. Project organizers provide feedback on paper drafts and recommend suitable journals for submission.[2] The workshop resulted in several published papers, including papers that include organizers as co-authors.

In Chapter 4, we mentioned that *Eterna* players developed new research questions based on their observation of unusual Poly(A) RNA signatures in *Eterna* data. Encouraged by the project organizers, one long-time player then proposed to develop these discussions into a paper, recruiting other interested crowd members at an annual conference that brings together the *Eterna* community. The team of co-authors then wrote the paper using tools such as Slack and Google Docs to coordinate their work. Even crowd members who did not contribute as co-authors were invited to provide feedback on working paper drafts.[3] The project organizers also helped a lot, e.g., by recommending which journal to target. After this paper was published (Wellington-Oguri et al., 2020), *Eterna* players co-wrote several other papers on topics such as crowdsourced algorithms to predict the degradation of crowdsourced RNA designs (Wayment-Steele et al., 2022) as well as developing reversible RNA-based sensors (Andreasson et al., 2022).

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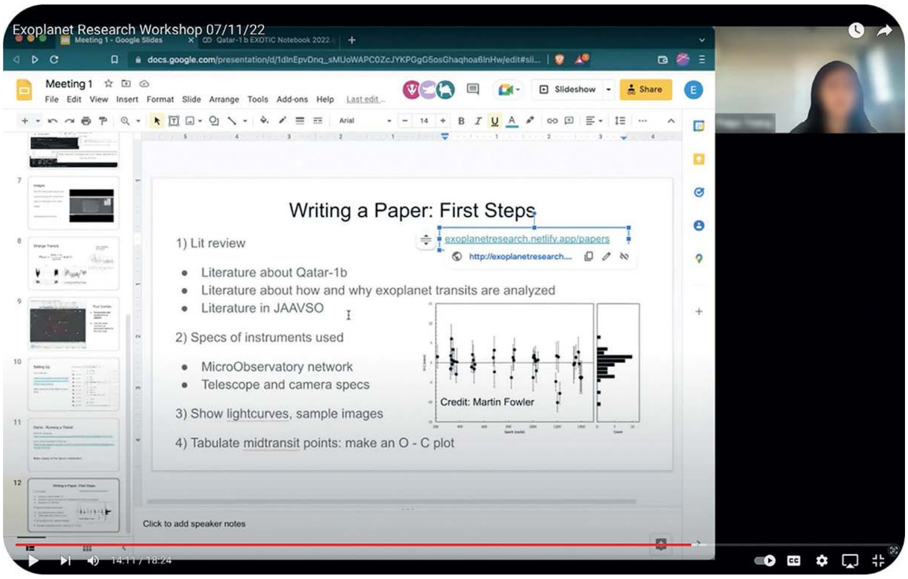
1 https://exoplanetresearch.com/.

2 https://docs.google.com/document/d/1pGp_VwcEvK5Trl8GANiz19qkd51OQOAOjb0idJ-0JME/edit.

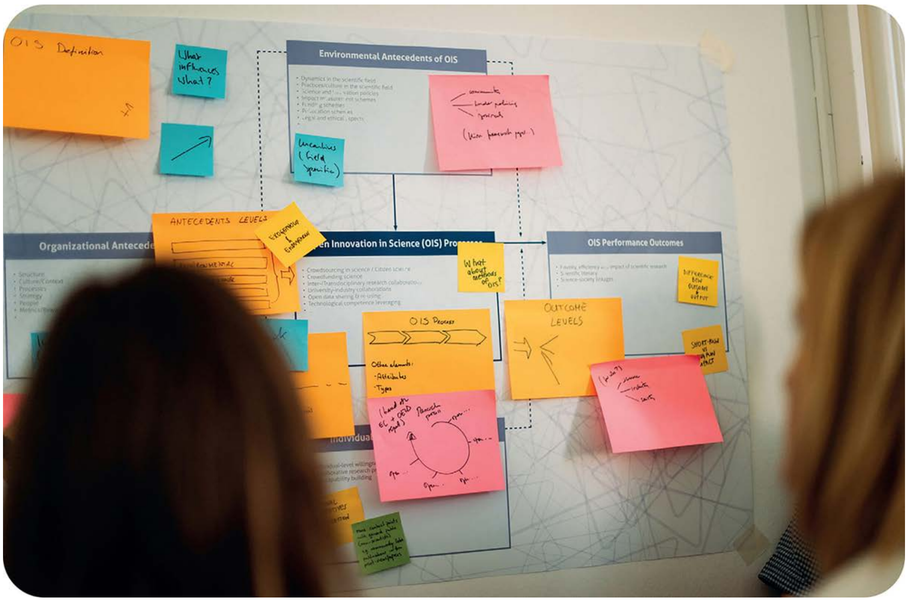
3 https://docs.google.com/document/d/14972Q36IDTYMglwMXTOrqd4P9orQ6-P3bPbCuITdv6A/edit.



Source: https://www.youtube.com/watch?v=Q6Eauf-klEs.

Figure 10.1 Screenshot from Exoplanet Research Workshop training session

The organizers of the *OIS Research Framework Development* used a collaborative process to write a paper with a crowd of professional scientists from the natural and social sciences as well as the humanities (Beck et al., 2022a). The organizers defined the objective to write an article that conceptualized the field of Open Innovation in Science (OIS) research from a multi-disciplinary perspective. The process started with joint in-person sessions at the OIS Research Conference, during which participants developed the overall structure of the conceptual model. The participants clarified disagreements resulting from different definitions or assumptions of openness and collaboration in science used in different fields, and brainstormed topics and existing work that should be integrated (Figure 10.2). Conference participants then decided after the conference whether they wanted to officially join the team of co-authors. Co-authors contributed to the further development of the paper over the course of several months, guided by a lead author who designed the organizational infrastructure, coordinated the division of tasks, and defined intermediate milestones and deadlines. The 47 co-authors contributed to different sections of the article using Google Docs, with intermittent alignment and integration



Source: OIS Research Conference 2019.

Figure 10.2 Crowd members conceptualizing a paper using Post-it notes at an OIS Research Conference session

of all contributions by a smaller set of core authors. All contributors were invited to make final comments before submission to a journal.[4]

Our AKRD analysis (Table 10.1) shows that the crowd contributions to writing in the example projects required substantive knowledge, often knowledge resulting from participation in other stages of the research. In *Eterna* and the *OIS Research Framework Development* project, contributors also needed to understand field-specific norms and requirements regarding what a paper has to include and how it should be written. Resources are required for online collaboration but also for physical meetings of teams to discuss how to conceptualize the paper and how to integrate different elements. Teams in the *Exoplanet Research Workshop* have limited decision rights regarding the topic or the data to be used, but they have considerable freedom to decide what and how much to write in different sections, or how to organize the writing process internally. Crowd members participating in writing in *Eterna* and the *OIS Research Framework Development* project were deeply involved in all major decisions, although some crowd members invested more time than others.

Figure 10.3 shows the crowd paradigms that we believe are most useful in understanding the benefits of crowd involvement for each example case. We

4 https://www.youtube.com/watch?v=XilE6rrjyYk&t=2s.

Table 10.1 AKRD Crowd Contributions for example projects (stage: writing)

	Exoplanet Research Workshop	Eterna	OIS Research Framework Development
Activities	Analyze assigned data on a pre-defined object and write up results using guiding template	Identify interesting aspects of RNA designs or design processes; conceptualize and write a paper	Conceptualize the framework and write the paper
Knowledge	Basic knowledge about exoplanets and light curves	Expert knowledge on the RNA design process; understanding of acceptable paper structure and publishing requirements	Expert knowledge on topic from different disciplinary perspectives; understanding of acceptable paper structure and publishing requirements
Resources	Computer and internet connection	Computer and internet connection	Transportation to conference; computer and internet connection
Decisions	Select options (depth of discussion)	Generate options (e.g., results, paper structure, depth of discussion, references, target outlet); select options	Generate options (e.g., elements of the framework, structure of the model and the paper, literature and references, depth of discussion); select options

will explain our assessment in more detail when discussing the general benefits of involving crowds in writing in the next section.

10.2 BENEFITS OF INVOLVING CROWDS IN WRITING

The number of projects involving crowds in writing is relatively small. It appears that many examples, such as *Eterna* or the *Exoplanet Research Workshop*, involve crowd members in writing because crowd members are also involved in other stages of the research, most notably data analysis or problem-solving. The knowledge gained in those other stages is then also useful in the writing stage – after all, much of the writing is about explaining relevant aspects of empirical activities or problem-solving (see Box 10.1). But let us think about the different projects and the underlying rationales for crowd involvement more systematically.

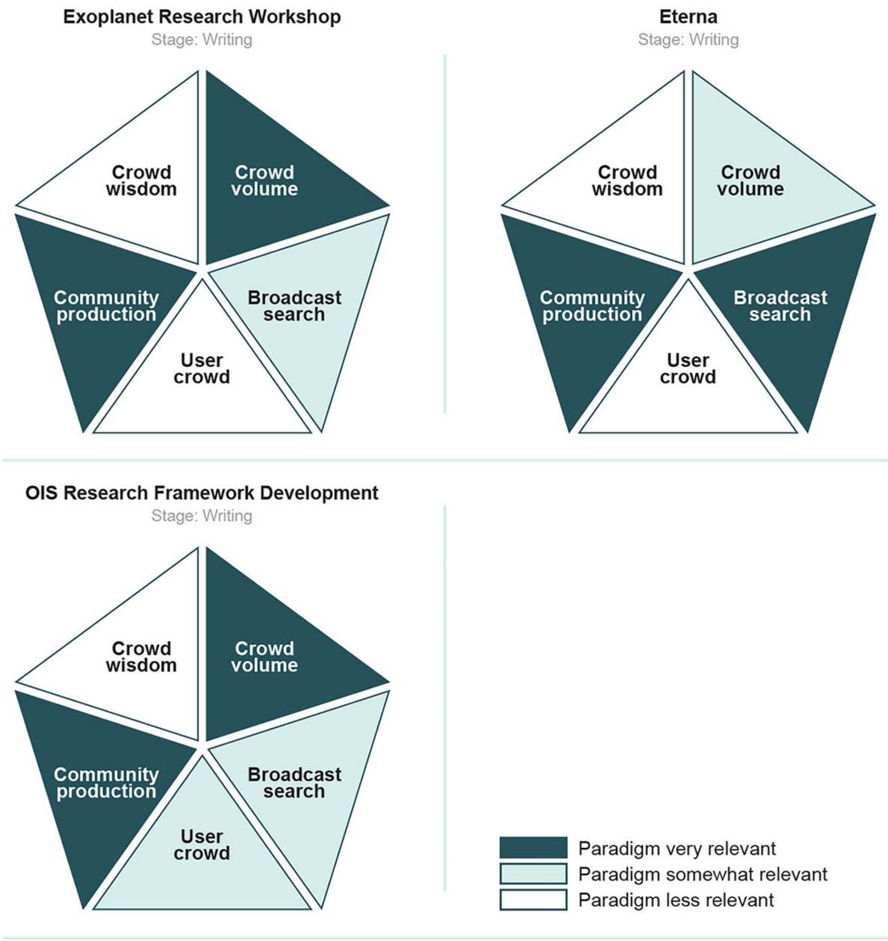


Figure 10.3 Crowd Science Paradigm Diamonds for example projects (stage: writing)

BOX 10.1 BENEFITS OF INVOLVING CROWDS IN WRITING

Involving players in the paper writing process leads to a more interesting, more robust, and more accurate paper. Players often catch errors in the manuscript and provide details about the different stages of the project on the puzzle side that researchers did not see or forgot. We are finding that reviewers often request more information about the player design process, the tools players use in their design process, and their findings.

-Jill Townley, *Eterna* research coordinator, personal communication.

The crowd volume paradigm is relevant in two respects. First, although the number of crowd members involved in writing tends to be small relative to that involved in other stages, it is still quite large relative to what is typical. For example, 47 co-authors on the publication of the *OIS Research Framework Development* project is a very large number relative to the average in the social sciences and even the other fields represented on the author team (Wuchty et al., 2007). In this project, the benefit was that such a large crowd could contribute a diversity of perspectives and come up with many ideas regarding aspects that should be covered by an OIS research framework. Similar to the benefits of reaching out to a large and diverse crowd to help collect biodiversity data across time and space (section 7.1), having so many co-authors helped the project cover a large part of the relevant knowledge space to write an unusually comprehensive paper. Of course, the idea of crowd volume also applies to effort: A larger number of co-authors allows projects to distribute the work across many shoulders, and even though the amount of time spent by the average contributor is relatively small, the total amount of effort is likely higher than it would be in a smaller team. A related aspect of crowd volume is visible in the *Exoplanet Research Workshop*, where the purpose of papers was not to report a breakthrough discovery but to systematically discuss a well-defined set of data about a particular object (the exoplanet Qatar-1b). By breaking up the large data set of observations into different modules, multiple teams could work in parallel, producing multiple complementary papers. Given the thoughtful design of supporting infrastructure such as article templates, it seems likely that the workshop could be scaled up efficiently, allowing scientists to involve even more crowd members to significantly increase the production of scientific articles reporting observational data on exoplanets.

One interpretation of why the number of crowd members involved in writing is often much smaller than that involved in data collection or analysis (Chapters 7 and 8) is that broadcast search is at play: Organizers place an open call for participation, but only a relatively small number of individuals self-select to participate in writing. This self-selection may be with respect to knowledge and skills (e.g., people who had discovered unusual patterns in the analysis of *Eterna* structures or who have prior writing experience) but also with respect to motivation and time (e.g., *Eterna* players who were willing to spend time on a project over several months). The *Exoplanet Research Workshop* also posted a broad call for participation on their website, with stepwise selection by the organizers but also self-selection by participants who decided (not) to move from the analysis to the writing stage. Thus, reaching out to a large initial crowd allowed organizers to identify that small number of individuals who had relevant knowledge as well as the motivation and time required to make meaningful contributions to the demanding task of writing a paper. In some cases, aspects of broadcast search carry over from other stages: Some crowd members make outlier discoveries or contributions in data collection or analysis, and these crowd members then join the smaller team of co-authors who further analyze those discoveries and write them up in a publication (e.g., Lintott et al., 2009). A crowd member in the project *Roadkill Austria*, for example, conducted systematic roadkill monitoring on foot along a 3 km route and co-authored a paper reporting the results of different monitoring approaches (Heigl et al., 2024).

The user crowd paradigm leads us to think about another potential benefit of involving crowd members in writing. Users of the knowledge produced by a project are likely to have a better sense of which particular aspects are most relevant and interesting to the audience, i.e., they could be extremely helpful in selecting which results to report in a paper. Similarly, users can take the perspective of recipients of the knowledge, enabling them to improve the writing style (e.g., less jargon) or to think about approaches to better convey information to the audience (e.g., using a figure rather than a regression table). This aspect is perhaps most salient in the *OIS Research Framework Development* project. After all, the goal of this project was to develop a conceptual framework that would guide future research on openness and collaboration in science – which would be performed by some of the participants themselves or by their peers and colleagues.

Examples such as *Eterna* and the *Exoplanet Research Workshop* involve interactions and discussions, pointing to the relevance of the community production paradigm. Different types of contributors (e.g., crowd members involved in data analysis as well as organizers who set up the research question) collaborate closely to integrate their relevant insights to create a complete paper that summarizes, explains, and interprets all aspects of the project. Community production was also clearly visible in the *OIS Research Framework Development* project, where different crowd members interacted in person to jointly conceptualize the paper and then used online tools to discuss how to integrate ideas and text coming from different individuals.

We see less relevance in this stage of the fifth paradigm – crowd wisdom. To some extent, this may reflect that writing a paper involves fewer estimates of facts or the need to learn about preferences of a broader population than other stages of the research process. Although we do not observe crowd wisdom in our example projects, one could imagine a setup where multiple co-authors vote implicitly or explicitly to make decisions such as which results to include in a paper or which visualization approach conveys key findings best. If the crowd is large and diverse, this may yield better decisions than alternative approaches.

10.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Knowledge requirements. Contributing to the writing of a paper requires knowledge about the substance (e.g., existing literature, the analyses performed). It also requires knowledge about "how to write a paper" in a particular field. As discussed earlier, this includes knowledge about things such as required elements of a paper, the way to report methods and findings, the language style to be used, and even which conference or journal to target.

Crowd members may have substantive knowledge from their involvement in prior stages of the research, e.g., from having analyzed exoplanet data or developed RNA designs. Indeed, we argued earlier that a main reason to involve (certain) crowd members in writing is exactly their specific knowledge about substantive issues. Some crowd members may also have knowledge about the process of writing a paper – this includes crowd members who are professional scientists (the *OIS Research Framework Development* example), but also crowd members who regularly consume original research articles out of an interest in the topic. Indeed, the lead author of the *Eterna* article on unusual Poly(A) RNA signatures could draw on knowledge gained from reading many articles in the field, as well as his formal PhD education in another field (see Chapter 4). Yet, many crowd members will lack such knowledge about how to write a paper.

The *Exoplanet Research Workshop* illustrates one potential solution: If papers are relatively simple and the requirements are clear, relevant knowledge can be codified and taught to crowd members in workshops or online tutorials. Such knowledge can also be embedded in templates that crowd members can use to develop their papers according to the conventions of particular fields. If such knowledge is difficult to transfer, however, teams may have to split responsibilities so that crowd members focus on substantive aspects while team members with a professional background take care of the aspects that require a more nuanced understanding of the paper writing process and the audience's expectations.

Need for coordination. Writing a paper is a very complex task because different substantive aspects need to be aligned with each other and need to be embedded in certain styles and formats. Although teams can try to split up the writing task into different pieces performed by different crowd members, this is often very difficult, exactly because of the interdependencies between different elements (Crowston et al., 2019). To avoid producing a "Frankenstein" paper, a greater division of the writing task also increases the need for coordination between different contributors (see Box 10.2). The examples above illustrate how this can be accomplished through regular meetings, online collaboration tools, as well as integrative leadership by a smaller core team (Melero & Palomeras, 2015). But these mechanisms are quite costly in terms of the time required from project organizers as well as individual contributors. And they can often be frustrating, especially in larger and diverse teams, where different contributors have different knowledge, levels of commitment, or even interpretations of tasks and quality standards (Beck et al., 2023). Given how important the division of tasks and coordination are for teamwork in general, we will deepen our discussion of these aspects in Chapter 13.

BOX 10.2 HERDING CATS

The success of the project lay in the combination of being very transparent and clear about the process, actively facilitating the discussions and interactions among the co-authors, and the enduring engagement and discipline of all scholars to keep deadlines. This helped the "cats" to "herd" themselves.

-Susanne Beck, coordinator and lead author in the *OIS Research Framework Development.*

The templates available at www.sciencewithcrowds.org help you explore whether and how crowd involvement in writing might be helpful in your project. To see how these templates are used, feel free to check out our examples using fictional characters in Chapters 4, 6, 7, and 9. Our website also lists additional helpful resources, including selected platforms and tools you could use to involve crowds in writing.

11. Diffusing and translating results

Even if the results of a research project are highly novel and relevant, they do not automatically have an impact. The knowledge that is created needs to be made visible and diffused to a broader audience, including not only professional scientists but also other relevant stakeholder groups such as companies, policymakers, and the broader public. Toward this end, researchers need to identify an audience that would find the new knowledge relevant and valuable, but they also need to find mechanisms to translate and diffuse the knowledge to that audience.

Within the academic realm, a common approach is to share new insights widely at conferences and through publications, hoping that the right people will see them and know what to do with them. Authors often complement this approach with more targeted "marketing", e.g., by sending new papers to colleagues and other scholars working in the same field. Diffusion to the broader public may involve science communication activities such as summarizing results in the popular press, writing policy reports, visualizing data on public websites, giving talks at practitioner conferences, or getting findings on the radar of National Academies committees. Many universities also have technology transfer offices or similar entities whose job it is to identify results with potential commercial value and support their transfer and application in industry. Scientists may even take the next steps themselves by starting a new company to commercialize research results into new products and services (Beck et al., 2022a). Even though protection through patents or other intellectual property mechanisms can sometimes be useful to stimulate the translation of results into practice, projects can often increase their impact through different forms of openness such as open access publishing, open data, and depositing materials in public repositories (Furman & Stern, 2011; Huang et al., 2024; Probst et al., 2023).

So, there are lots of avenues to diffuse and potentially translate research results. And yet, there is a feeling among researchers and especially among outside stakeholders that much valuable knowledge fails to reach the right audience and make an impact. Can crowds help?

11.1 EXAMPLES

The project *CurieuzeNeuzen* illustrates two interesting diffusion mechanisms that involved crowds. Perhaps the most important aspect is that crowd participants themselves are exposed to knowledge that is generated by the project. In this particular case, recall that crowd members were, among other activities, involved in collecting and analysing data as well as in discussing maps that show the air quality in different areas of Antwerp (section 2.3). By engaging in these activities, crowd members contributed to new knowledge while simultaneously consuming some of this knowledge – participation in the project enabled them to learn about air quality in their region as well as potential causes and effects of air quality (Van Brussel & Huyse, 2018). Crowd members in *CurieuzeNeuzen* also engaged more explicitly in the dissemination of results to third parties. Among other methods, they presented results at festivals and hung up posters with project results near their homes in order to reach citizens who were not involved in the project (Figure 11.1). They also took project results to policymakers to advocate for changes to traffic regulations and public transportation (Van Brussel & Huyse, 2018).

Source: Johan Meuris for ringland.be.

Figure 11.1 CurieuzeNeuzen event diffusing project results

The Collaboration for Leadership in Applied Health Research and Care (CLAHRC) West Midlands is a consortium of the universities of Birmingham, Warwick, and Keele, as well as other healthcare organizations. These institutions perform research in a wide range of fields, including mental health, maternity, child health, and chronic diseases. To make research results more accessible to a wide audience, CLAHRC West Midlands started the *Brokering Innovation through Evidence (BITE)* project. *BITEs* are accessible, bite-sized summaries of research findings that use plain English language and make recommendations for practice for National Health Service staff and inform the broader patient community. The *BITEs* are co-produced between researchers and crowd members, in this case primarily patients and patient advisors. Involving crowd members in the development and review of these summaries ensures that they are informative and comprehensible to the target audience.[1]

In the project *JPL Infographics*, NASA's Jet Propulsion Lab (JPL) invited "space aficionados and graphic wizards" to dig into the agency's vast trove of data and mission results to transform them into infographics that make scientific concepts and results more accessible to the broader public.[2] Many crowd members followed this call and created infographics on topics as diverse as solar winds, geomagnetically induced currents, or Juno's ability to withstand intense radiation environments. Anyone can now download these infographics from a dedicated website, benefiting from NASA's research as well as crowd members' efforts in translating this research for the general public (see Box 11.1).

BOX 11.1 GOALS OF *JPL INFOGRAPHICS*

The goal of JPL Infographics is to tap into the creative power of the public, uncovering new ways of explaining and understanding the wonders of space and space exploration. The marriage of science data and design may entice a brand-new audience and may even inspire those who have seen the data before to envision it in a new light.

-Quote from *JPL Infographics* website.

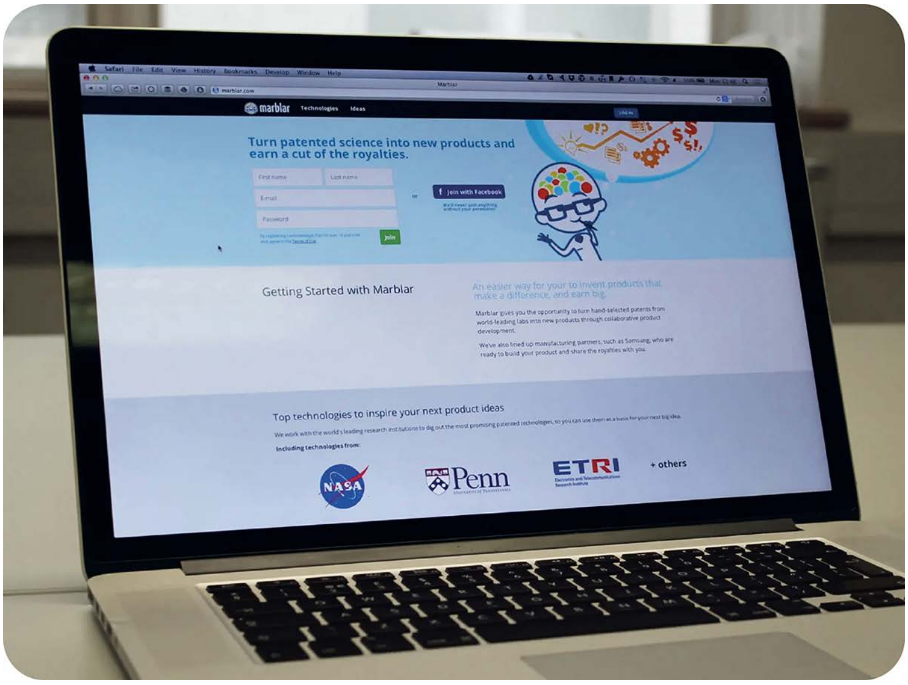
The platform *Marblar* tried to crowdsource the search for applications of new scientific discoveries.[3] Working with university technology transfer offices and various government institutes, the platform asked researchers to post a listing of their inventions on the *Marblar* website (see Figure 11.2), written in a style that is accessible to the broader public. Users were then asked to enter ideas for potential commercial uses, and they could interact with the researchers in

1 https://warwick.ac.uk/fac/sci/med/about/centres/clahrc/impact/bites.

2 https://www.jpl.nasa.gov/news/jpl-infographics-site-wants-you-and-your-creativity.

3 https://techcrunch.com/2012/10/22/dust-off-that-science-marblar/.

a Q&A section of the website. *Marblar* also asked the community to vote on ideas that had been submitted, allowing particularly promising applications to rise to the top, while giving crowd members points for submitting good ideas. Despite considerable initial momentum, as well as a pivot that allowed crowd members to benefit financially from their ideas, *Marblar* failed. One potential reason is that the platform generated ideas on how scientific findings could be used, but limited time and resources prevented researchers from following up on those ideas.[4]



Source: https://techcrunch.com/2013/10/23/marblar-samsung/.

Figure 11.2 Screenshot of Marblar website

Table 11.1 shows that crowd members in these example projects performed very different activities to diffuse and translate results. Accordingly, they also contributed different types of knowledge – including both substantive knowledge on project results as well as knowledge about different diffusion mechanisms (e.g., graphic design) and about relevant audiences. Although many diffusion activities just required a computer, resources for travel and physical meetings were essential in others. Crowd members tended to have considerable

4 https://techcrunch.com/2013/10/23/marblar-samsung/.

decision input regarding which particular results to diffuse, which audience to focus on and how to package the knowledge to transfer it to the audience.

Table 11.1 AKRD Crowd Contributions for example projects (stage: diffusing and translating results)

	CurieuzeNeuzen	BITEs	JPL Infographics	Marblar
Activities	Diffuse results in events and via posters; lobby with policy makers	Help develop and review short summaries of research findings	Turn NASA data and results into infographics for the general public	Come up with potential applications of scientific findings; vote on others' ideas
Knowledge	Knowledge of relevant audiences and policy contexts	Basic understanding of medical research; experiential knowledge about the respective disease or health-care challenge	Basic understanding of topic and results; specialized skills in graphical design	Knowledge of problems and different application areas
Resources	Transportation to events and meetings; space to put up posters	Computer; transportation to meetings	Computer and internet connection	Computer and internet connection
Decisions	Generate options (what results to highlight, where to diffuse, whom to approach); select options	Generate options (what results to highlight, what recommendations to make and what language to use); select options	Generate options (data and results, design choices); select options	Generate options (e.g., potential applications); select options (non-binding votes)

Figure 11.3 shows, for each case, the Crowd Science Paradigms that we believe are most useful in understanding the benefits of crowd involvement; we will explain our assessments in the next section.

11.2 BENEFITS OF INVOLVING CROWDS IN DIFFUSING AND TRANSLATING RESULTS

As discussed earlier, one important mechanism to improve diffusion and translation through crowd involvement is that participants themselves learn about the data, results, or implications of the research by participating in any of the stages of the research. This is illustrated by *CurieuzeNeuzen* but also

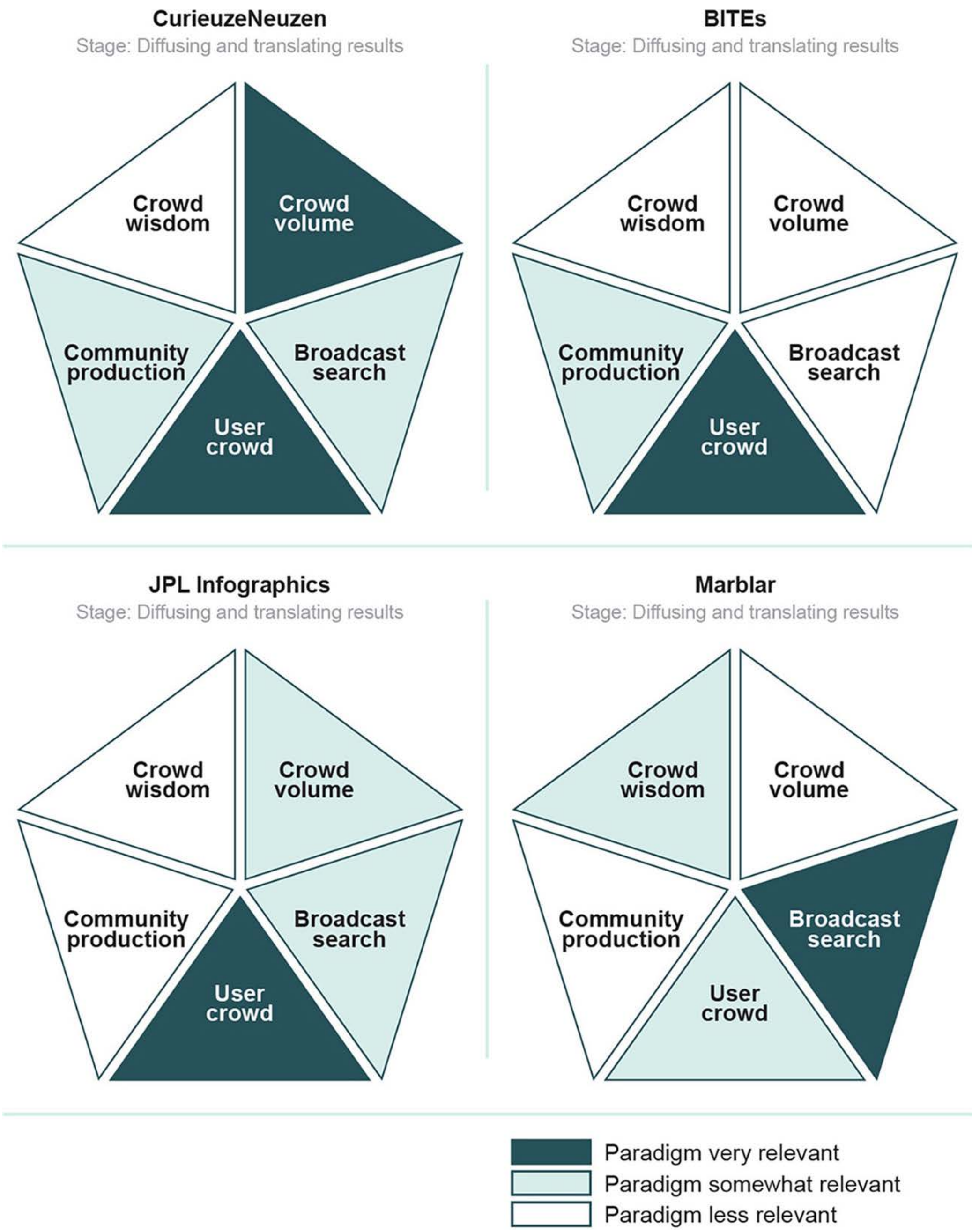


Figure 11.3 *Crowd Science Paradigm Diamonds for example projects (stage: diffusing and translating results)*

by other examples such as *eBird*, which provides a large suite of products to visualize bird data or to enable bird identification, as well as *Mosquito Alert* or *Aurorasaurus*, which map results for contributors and the public (see section 7.1). Many projects provide extensive scientific background information for participants that goes beyond what would be needed to perform required tasks, and they also promote project outputs among participants. *Zooniverse*, for example, publishes regular reports featuring different projects and their results and distributes these reports to contributors by email.[5] Learning opportunities for participants are a key rationale for the growing public support of crowd science (National Academies, 2018; Turrini et al., 2018). Enabling learning is also an important goal of many organizers (see section 1.2), and learning opportunities may motivate individual crowd members to join (see Chapter 14). Either way, diffusion through participant learning is closely linked to the crowd volume paradigm – the more people participate, the greater the diffusion by participation. Of course, the crowd volume paradigm also captures well some of the benefits of explicit outreach activities undertaken by participants in projects such as *CurieuzeNeuzen*: The more people hang up posters with project results or participate in outreach events, the wider the diffusion of the results to the public is.

The broadcast search paradigm appears particularly relevant to *Marblar*, which announced scientific discoveries broadly on the website, hoping to catch the attention of those people who have an outlier idea regarding the best commercial applications of these discoveries. To some extent, broadcast search is also a useful lens to understand *JPL Infographics*; this project broadcasts the call for contributions to the public to identify those individuals who are interested in JPL data and missions and, more importantly, have the skills to design effective infographics.

All example projects also reflect benefits highlighted by the user crowd paradigm. A key benefit of involving crowd members in the diffusion and translation stage is that these people are also typically part of the audience that projects seek to reach with their results. For example, involving patients and patient advisors in writing and reviewing summaries of medical research helps the *BITEs* project because these people likely represent one of the key audiences for which such summaries are written. Similarly, non-professional crowd members designing infographics for JPL may have a good sense of what people without a professional research background find interesting and are able to process. And the same goes for *CurieuzeNeuzen*: By involving residents in the diffusion of results, the project can leverage their knowledge about how those results can be used, what results may resonate most with different stakeholders, and how results should be framed to have a greater impact on citizens' behaviors. Crowd members helping find applications for new technologies on *Marblar* may also benefit from having worked in potential application

5 https://www.zooniverse.org/about/highlights.

contexts (Shane, 2000), although this does not seem to be as important as in the other example projects.

The community production paradigm leads us to think about potential benefits resulting from interactions and the integration of knowledge held by different crowd members. This may be somewhat important for the learning-by-doing aspect of diffusion: If projects involve interactions between crowd members (as well as organizers) at any of the stages of the research process, participants may help each other to understand data, results, as well as potential implications for practice. Examples include *CurieuzeNeuzen*, *Eterna*, and *Epidemium* projects, as well as *BITE*s. Community production appears less relevant in projects that specifically involve crowd members in individual activities related to diffusion, such as *JPL Infographics* or *Marblar.*

In addition to broadcast search, *Marblar* also relied to some extent on crowd wisdom. Even crowd members who had no ideas for applications of technologies could read others' ideas and judge whether they had potential – the more users voted for a particular idea, the more attention this idea would receive. And the more people vote, the more representative the results are likely to be regarding the underlying preferences and knowledge of the general population. This example has many similarities with our discussion of voting at the beginning of the research process, e.g., in the selection of research questions or funding proposals (Chapter 4). No matter the stage, involving the crowd in decisions about which ideas to move forward provides a greater opportunity for the crowd to contribute their knowledge as well as preferences (Beck et al., 2023). Whether and how much of this is desired depends, of course, on the goals of the project organizers.

11.3 STAGE-SPECIFIC CHALLENGES AND POTENTIAL SOLUTIONS

Rewards for researchers. In Chapter 14, we will discuss the cross-cutting challenge of how to recruit and motivate crowd members to contribute to research. We tend to take the motivation of project organizers as a given, since their job (and often intrinsic desire) is to create new knowledge and publish it (Merton, 1973; Stephan, 2012). This assumption is less realistic, however, for research dissemination because dissemination activities beyond the community of peers are not always rewarded by academic institutions and their performance assessments. Indeed, the additional work required to enable crowd members to learn by participating in research projects or to engage in other dissemination activities may create trade-offs in terms of lower research productivity due to time and resource constraints that most project organizers face (Druschke & Seltzer, 2012). Of course, crowd involvement in diffusion can in some cases help researchers accomplish other goals, e.g., when crowds help identify technology applications as a starting point for out-licensing or other forms of academia-industry collaboration (Perkmann et al., 2013). Dissemination activities are also increasingly included in tenure and promotion guidelines and are becoming important criteria for funding agencies. Many researchers also have an inherent motive to contribute to society with their work (Beck et al., 2019; Cohen et al., 2020). Thus, at least some organizers will see dissemination – with the help of crowd members – as a valuable mechanism to have a broader impact and are willing to make the required investments of time and effort. Crowd members who feel that opportunities for their own learning and for the diffusion to other audiences are untapped can also ask for organizers' support in such activities in return for the many contributions they are making to achieve the scientific goals of a project.

Quality standards and risk of bias. An important aspect of successful crowd science projects is to ensure the quality of crowd contributions so that project results pass the evaluation of peers and are accepted as scientific contributions (see section 13.4). Agreeing on quality standards and ensuring quality is difficult at all stages of the research process, but it seems even more difficult in the area of diffusion. Of course, it may be possible to judge whether infographics produced by *JPL Infographics'* contributors or *BITEs* produced with patient input are easy to understand. But it is harder to judge whether the information conveyed is accurate and sufficiently comprehensive. Communicating research results to the broader public almost invariably necessitates a loss of fidelity and nuance, but we lack a good understanding of the trade-offs between accuracy and accessibility to non-scientific stakeholders, and there is often disagreement about how such trade-offs should be resolved (Brownson et al., 2018).

Perhaps even more importantly, there is a concern that crowd members who get engaged in diffusion may seek to further their personal goals rather than the interests of science or the public. For example, crowd members who advocate for particular social issues or policy decisions may selectively diffuse project results to support their views while ignoring results that may challenge their views (Doche, 2021; Schmidt, 2015) (Box 11.2). Not everyone may see this as a concern – after all, public involvement in science is also meant to democratize access to knowledge, and individuals, in most countries, are free to argue their points based on whatever evidence they wish to bring to bear. But this issue highlights a tension between professional norms of "disinterestedness" in the realm of scientific knowledge production on the one hand (Merton, 1973), and ill-defined or contested norms regarding knowledge diffusion on the other (Cologna et al., 2021). It is not clear how big of a problem this is or what can be done, but we suggest having explicit discussions among project participants to clarify the goals of a project's diffusion and translation activities, being open about the inevitable role of preferences in related decisions, disclosing conflicts of interest, and agreeing on minimum standards for diffusion activities (Schmidt, 2015).

BOX 11.2 DIVERSITY IN MOTIVES AND USE OF RESULTS

Factors such as gender, employment, and social class strongly influence why people enter citizen science, how science is mobilized, and how data about a controversial hazard ends up being interpreted. For instance, people like Natsuo have used the results gathered by citizen science to highlight the dangers of living in Fukushima, while other citizen science organizations help bring people back to their beloved region.

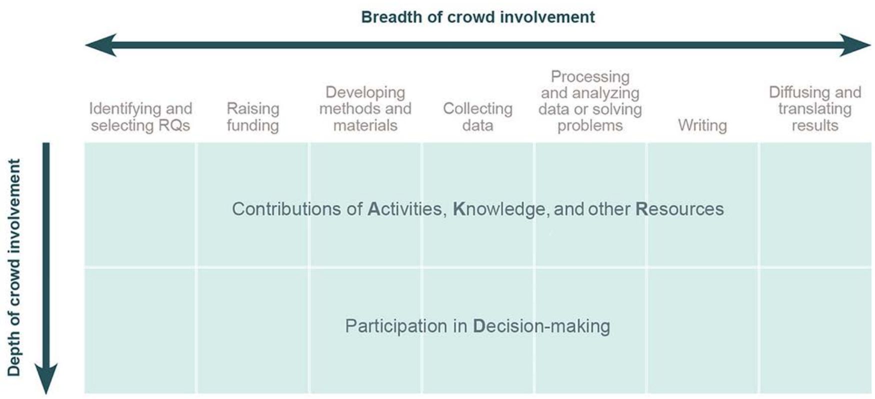
-Polleri (2020).

Our website www.sciencewithcrowds.org includes stage-specific templates of the 4Q Tool and Crowd Science Design Canvas. These templates will help you explore whether and how crowd involvement in diffusing and translating results might be helpful in your project. To see how these templates are used, check out the examples using fictional characters ("personas") in Chapters 4, 6, 7, and 9. The website also lists additional resources, including selected platforms and tools you could use to involve crowds in this stage.

12. Crowd involvement across multiple stages

12.1 THE BREADTH OF CROWD INVOLVEMENT

Chapters 4–11 each focus on a particular stage of the research process. However, several example projects came up in multiple chapters, suggesting that they (and many others) involve crowd members across multiple stages. Conceptually, this can be thought of as greater "breadth" of crowd involvement in a project, as opposed to greater depth in terms of contributions within a given stage (see Figure 12.1).



Source: Based on Beck et al. (2023).

Figure 12.1 Breadth vs. depth of crowd involvement

Some advocates believe that broader crowd involvement is better because projects can generate more crowd contributions, but also because broader involvement often implies more meaningful activities and a greater role in decision-making for crowd members. As highlighted in section 2.3, however, shared decision-making can also be implemented in a single stage. Moreover, the observation that most projects involve crowds only in one stage of the research (mostly in data collection or processing) suggests that crowd involvement across multiple stages may not always be desirable or even feasible. So, when does broader crowd involvement make sense, what challenges can arise, and how can organizers address those challenges?

Decisions regarding the appropriate breadth of crowd involvement should, of course, reflect the benefits and costs of involving crowds at any of the stages discussed in Chapters 4–11 in isolation. However, organizers should also consider interdependencies that can arise across stages – both positive (synergies) and negative (trade-offs). In the following sections, we discuss such synergies and trade-offs from the perspective of both organizers and crowd members, and we outline some strategies that organizers can use to enable crowd involvement across multiple stages (summarized in Table 12.1).

Table 12.1 Synergies, trade-offs, and design implications when involving crowds in multiple stages

Potential synergies and trade-offs	Design implications
For organizers • Some costs are "fixed" and can be shared across stages. E.g., – Building digital project infrastructure, algorithmic management tools – Recruiting crowd members – Organizers' skills and relationships → Larger synergies if the same Crowd Science Paradigms can be leveraged across multiple stages • Involving crowds across multiple stages requires greater resources in terms of time, infrastructure, etc	• Optimize design decisions across multiples stages (including potential future expansion) • Identify core infrastructure that can be used across multiple stages (especially if the same Crowd Science Paradigms apply) • Develop additional modules for needs that are stage-specific • Develop specialized roles on project teams to leverage learning that applies across stages and to provide stable points of contact for participants
For crowd members • Knowledge gained by crowd members in one stage can increase their effectiveness in other stages • Broader involvement across stages can increase motivation and engagement • Broader involvement imposes additional costs on participants. E.g., – Time to train and learn, time to perform multiple activities, stress if cannot live up to expectations – Costs of other resources such as materials, transportation, etc. (see AKRD Crowd Contribution Matrix) → Benefits and costs typically differ for different crowd members in a given project	• Develop mechanisms to transfer knowledge across stages and crowd members (e.g., knowledge repositories) • Enable crowd members to see the "big picture" that arises over the course of the project; explain how involvement in one stage helps in another • Recognize and help mitigate costs especially for highly involved crowd members • Offer different levels of engagement (with respect to breadth across stages but also depth within each stage); enable crowd members to self-select based on abilities, interests, and time • Create "career ladders" for participants that lead from smaller to larger breadth of involvement

12.2 SYNERGIES AND TRADE-OFFS ARISING FOR ORGANIZERS

Involving crowds in multiple stages may allow organizers to benefit from a broader range of crowd contributions. However, broader crowd involvement also requires infrastructure, time, and skills to enable and manage participation in multiple stages.

One important type of synergy for organizers arises if the costs of setting up infrastructure and running projects are largely fixed, such that they can be spread out across multiple stages of the research process. For example, the costs of developing a digital platform to recruit and coordinate crowd members are largely fixed, and once the platform runs, the additional costs to recruit crowd members for an additional stage tend to be small. Similarly, the costs to develop tools to train participants or to implement algorithmic management may partly be fixed (see section 15.3), reducing the incremental costs of using these tools for additional stages. Finally, one of the largest costs is the time organizers need to learn how to set up and manage projects and to develop a trusting relationship with the crowd. Once these costs have been borne, the knowledge and relationships can be leveraged to involve crowds in additional stages.

Such synergies from re-using existing infrastructure or approaches of crowd involvement will be limited, however, if the relevant Crowd Science Paradigms (section 2.4) differ across stages. The reason is that different paradigms often require different kinds of crowds to be involved, as well as different approaches and infrastructure to motivate and facilitate their contributions. Consider our fictional character Linda. The dominant paradigms she leveraged when involving the crowd in developing better methods and materials were community production and user crowds: A relatively small number of highly engaged organizers of substance use disorder (SUD) support groups helped her design methods and materials for a research study, building on their unique knowledge and relationships with people affected by SUD (Chapter 6). When using the crowd for problem-solving, however, Linda primarily relied on the broadcast search paradigm to identify creative and effective designs for digital therapy tools using a crowdsourcing contest (Chapter 9). The ideal crowds for the two stages were quite different, and Linda had to use very different infrastructure to enable crowd participation (offline and online workshops, a contest platform). At the same time, Linda discovered potential synergies in that she could re-engage some of the crowd members from the first project for the second project: The organizers of support groups could help her evaluate designs for digital therapy tools submitted by participants of the contest. Recruiting this crowd of support group organizers only for that purpose may not have been worth it in isolation, but given that she had already established relationships, it made sense to also involve them in the evaluation of solutions. And there may be even further synergies down the road (e.g., when Linda needs to design clinical trials for testing the digital therapy tool or when she needs to recruit trial participants).

This discussion has important implications for organizers. First, organizers considering crowd involvement in a particular stage should think ahead to whether crowd involvement might also be useful in later (or earlier) stages of a project. If so, they should optimize project design holistically, considering how the different types of crowd contributions can be managed most effectively. For example, the ideal design to maximize the benefits of community production in one stage may be a series of elaborate offline co-creation workshops, while the ideal design to maximize the benefits of broadcast search in another stage may be a digital platform. When organizers realize that they have to build an online platform anyway, they may find it more cost-effective to also move (some of) the co-creation activities online, saving lots of resources while still generating most of the benefits.

Second, organizers should try to identify which aspects (and costs) can be made fixed and leveraged across stages, and which aspects have to be modular to enable customization for each stage. *Epidemium*, for example, uses a standard infrastructure to enable coordination among crowd members regardless of what stage of the research they are working on, but then also offers specialized tools for different stages.

Third, as projects scale in terms of crowd participants but also stages of involvement, the total volume of work for organizers will increase. This will often make it impossible for individual organizers to handle all important aspects of a project, and projects will have to be run by larger teams. This, in turn, provides opportunities for specialization such that individual organizers in a team can develop skills and capabilities in particular areas and leverage them across stages. Large projects, such as *Eterna,* for example, may have a dedicated community manager or research coordinator who builds and maintains relationships with crowd members across different stages. Others may have technologists who develop digital infrastructure regardless of what stage it is used for, allowing them to stay up to date on technical developments but also to design tools that can be leveraged across multiple stages of the research process.

12.3 SYNERGIES AND TRADE-OFFS ARISING FOR CROWD MEMBERS

Turning to the perspective of crowd members, one potential synergy is that the knowledge they acquire when participating in one stage may also increase their effectiveness in other (subsequent) stages. For example, crowd members may learn about methods while participating in the design of methods and materials, which then allows them to better utilize those methods in data collection or analysis (ExCiteS, 2019). Similarly, involvement in data collection can give crowd members insights about the phenomenon that is being studied, and these insights can be useful in interpreting results at a later stage (Van Brussel & Huyse, 2018). In some sense, these knowledge-related synergies reflect interdependencies between tasks that make it advantageous for the same person to perform multiple tasks, i.e., to use less task division (see section 13.1).

A second type of synergy can arise with respect to crowd members' motivation and engagement. Research in organizations has shown that people appreciate working on more holistic tasks that allow them to see the big picture and have a feeling of accomplishment, while small micro-tasks can quickly become boring (Hackman & Oldham, 1976). This suggests that involvement across multiple stages can make project participation more interesting and rewarding for crowd members. The support group organizers in Linda's case, for example, may be more interested in helping her develop the methods and materials for learning about challenges with digital healthcare tools if they know that they can also participate in selecting which designs will be tested and possibly implemented at a later stage (Chapters 6 and 9).

However, involvement across multiple stages also imposes greater costs on participants, and many may not be willing to bear those costs. This includes the cost of time – crowd members may not have the time or interest to spend many hours participating in multiple activities, or to stick around for months and even years as a project moves through different phases. Costs also include other resources such as money or materials that are required to participate in each of the stages (the "R" component of the AKRD Crowd Contribution Matrix). The higher these costs are when added up across multiple stages, the less likely it is that crowd members are willing to participate in multiple stages.

Organizers should consider these synergies and trade-offs in their project design. First, they should identify potential knowledge-related synergies and devise mechanisms that reinforce and leverage them. This may include, among other things, knowledge repositories that allow individual crowd members (and the crowd as a whole) to store and carry forward knowledge across stages. Such repositories can develop naturally if discussions among crowd members are stored digitally (e.g., Slack channels in *Eterna*; *Zooniverse* Talk pages), but it may also be useful to ask crowd members to summarize key insights or document processes at the end of important milestones to ensure nothing gets lost. Organizers should also activate relevant knowledge at the right time, e.g., by alerting crowd members that the knowledge acquired in a prior stage may be useful for performing a new task.

Second, projects asking crowd members to participate in multiple stages should clarify for participants how their various contributions add up to the big picture and can result in a bigger scientific and societal impact (e.g., an effective digital therapy tool in Linda's case). Clarifying these linkages may better enable crowd members to leverage learning across stages and increase their motivation to participate more extensively.

Third, projects should always try to minimize the costs that have to be borne by crowd members, but this is particularly important if they expect participants to contribute in multiple stages. In some cases, organizers may be able to reduce costs by combining activities that pertain to different stages of the research process (e.g., using the same workshop to discuss both research questions and methods). In other cases, organizers may want to help highly involved participants pay for resources they could otherwise not afford.

Perhaps most importantly, organizers should recognize that the motivational benefits as well as the costs of broad involvement will differ across crowd members. While some participants may find it exciting to get involved across multiple stages and for longer periods of time, others will have little interest and perceive requests for broader involvement as a burden. Therefore, organizers should design different options and allow crowd members to choose how broadly they want to get involved (see Box 12.1). Examples include *Eterna*, where most crowd members just develop RNA designs, but some contributors decide to get involved in voting for RNA designs or in writing papers. Similarly, most contributors in *Galaxy Zoo* use the easy-to-use classification interface to help with data processing, but some users decide to also discuss difficult cases on the discussion board or co-author papers on noteworthy discoveries. In *CurieuzeNeuzen*, most people participated by collecting air samples, but some decided to also get involved in data analysis and the diffusion of results. An intriguing idea is to use algorithmic management to facilitate this aspect: AI could use data on contributors' skills and activity patterns to predict who might be interested and able to participate in additional activities and then invite them to broaden their involvement.

BOX 12.1 FLEXIBLE PARTICIPATION IN *EPIDEMIUM*

Sustaining participation in volunteer-driven communities can be challenging, particularly when participants come from diverse backgrounds and disciplines. *Epidemium* is an excellent example of how teams can create synergies across various fields. To facilitate this, they developed a system allowing users who cannot fully commit to a project to donate their skills and respond to the specific needs of different teams.

-Olga Kokshagina, Professor of Innovation and Entrepreneurship and advisor to the *Epidemium* platform, personal communication.

PART III

Cross-cutting themes

13. Organizational challenges and solutions

The prior chapters discussed how crowd involvement can provide benefits at different stages of the research process. We now turn to cross-cutting themes that are relevant regardless of the particular stage of research. Chapter 13 focuses on challenges related to the organization of projects, e.g., how to allocate tasks to crowd members, how to coordinate and share information, and how to help crowd members learn and improve their skills. Although such challenges can sometimes be addressed once they arise, it is better to consider them explicitly when designing projects. Our discussion draws on a large literature in organization theory and management that interested readers can consult if they wish to explore any of the topics in more depth.

13.1 DIVIDING TASKS AND ALLOCATING THEM TO CROWD MEMBERS

Research tasks are typically too large to be performed by individual crowd members. For example, a crowd member involved in the development of research questions cannot review all the relevant prior literature, and a crowd member helping collect biodiversity data cannot collect data on all relevant species in all relevant locations. Thus, large tasks such as developing research questions or collecting comprehensive data on animals need to be broken into smaller sub-tasks (task division), and these sub-tasks need to be allocated to different participants (task allocation) (Puranam et al., 2014; Shibayama et al., 2015).

For some kinds of tasks, task division is quite natural and relatively simple. For example, each image in *Zooniverse* projects is a self-contained sub-task that can be assigned to different contributors for classification. In *CurieuzeNeuzen*, data collection tasks are naturally defined by different locations at which crowd members are located. Other projects may find it more difficult to divide tasks. Consider the examples of *Epidemium* projects or *Polymath*, where crowd members participate in more complex activities such as identifying problems, formulating hypotheses, or developing a mathematical proof. In those cases, it is more difficult to split the task into pieces because potential sub-tasks tend to be interdependent, such that the best solution to one depends on what is done in another. For example, evaluating the novelty of a research question requires knowing about the research that has already been done, and it is difficult to separate these two activities.

A useful rule is that tasks should be divided such that interdependent sub-tasks are kept together to be assigned to the same individual, while sub-tasks that are less interdependent can be separated. In other words, the challenge is to create task "modules" that have little interdependency with each other, allowing different individuals to work on them relatively independently (Baldwin & Clark, 2000). This is true in organizations generally but especially in distributed organizations such as crowd science projects, where it is often difficult for crowd members to coordinate and exchange task results (see section 13.2 below). Modularization also reduces risk because problems with one module can remain isolated without spilling over into other modules. For example, a contributor failing to submit their work affects only the sub-tasks included in that worker's module but not the work of others.

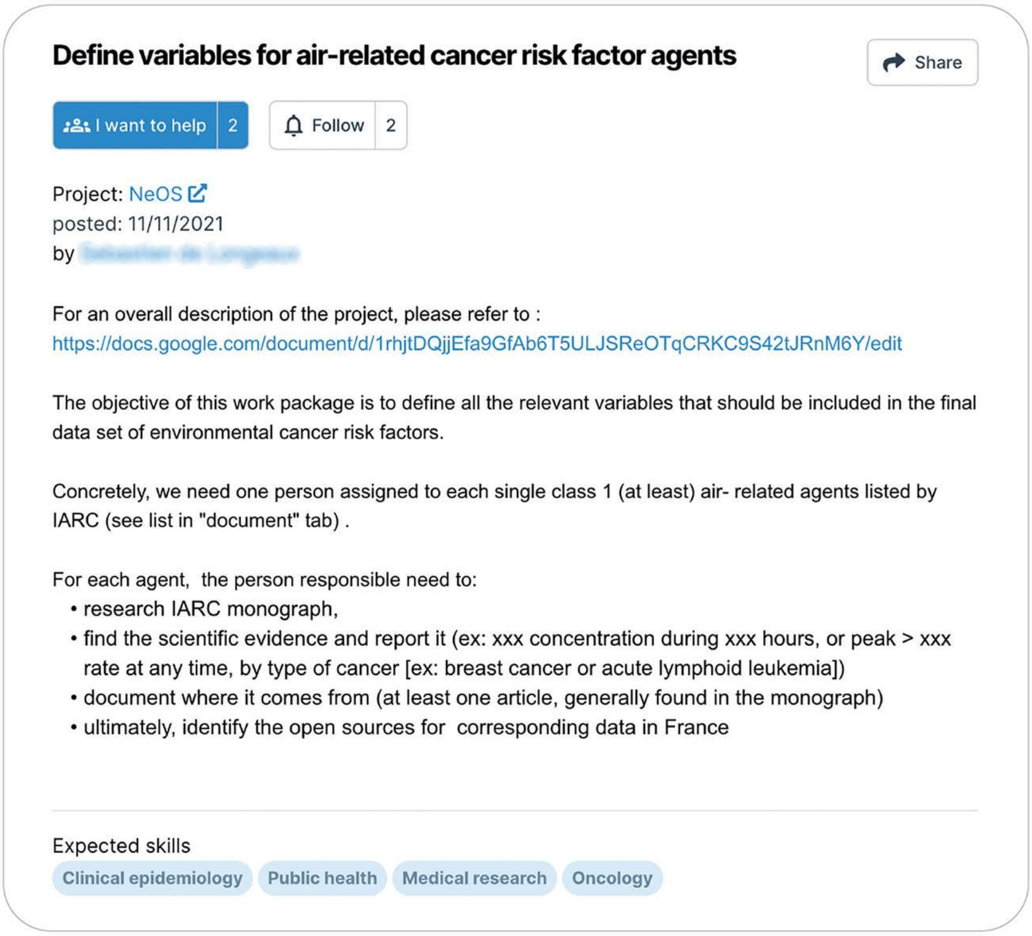
BOX 13.1 TASK DIVISION AND TASK ALLOCATION

Task division: Breaking down a large task into sub-tasks that can be performed by different individuals. Recommendation: Create modules that have low interdependencies between each other (but may have interdependencies within).

Task allocation: Deciding which crowd members should perform which sub-tasks. Recommendation: Create a match with respect to skills but also time commitments and interest. Rely on self-selection or learning about participants over time.

With respect to task allocation, organizers should strive for a good match between tasks and participants in terms of task difficulty and required skills, but also in terms of the nature of the task and participants' interests. In traditional organizations, task allocation is often handled by managers who have good knowledge about tasks as well as about their employees. In crowd science projects, organizers may have good knowledge about the tasks but often do not know much about the skills or interests of potential contributors. Two main approaches can be used to overcome this challenge.

First, many projects rely on self-selection. If it is easy to see what a task involves, potential contributors can decide for themselves which task is the best match for them (Raveendran et al., 2022). For example, people who think they have high skills can choose to work on more challenging tasks, people with little time can choose to work on small tasks, and people who are more interested in task A can choose to work on task A rather than on task B. To facilitate this self-selection, projects should provide sufficient information about the different tasks that are available. The AKRD Crowd Contribution Matrix introduced in section 2.3 is a good tool projects can use to provide such descriptions. Figure 13.1 shows an example of a "help wanted" posting by the *Epidemium NeOS* project that provides useful information for potential contributors to self-select into a particular task. Videos of project meetings or research activities can also help interested individuals to get a better sense of different tasks. And, of course, crowd science projects are usually very open and transparent so that interested people can simply join and try them out: They can read a live *Polymath* blog to see if and how they can contribute or sign up for different *Zooniverse* projects to see which ones are most fun.



Source: http://epidemium.org.

Figure 13.1 *Task description in Epidemium NeOS project facilitating self-selection*

Second, organizers of crowd science projects can learn more about participants over time and subsequently better allocate tasks. For example, many large projects on *Zooniverse* as well as *Eterna* invite contributors who have shown high levels of skill and dedication to work on more challenging objects or to move to more demanding tasks such as managing discussion boards, helping beginners with difficult cases, or participating in data analysis (Trouille et al., 2019). Organizers of small projects will typically see who emerges as key contributors. Organizers of larger projects who find it difficult to get to know crowd members can use IT tools and even artificial intelligence to do so. For example, online projects often ask participants to log in, allowing organizers to measure crowd members' activity and contributions as a basis for more customized task allocation. Some advanced projects have moved towards fully automating task allocation using AI: Algorithms can estimate the difficulty of different tasks, update records of crowd members' skills and interests, and then match tasks and crowd members on an ongoing basis. This use of AI to help organize crowd members is an example of "algorithmic management"; we will discuss additional examples below (see also Koehler & Sauermann, 2024; Trouille et al., 2019).

13.2 COORDINATING

When the tasks assigned to different crowd members are highly modular, contributors can work independently, and their outputs can be simply collected and combined afterward. Examples include most image classification projects on the *Zooniverse* platform. In other cases, however, the tasks of crowd members are not fully independent and still need coordination. In monitoring projects such as *eBird*, for example, a common challenge is that crowd members' activity is unevenly distributed – many people look for birds when the weather is nice but not when it is raining, or in places that are easy to reach rather than places that are more difficult to access (August et al., 2020). To get the balanced coverage needed for valid scientific research, the activities of different observers need to be coordinated.

One approach to accomplishing coordination is to share information with project participants. *eBird*, for example, publishes maps that show where others are birding, allowing contributors to adjust their own activities to cover areas that are in greater need of observation. Organizers have even developed an algorithm that provides different levels of rewards for collecting data in different locations, steering people into areas that have been insufficiently covered by others (Xue & Gomes, 2019).

Coordination is also required if some crowd members work with the outputs of others, or if the knowledge of one person can be helpful to another. For example, crowds in *Epidemium* projects perform all stages of the research, but individual contributors may focus on different tasks. As such, they need to coordinate regarding the timing of activities, quality standards, or the format in which intermediate results should be exchanged. Organizers can facilitate such coordination by setting pre-defined rules, e.g., regarding which statistical programs and data formats should be used or when outputs should be delivered. If such rules cannot be set ex ante because coordination needs also depend on the needs and capabilities of participants and on how the work develops over time, organizers can provide infrastructure that enables participants to interact and coordinate in real time over the course of the project. *Epidemium* projects, for example, use tools such as Slack, GitLab, Google Docs, as well as virtual and physical meetings.

If coordination and knowledge exchange are particularly difficult, organizers can facilitate interactions between crowd members in workshops or related formats. Examples include co-creation projects that often require intensive discussions and sometimes also contentious balancing of competing goals and interests, especially if crowd members participate in decision-making (see AKRD Crowd Contribution Matrix in section 2.3). In such situations, facilitators – including project organizers but also external experts – may be needed to ensure a productive exchange. Sessions to co-create research methods in the *TARGet Kids! PACT* project, for example, comprised not only researchers, clinicians, and parents, but also a facilitator who was responsible for ensuring open communication between participants (Vanderhout et al., 2021) (see section 6.1).

BOX 13.2 COMMON COORDINATION MECHANISMS

Common coordination mechanisms include:

- Information about others' activities
- Rules on how to perform activities
- Infrastructure for real-time interactions among individual crowd members
- Moderated group interactions

Of course, such high-touch coordination is resource-intensive, requiring considerable amounts of time from facilitators and crowd members. Moreover, it is often easier to accomplish in face-to-face meetings rather than online, but physical meetings impose additional costs and may narrow the number and diversity of crowd members who are able to join (Beck et al., 2023). Given these coordination costs, organizers should seek to reduce the need for coordination to begin with, i.e., by creating task modules that require less coordination between different contributors (see section 13.1).

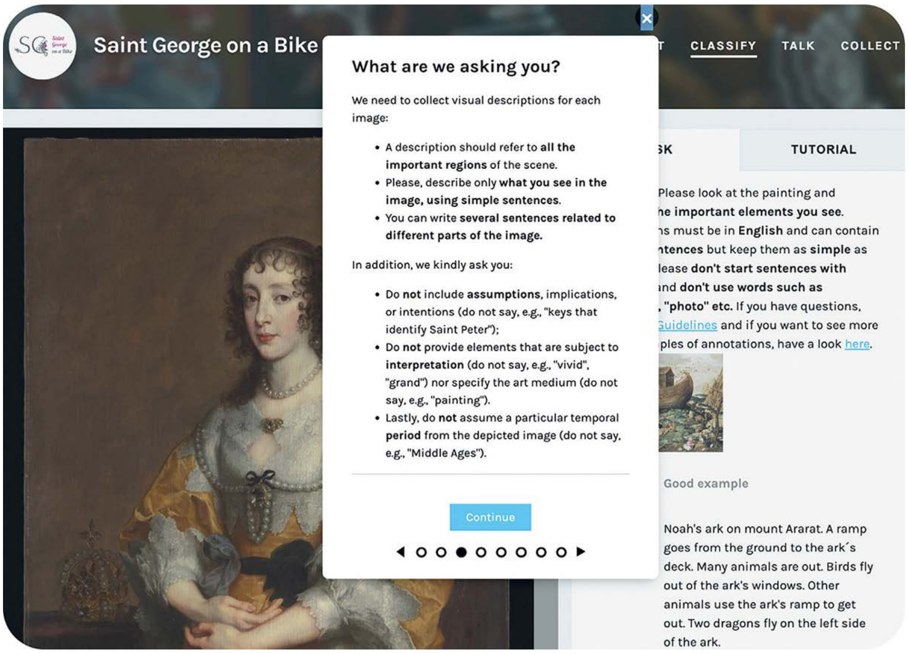
13.3 TRAINING AND ENABLING LEARNING

Trying to match tasks and crowd members based on task requirements and existing skills is often not enough. Projects also need to train crowd members and facilitate their learning over the course of the project. This is important to improve efficiency, e.g., to enable crowd members to make higher-quality contributions without having to spend too much time on tasks. Training and educating crowd members is also an important democratization goal for many projects (see section 1.2), can be an important motivator for some contributors (section 14.1), and is an important way for projects to give back to the broader community.

Many projects involve initial onboarding and basic training that tell crowd members what they are asked to do and familiarize them with the necessary tools and infrastructure (Figure 13.2). Such training often involves practice tasks that allow participants to get feedback on mistakes and opportunities for improvement without jeopardizing scientific output. In image classification projects, for example, new crowd members are often asked to classify images for which the correct answer is already known. Although many projects limit feedback to information about whether an answer was correct or incorrect, customized (potentially AI-generated) feedback that points out potential reasons for a misclassification or highlights features the contributor should pay attention to in the future can significantly improve learning (van der Wal et al., 2016). Depending on the nature of the project and the skill levels of the crowd, organizers may also design other formats to train new participants, e.g., in-person training sessions, allowing new members to shadow experienced contributors, or providing participants with written training materials.

Although training can be effective, many contributors prefer to get to work immediately. The time required for training also typically reduces the amount of time contributors will be productively engaged. Finding the right balance is difficult because of significant differences across contributors in terms of existing skills and knowledge, their speed of learning, but also their willingness or ability to spend time on the project. A recent study suggests that AI can help organizers to personalize training by tracking crowd members' progress and adjusting the training experience accordingly (Jackson et al., 2020).

One approach to avoid using time for initial training is to give new crowd members real tasks that are relatively easy. Projects can then systematically guide participants towards more difficult tasks, enabling "learning by doing". This setup can be difficult to implement, however, because it requires features that facilitate learning throughout the work process (e.g., feedback



Source: https://saintgeorgeonabike.eu.

Figure 13.2 Tutorial in the art history project Saint George on a Bike (hosted on Zooniverse, using a standard Zooniverse tutorial template)

mechanisms, tracking progress) and may result in some lower-quality work early on. Moreover, it only works if there are some tasks that are easier than others, and if projects have mechanisms to allocate those tasks based on participants' experience and skill levels (see section 13.1).

Before designing training mechanisms, organizers should think carefully about *what* crowd members should learn. The answer seems obvious in projects asking for data collection or image classifications – although even there, contributors may wish to learn more or different things than just what is required to get the job done. Things are less clear in projects that involve crowd members in other stages of the research process and projects that involve participants more deeply in decision-making. In such projects, crowd members may need to learn not only about objects of study (e.g., bees) but also about scientific processes (e.g., the advantages and disadvantages of different methods to study bees). They may even have to learn some scientific jargon to have productive discussions with each other and professional project organizers (Beck et al., 2023).

Although our focus has been on training and educating crowd members, we note that professional project organizers also need to learn, especially about many of the cross-cutting themes discussed in this chapter and Chapter 14. As such, project organizers should explicitly identify their own learning goals and put in place mechanisms to ensure progress. This may include, among other possibilities, going through online training offered by organizations such as the European Citizen Science Association (ECSA), the Association for Advancing Participatory Sciences, or universities,[1] as well as getting feedback from experienced crowd science organizers. They should also gather feedback from project participants at regular intervals and establish key performance indicators that can be used to track progress, detect problems, and verify improvements when changes have been made (for an example, see Cox et al., 2015).

13.4 INCREASING THE QUALITY OF CONTRIBUTIONS AND EVALUATING SUBMISSIONS

13.4.1 Increasing the Quality of Contributions

A large body of prior research has discussed the quality of crowd contributions, primarily in the context of data collection or processing. Recent reviews suggest that data quality is sometimes low, but it can meet, and even exceed, the quality generated by professional scientists if projects are set up appropriately and recruit the right crowd (Aceves-Bueno et al., 2017; Balázs et al., 2021). Among other factors, quality can be expected to be higher if crowd members have the necessary skills and knowledge. This can be accomplished by dividing tasks so that they are not too difficult and complex, matching participants and tasks based on task difficulty and skills (section 13.1), and training crowd members more extensively (section 13.3). Moreover, quality is higher if crowd members are motivated to make meaningful contributions – whereas it may suffer if they pursue secondary goals such as winning in gamified contests (section 14.1).

Some projects now provide AI-based tools that help participants to perform their work, reducing the time and effort required while also increasing quality. For example, environmental monitoring projects such as *eBird* or *Waarnemingen* provide tools that predict the correct species based on simple inputs such as the size and color of a bird, a photograph, and the observer's location. These tools enable projects to involve crowd members with lower levels of expertise, while not compromising, and sometimes even increasing the quality of the submitted data (Box 13.3).

1 https://extendstore.ucl.ac.uk/product?catalog=UCLXICSSCJan17.

BOX 13.3 ARTIFICIAL INTELLIGENCE IN *WAARNEMINGEN*

We put AI central in the new app and the website ... species recognition became available for 10 times more people, so we democratized for 10 time more people. Now, we have around 600,000 people in Belgium alone and before we had 60,000 observers.

-Wouter Vanreusel, co-organizer of *Waarnemingen*, personal communication.

Projects can also increase data quality by designing processes that reduce the risk of errors. For example, monitoring projects such as *eBird* use algorithms to flag submissions that are unlikely to be correct given existing data from the same location (Kelling et al., 2013). Crowd members can then be asked for additional information, and submissions can be verified by expert users.

Another common mechanism is to have multiple crowd members perform the same task and use consensus methods to determine the solution that is most likely to be accurate. Difficult images in *Zooniverse* projects, for example, can be classified by dozens of crowd members until a consensus emerges, or until the image is passed on to experts to figure out why crowd members seem to be unable to agree (Swanson et al., 2016; Willi et al., 2019). This mechanism is useful for images that are difficult to classify but also reduces the influence of random errors that can happen to any individual contributor and for any kind of image, e.g., due to inattention or distraction (see our discussion of the crowd wisdom paradigm in section 2.4). That being said, consensus mechanisms may have a bias against findings that are novel or easy to miss (Lin et al., 2014), such that organizers need to think carefully about what they are trying to accomplish and what quality means in their particular context.

In some types of projects, crowd contributions are not simply correct or incorrect, but differ more gradually with respect to their quality. Consider the example of *Tell Us! Accidental Injuries*, which asked crowd members for novel research questions, or *Eterna*, which asks crowd members to come up with novel RNA designs. Such projects can increase quality by giving crowd members clear instructions regarding what criteria to pay attention to. When asking crowd members to formulate research questions, for example, organizers can clarify that good research questions should not just restate a problem and that they need to be novel, potentially impactful, as well as feasible (Beck et al., 2022b).

Projects can also provide templates and other tools that reduce common problems and guide crowd members toward higher-quality submissions. And of course, projects can incentivize crowd members to submit high-quality work using mechanisms such as prizes or even co-authorship on publications that are based on verified extreme-value contributions.

13.4.2 Evaluating the Quality of Contributions

Although organizers will be excited to receive a large number of contributions, evaluating all these contributions can take a lot of time and effort. This puts a strain on the capacity of organizers, and it can also have unintended side effects (Piezunka & Dahlander, 2015): When evaluating ideas or problem solutions, for example, projects that receive too many submissions may narrow their attention down to those submissions that look more familiar, leading to a bias against potentially more promising ideas that are unusual and more difficult to understand (see Box 13.4).

BOX 13.4 BIASES IN EVALUATING CROWD CONTRIBUTIONS

Despite the common belief that "more is better" an abundance of crowd contributions can foster biases that sideline novel ideas in favor of the familiar.

-Linus Dahlander, Professor of Strategy, personal communication.

There are several approaches to deal with these challenges.

Some projects use automated tools to screen quality. For example, algorithms can identify submissions that do not meet certain minimum criteria, e.g., research questions that include only problem statements but no potential causes or solutions. Algorithms can also detect suspicious outliers: The AI in a biodiversity monitoring project, for example, may flag a reported observation of an alligator in German rivers and pass it on to human experts for a closer look (Trouille et al., 2019). In other cases, AI can predict the quality of submissions from having seen prior judgments of humans, taking into account various types of information about the submissions as well as the crowd members (Nagar et al., 2016). In yet other types of tasks, quality can be computed automatically. In protein folding, for example, the quality of a solution can be computed as a function of various objective criteria based on physical laws (see section 9.3). Similarly, the quality of software algorithms in problem-solving tasks such as solar flare prediction can be judged automatically based on factors such as the fit with training data or the accuracy of predictions in test data.

Another approach to cope with large numbers of submissions is to involve the crowd in evaluations. Recall that *Eterna* players come up with new RNA designs but can also vote on which designs should undergo expensive lab tests (Chapter 9). Such crowd voting is more likely to work if crowd members have relevant knowledge to evaluate submissions, if their preferences are directly relevant to judging the value of submissions (Mollick & Nanda, 2016; Müller-Trede et al., 2018), or if evaluations are subject to errors and biases such that a large number of votes can lead to "wisdom of the crowd" effects. Recent work suggests that crowd voting can also increase crowd members' motivation to submit ideas in the first place (Chen et al., 2020). But organizers need to be careful about incentive conflicts – if the crowd members who are asked to evaluate solutions also submitted solutions, they may favor their own solutions even if they are not necessarily the ones of the highest quality. Of course, evaluation systems can be tweaked to avoid such problems, e.g., by separating the roles of evaluators and submitters or by preventing people from voting for their own ideas.

Whether it concerns quality in the sense of accuracy (of data) or in the sense of identifying better research questions or problem solutions, it is important to keep in mind that the relevant dimensions of quality, as well as quality thresholds, are often subjective. For example, there may be no objective "true" quality of research questions, choices of research methods, or solutions to complex problems. Rather, different people use different preferences or knowledge when judging those types of contributions, and assessments may differ between stakeholders such as professional scientists versus crowd members (Beck et al., 2022b; Ottinger, 2010). Moreover, given that perfection is impossible or extremely costly, many organizers do not seek to eliminate all errors but instead define acceptable quality thresholds depending on the project goals and the standards of their respective scientific communities (Balázs et al., 2021). The more explicit the relevant goals and standards are made in advance, the easier it is for organizers to design mechanisms that ensure the required quality. Just as importantly, clear standards make it easier to get crowd members on board and to explain or agree upon quality evaluations.

14. Motivating and recruiting contributors

14.1 MOTIVATION

14.1.1 Overview and Key Motivations

One of the most important challenges is to motivate participants and keep them engaged over time (Druschke & Seltzer, 2012; Geoghegan et al., 2016). Some projects cannot generate enough interest to begin with, while others struggle to keep crowd members engaged. Even very successful projects such as *Galaxy Zoo* or *Planet Hunters* need to constantly recruit new participants because existing ones drop out (Sauermann & Franzoni, 2015; Spiers et al., 2018).

Organizers of crowd science projects lack some of the tools traditional organizations use to motivate employees. In particular, crowd members are typically unpaid, eliminating financial rewards as an instrument (Haklay et al., 2021). Organizers also lack formal authority to demand specific actions and cannot threaten to dismiss contributors. As such, they need to understand the motives of contributors (i.e., what they care about) and find ways to address those motives through effective project design and different types of rewards. Prior research suggests that the motives of participants are quite diverse, differing across projects but also across individuals in the same project (Geoghegan et al., 2016; Raddick et al., 2013). Table 14.1 summarizes some of the key motives and suggests features that project organizers can use to address them. However, using the various levers mentioned in Table 14.1 can be challenging for several reasons.

First, crowd members are typically highly heterogeneous, even within one project. For example, while some may primarily care about contributing to science, others may be most excited about social interactions. Addressing multiple motives at the same time requires a comprehensive set of project features that can consume considerable resources to build and maintain.

Second, there may be trade-offs between different goals and motives. For example, the objects that are most enjoyable to see for participants may not be the ones that are most important to study, and time that contributors spend on enjoyable social interactions may reduce the time spent doing the core scientific work. Of course, the hope is that addressing contributors' needs

Table 14.1 Common contributor motives and supporting project features

Motive	Description	Project features to address motive
Contribute to generating scientific knowledge	Crowd members donate effort, time and other resources (AKRD) in order to help advance science.	• Explain the scientific background and the need for new research • Involve crowd members broadly enough that they can see the scientific contribution • Share research findings, publish Open Access • Give scientific credit by listing crowd members as contributors or even co-authors
Help solve specific problems	Crowd members are concerned about issues such as biodiversity, air quality, particular diseases. They contribute to better understand problems and come up with solutions for themselves or others.	• Clarify the importance of the problem • Updates on problem solving progress • Ensure diffusion, translation of results and practical impact • Demonstrate how participants or others can or do benefit (e.g., early use cases) • Allow crowd members to participate in decision making on which problems to study
Interest, enjoyment, curiosity (see focus section 14.1.2).	Crowd members are curious about certain topics and enjoy the research activities themselves.	• Provide choice so that contributors can find objects of interest • Engaging and user-friendly interfaces • Offer objects and tasks that are complex, novel, uncertain, and involve cognitive conflict • Tools to enable discovery and preservation of the experience (e.g., an album tool to create personal collection of favorite images)
Social interactions, being part of a community	Crowd members enjoy the company of others as well as exchanging knowledge and ideas with others as part of a project.	• Create places to meet and interact (e.g., discussion forums, social media groups, webinars, joint outdoor activities, workshops) • Assign tasks to teams rather than individuals (see section 13.1) • Mechanisms to match crowd members based on shared interests or geographic location • Ensure that social interactions remain safe and within scope (e.g., have moderators in discussion forums)
Learning and skill development	Crowd members learn about specific topics and about the research process itself. This may include students who participate as part of school assignments, young adults who prepare for formal science education, others with a desire to learn.	• Enable contributors to see general patterns and learn about general mechanisms • Explanations regarding the scientific rationale, or reasoning behind methodological choices • Involve participants in decision making to encourage deeper thinking • Provide feedback, mechanisms to track learning progress (e.g., skill levels) • Certify participation (e.g., certificates, letters of participation for course credit or resumes)

encourages them to spend more time with the project overall, thus generating benefits for both the project and the contributors.

Finally, many contributors go through a lifecycle characterized by different motivations, e.g., they may join a project out of curiosity, continue in order to make a contribution to science, and stay long-term because of the strong relationships they have formed with fellow contributors (Crowston & Fagnot, 2018). Such dynamics make it even more difficult to offer the right kinds of rewards, and organizers need to keep in close touch with crowd members to maintain alignment between what crowd members care about and what the project offers to keep them engaged.

14.1.2 Focus: Curiosity and Interest

One important motive for contributors is their curiosity and interest in particular topics or subjects, as well as their enjoyment of tasks related to those topics. For example, many contributors in *Galaxy Zoo* are interested in astronomy and enjoy looking at images of galaxies, while contributors to *eBird* typically enjoy discovering birds outdoors (Box 14.1). This motive is closely related to the concept of "intrinsic motivation" studied by psychologists (Ryan & Deci, 2000), and the concept of "interest" studied by educational researchers and scholars of science (Sauermann & Franzoni, 2013; Silvia, 2006). The upside of this motive is that it can be very effective in projects that are in popular domains, e.g., in the areas of birding and astronomy, which have long had large numbers of interested hobbyists.

BOX 14.1 EXCITEMENT IN *GALAXY ZOO*

You need to warn people just how addictive this is! It's dangerous! […]. After doing a couple hundred I was starting to burn out … suddenly there was a kelly-green star in the foreground. Whoa! […] being the first to see these things: who *knows* what you might find? Hooked!

-*Galaxy Zoo* participant, quoted in Franzoni and Sauermann (2014).

The downside is that this motive is difficult to address for topics that are generally perceived as less interesting or for tasks that are perceived as less enjoyable. However, one powerful aspect of crowdsourcing is that reaching out to many potential contributors may allow projects to identify the small share of the population that happens to be interested in obscure topics. In other words, crowdsourcing allows projects to perform broadcast search not only with respect to knowledge and problem solutions but also with respect to contributors' interests (see section 2.4). The project *Bat Detective*, for example, has attracted thousands of individuals who are interested in an animal that most other people find less appealing.

Interest is not necessarily fixed but can be shaped. Research suggests that objects are perceived as more interesting when they are complex, novel, uncertain, and involve conflict (Berlyne, 1960; Silvia, 2006). In this context, *complexity* refers to the number of elements, the dissimilarity of elements, and the degree to which the whole can be predicted from a part. In experimental studies, for example, people judge complex polygons as more interesting than simple polygons and spend more time studying the former. *Novelty* of an object refers to the degree to which it does not fit a person's existing categorizations or is unexpected. Thus, a picture that one has not seen before is typically more interesting than a previously seen one, and a new picture that includes an unknown or unexpected object (such as a UFO or a green galaxy) will be most interesting. *Uncertainty* refers to the predictability of events and is highest when there are many alternative events that are likely to occur with similar probabilities. A soccer match with two equally good teams tends to be more interesting than one where one team is the clear favorite. Finally, (cognitive) *conflict* is generated if an object entails information that is inconsistent with the information already possessed by the person or that violates certain assumptions the person holds: Seeing a human floating in mid-air is interesting because it contradicts our prior knowledge about physics and about which kinds of animals can (and cannot) fly. These findings suggest that organizers can create and maintain interest by smartly designing projects and tasks. Take the example of the project *Snapshot Serengeti*, which asks participants to classify animals in images taken by camera traps. Even though it seems more efficient to automatically remove images without any animals in them, a study found that removing blank images reduced participant engagement (see Bowyer et al., 2015; Trouille et al., 2019). As such, projects can increase engagement by keeping some blank images in the data set – making the task more interesting for crowd members who may now ask themselves, "Will there be something on the next image?"

14.1.3 Focus: Gamification

Gamification is the application of game elements in non-game contexts, often to encourage participation and engagement (Prestopnik et al., 2017; Seaborn & Fels, 2015). Examples of game elements include leaderboards, counters of the volume of work completed, badges for the successful completion of different tasks or training modules, and immersive stories with multiple levels that motivate participants to move forward in a fictional environment (Prestopnik et al., 2017; Sullivan et al., 2018). Game elements can help address several different underlying motives mentioned in Table 14.1 such as curiosity (e.g., what happens at the next level of the game story?), contribution to science (e.g., how many data points have I collected?), social competition (e.g., can I beat other players?), or learning (e.g., how many skill badges have I collected?).

Research has explored gamification in many contexts, including crowd science. While some studies have found significant benefits, others caution that the motivating effects of game features can quickly wear off (Hamari et al., 2014; Prestopnik et al., 2017; Sailer & Homner, 2020). Moreover, gamification may have negative consequences, such as creating stress among participants (Eveleigh et al., 2013), distracting from the scientific contribution of a project (reducing a potentially important source of motivation), or encouraging participants to "game the game" by submitting low-quality work or taking shortcuts that undermine scientific objectives.

While gamification may not be the best approach in areas that offer many other powerful motivators (e.g., medicine, bird observation), it can be useful in areas that are perceived as less interesting or accessible by the general public, such as quantum physics or the study of moths (Jensen et al., 2021; Prestopnik et al., 2017). Indeed, such uses of gamification are reflected in the commonly used analogy of "chocolate-dipped broccoli" – although one may disagree on whether that is a good or bad thing (Bruckman, 1999). Either way, organizers should consider gamification as part of the motivational toolkit, while carefully considering potential limitations as well as alternative approaches to motivating participants (Box 14.2). Our website www.sciencewithcrowds.org lists some guides and tools that can help.

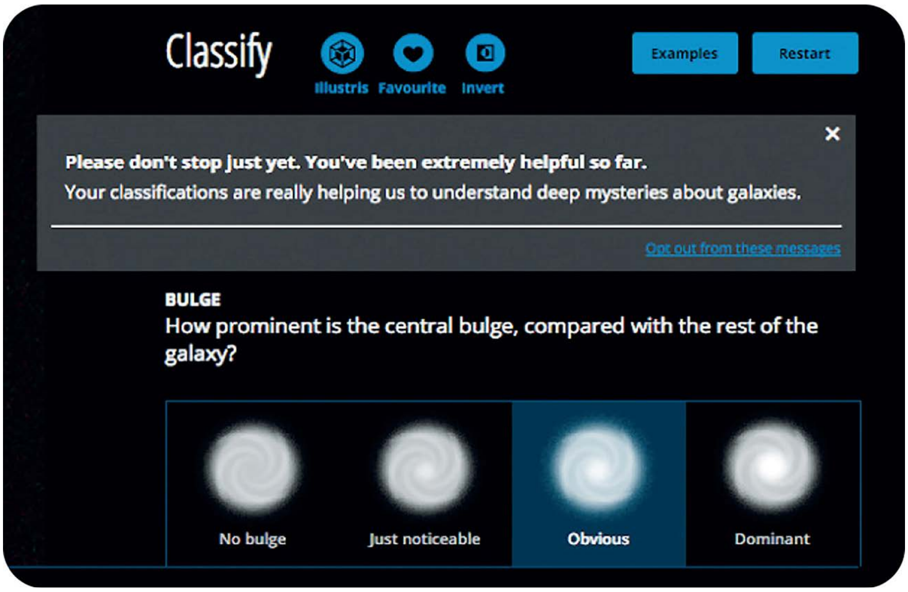
BOX 14.2 PROS AND CONS OF GAMIFICATION

Gamification can be narrowly understood and wrongfully applied. Like many things, context and the aim behind the use-case are even more important than the gamified intervention or the game mechanics that we might initially focus on. When done well, gamification can unlock deeper engagement and understanding. When not, people may have short-termed fun or excitement but beyond that will be less engaged and, in some cases, even bored from the game intervention. A good game is not only one that makes you laugh or smile but also think.

-Rajiv Vaid Basaiawmoit, gamification architect, personal communication.

14.1.4 Focus: Increasing Motivation with AI

Many project organizers face difficulties in motivating crowd members, and it is not surprising that some projects have experimented with using artificial intelligence to increase engagement and retention (Koehler & Sauermann, 2024). For example, researchers have shown that AI can analyze contributors' activities to predict when they are likely to drop out, and that sending customized messages asking them to continue supporting a project can significantly increase engagement (Segal et al., 2016). Figure 14.1 shows what such an intervention can look like. The platform *SciStarter* uses AI to better match crowd members to projects, and this approach has been shown to lead to higher levels of engagement (Zaken et al., 2021). This improvement may reflect a better matching with respect to skills for particular tasks or knowledge about particular problem domains; it may also reflect that crowd members are matched to projects that they find more interesting, increasing their motivation to stick around.



Source: Segal et al. (2016).

Figure 14.1 Algorithmically-generated message to keep contributors engaged

One could imagine many other interesting applications of AI to increase motivation, such as personalized task assignment based on skills and interests; AI-based gamification; dynamic feedback about task performance that increases enjoyment from learning; as well as generative AI that engages participants with personalized text, speech, or video. As exciting as it seems to use AI to increase participants' motivation, however, such ideas also raise ethical concerns – greater amounts of time spent on projects may be good from organizers' perspectives but they may create problems for participants in other areas of their lives and even be exploitative (Schelenz et al., 2020). We will return to such concerns in Chapter 15.

14.2 RECRUITING

14.2.1 Rewards for Potential vs. Current Contributors

Another important challenge for organizers is to attract enough participants. One aspect of this challenge is related to the prior section: Projects need to convince potential contributors that they will receive some type of intrinsic or extrinsic reward that makes participation a worthwhile investment – more worthwhile than other activities such as working for money, helping with another social cause, or simply relaxing in front of the TV. Several of the mechanisms listed in Table 14.1 on motivation should also be helpful in attracting potential crowd members to sign up.

There is a problem, however: While outsiders can appreciate some rewards even before participating (e.g., a fascinating image of a galaxy on the project website gives an impression of what can be experienced in an astronomy project), other rewards are "experience goods" that are difficult to appreciate prior to participating (e.g., the joy of learning, social interactions with other participants, impact on policymaking). Although projects will often find it easier to focus their recruiting message on benefits that are easily appreciated by outsiders, they can also find ways to make other types of rewards salient. Among other strategies, projects should reduce barriers for people who would like to try out a project and experience it first-hand, and they may rely on word-of-mouth from existing crowd members who can speak to other types of rewards they have received from participating.

14.2.2 Broad vs. Targeted Recruiting

Organizers should think carefully about *which* crowd members to recruit. While some projects broadcast their call for contributions very broadly (e.g., *Zooniverse* projects), others, such as *Tell Us! Accidental Injuries*, target very specific communities such as patients with particular diseases, as well as their relatives and medical professionals. Targeting specific crowds can have two key benefits. First, it is often easier to tailor the project design and the recruiting message for a targeted audience. The underlying reason is that such crowds tend to be more homogenous with respect to their interests and motivations – a community of patients and medical professionals, for example, is likely to share a concern for addressing certain medical problems and will worry less about enjoyment or outcompeting other crowd members. Second, targeting a specific crowd can also help recruit individuals with specific skills and knowledge that may be required in a project. This may increase the quality of contributions while also reducing the need for additional training (section 13.3).

The downside of targeting a specific crowd is that it reduces the number of potential contributors, which may be particularly problematic for projects that require a large volume of contributions. Moreover, while greater homogeneity of crowd members can reduce the complexity of managing the project, it can also be detrimental for projects that look for creative outlier solutions because such solutions are often found outside of projects' usual domain and in places that are difficult to foresee (see Chapter 9). Diversity is also important for projects that seek to gain insights into societal preferences, such as the voting process initiated by *A Healthier Southern Denmark* (section 4.1).

Ultimately, the decision to recruit broadly versus with greater focus relates to the frameworks we discussed in Chapter 2: Which Crowd Science Paradigm does the project try to leverage, what kinds of contributions are crowd members expected to make, and what kind of diversity does the project need to fulfill its scientific and broader objectives? Table 14.2 reinforces this point by linking Crowd Science Paradigms to important aspects of the recruiting strategy.

Table 14.2 Crowd Science Paradigms and their implications for recruiting

Paradigm	Implications for recruiting
Crowd volume	Recruit broadly, if relevant with geographic diversity; keep barriers to participation low
Broadcast search	Recruit broadly, look for diversity along relevant dimensions of knowledge and preferences
User crowd	Target participants with experience in the problem domain; potential users of research outputs
Community production	Target participants with more time, interest in and skills for collaboration
Crowd wisdom	Recruit broadly, look for diversity in knowledge and preferences

14.2.3 Partnerships vs. Independent Recruiting

Although projects can try to recruit contributors independently, building an active crowd often takes a considerable amount of time – if it succeeds at all.

Organizers also need to invest a lot of effort and even money to broadcast the call for contributions via channels such as social media, personal networks, or traditional flyers on a lamp post. It is often more effective to partner with organizations that already have ties to targeted communities (see Box 14.3). A project targeting patients and their relatives, for example, could reach this audience by collaborating with patient organizations or hospitals. Some projects have been extremely successful in recruiting contributors by working with schools and other educational institutions, especially if participation in real scientific research can enrich curricula and offer students authentic learning experiences (Bonney et al., 2016).

BOX 14.3 WORKING WITH FACILITATOR ORGANIZATIONS

We see an increasing interest from facilitator organizations such as museums, libraries, even the Girl Scouts. It makes sense to work with them because they know best how to communicate with, engage, and support their communities. Some also have embedded reward systems set up, such as credit at schools or badges for Girl Scouts. These organizations benefit by getting access to authentic and curated science experiences that they can offer to their members.

-Darlene Cavalier, founder of the *SciStarter.org* platform, personal communication.

Another type of partnership is to join an existing crowd science platform such as *Zooniverse*. These platforms have large existing user bases that can be reached through regular announcements of new projects as well as customized recommendations based on crowd members' profiles of skills and interests. Large platforms and catalogues, such as *SciStarter*, also tend to get more attention in the media and are better known by the public, serving as common entry points for people who are interested in joining a crowd science projects.

Of course, organizers' decisions to join a platform should be made in light of both pros and cons. Benefits include not only a pre-existing crowd but often also access to standardized infrastructure such as training tools, discussion boards, and even algorithms that can be used for project management (Koehler & Sauermann, 2024). At the same time, joining a platform can create additional financial costs (e.g., development fees), while using standardized tools or practices comes with a loss of control compared to a custom-made project. And while joining a platform may increase the pool of crowd contributors, projects with similar topics may also be competing more directly with each other. The net impact on the ability to recruit crowd members is an important open question for future research on crowd science.

15. Research integrity, protecting participants, and using AI responsibly

15.1 ENSURING RESEARCH INTEGRITY

Scientists need to ensure the integrity of research so that relevant stakeholders can have confidence and trust in the results. Without such trust, stakeholders will not support research (e.g., by providing funding or other resources) and will not build on the results that are generated (e.g., citations, policy action). Research integrity is an important challenge in research generally, as evidenced by ongoing discussions around scientific misconduct and the lack of reproducibility in many fields (Fang et al., 2012; Lacetera & Zirulia, 2011; Open Science Collaboration, 2015). However, ensuring research integrity is particularly important when crowds are involved. One reason is that crowd science is relatively new, which naturally results in greater scrutiny from skeptics. More importantly, there are valid reasons to be concerned about research integrity when crowds are involved, such as participants' lack of professional training as well as potential conflicts of interest. Perhaps most fundamentally, many traditional mechanisms to ensure research integrity rely on the screening of scientists (e.g., getting a PhD) and regulations of research processes (e.g., Institutional Review Board approval), yet a defining feature of crowd science projects is that they tend to be very open in terms of participation and processes. This high degree of openness may reduce the effectiveness of traditional gatekeeping and quality assurance mechanisms (Rasmussen, 2019). In the following sections, we discuss two key aspects of research integrity and how they may be addressed in crowd science projects: Quality and potential misconduct.

15.1.1 Quality and Peer Review

One of the most common concerns with crowd and citizen science projects is that crowd contributions may be of low quality (Balázs et al., 2021). One reason is that crowd members tend to lack professional training, which means they are less familiar with quality standards or may not have learned how to produce high-quality results. Another reason is that crowd members may have weaker incentives to make high-quality contributions: People who are not part of the professional scientific system and participate primarily for fun (see Chapter 14) may not gain much from producing high-quality results in terms of career progress or financial rewards. And they may not lose much if their contributions turn out to be low quality or even misleading. Of course, many crowd members do care deeply about the quality of their work, and core contributors in projects such as *Eterna* or *eBird* have both the knowledge and motivation to make contributions that match or even exceed professional standards.

We discussed in section 13.4 several specific mechanisms that projects can use to evaluate and improve the quality of crowd contributions. Taking this discussion to a more general level, we note that research is never perfect – all research can involve errors and mistakes, and every study involves trade-offs between competing objectives such as causal identification and generalizability. Whether a particular level of quality is acceptable also depends on the intended use of the contributions. If the goal is to track changes over time, for example, crowd members' tendency to over- or under-report certain species may not be a problem, while the same biases may be problematic if the goal is to establish population statistics at a given point in time. In other words, crowd contributions should be judged with respect to their "fitness for intended use" (Elliott & Rosenberg, 2019). Moreover, quality standards, even for a given use, may not be universally shared among scientists with different disciplinary backgrounds, no less scientists and crowd members (Ottinger, 2010).

Despite – and because of – these subjective and context-specific aspects, quality standards should be discussed explicitly with crowd members and should be considered in the design of materials and methods. Just as importantly, the quality of crowd contributions should be discussed explicitly in publications, e.g., in methods sections of articles using crowd-generated data. If crowd contributions result in open-access data sets, the methodological choices and potential limitations of the data should also be detailed in the documentation to enable potential users to judge the fitness of the data for their particular use. Indeed, making raw data (or other crowd contributions) openly accessible may enable others to re-analyze the data, spot potential problems, and ultimately help increase the quality and integrity of research.

Perhaps the most common formal mechanism to ensure research integrity is peer review by professional scientists. Reviewers look out for methodological problems and questionable results and – although not perfect – play an important gatekeeping function in the professional scientific system. Crowd science project leaders who are professional scientists will typically submit results for peer review in established journals. However, even projects that do not have to go through professional journals (e.g., because they are led by non-professional crowd members) should use review mechanisms to get feedback and external validation. This could be done by submitting to traditional journals but also by using emerging alternatives such as post-publication review, collaborative review in a larger community, or iterative review throughout the research process. And while peer review has traditionally implied review by professional scientists, the notion of peers may be broadened to others who have the required substantive or methodological expertise. Of course, peer review is a costly process and reviewers may apply quality standards that are not shared by crowd members (Gadermaier et al., 2018). Getting results through peer review will also typically take longer than simply posting them on websites or blogs. Yet, the benefits of quality assurance likely outweigh the costs, especially if projects seek to be taken seriously by professional scientists and policymakers.

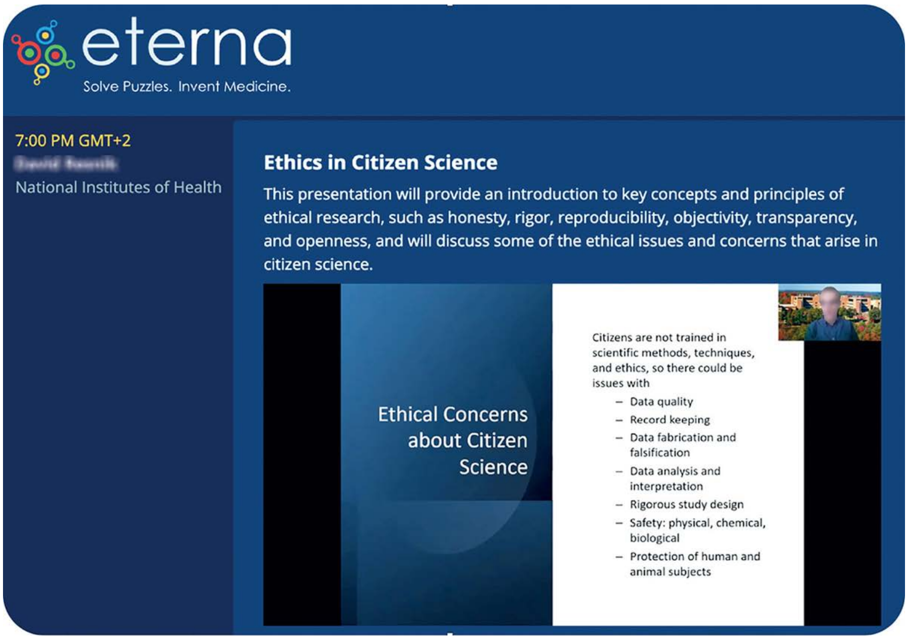
15.1.2 Research Misconduct

The quality concerns raised in the prior section typically arise from concerns about crowd members' lack of training or attention. Even more serious concerns relate to intentional research misconduct: Issues such as the fabrication and falsification of data or analyses, plagiarism, and even sabotage (Fang et al., 2012; Hall & Martin, 2019).

As noted earlier, one of the challenges is that crowd involvement requires greater openness, such that some of the traditional control mechanisms may not apply. For example, projects that originate outside the professional system may not be subject to the institutional processes that have been designed to detect and investigate potential misconduct (Rasmussen, 2019). The challenge of detecting problems is exacerbated by the fact that large crowd science projects can involve thousands of contributors who participate at different times and from different places. But given that scientific misconduct is often attributed to the publication pressures of the academic system, why would (non-academic) contributors engage in misconduct?

One reason relates to potential conflicts of interest. Such conflicts may be financial, e.g., if firms are involved (Blacker et al., 2021). Contributors may also have non-financial interests in particular study outcomes, especially if research is sponsored by advocacy groups or involves contentious topics. For example, some participants in environmental monitoring projects may have an interest in exaggerating problems to trigger policy action, while others may prefer to downplay issues to avoid policy measures that negatively affect them personally. Although there is no systematic evidence on the incidence and impact of such conflicts of interest, organizers should consider what potential conflicts of interest may exist in their context and how they may affect the integrity of research (Elliott & Rosenberg, 2019). Of course, a personal interest in particular outcomes does not mean that participants will engage in misconduct, and personal concerns about certain topics are often an important motivator for crowd members to participate in a project.

One way to reduce the risk of misconduct is to create a culture of integrity that makes participants aware of problematic behaviors and creates a shared expectation of integrity (Rasmussen, 2019). This could happen at different levels, including at the level of broader communities such as professional societies or citizen science associations, at the level of research institutions, but also at the level of individual crowd science projects. The Association for Advancing Participatory Sciences, for example, has a working group that develops and promotes guidelines related to ethics and research integrity.[1] The *Eterna* project promotes research integrity at its annual EternaCon conference, e.g., through presentations and open discussions on ethics in citizen science (Figure 15.1).



Source: https://eternagame.org/eternacon/2022.

Figure 15.1 Session on "Ethics in Citizen Science" at EternaCon 2022

Projects should also put in place monitoring mechanisms. An example is the cross-validation of data by different contributors or the flagging of unusual patterns using AI (see section 13.4). Particularly important is transparency in both data and methods, e.g., by running analyses on shared infrastructure, which allows different contributors to analyze the same data and to spot

[1] https://participatorysciences.org/groups/.

inconsistencies that may result from misconduct (as well as honest errors). Although diversity among contributors may make it more difficult to align culture and monitor research activities, diversity may also be beneficial by allowing contributors to look at the same issues from different perspectives, potentially yielding more robust analyses and results. Moreover, interactions among diverse contributors may help uncover implicit biases and values that shape research choices and should be made explicit and disclosed (Elliott & Rosenberg, 2019).

The risk of misconduct cannot be eliminated completely. Thus, projects should be transparent about potential conflicts of interest, allowing others to consider remaining risks when deciding whether and how to use study results (Resnik et al., 2015). Study results should not be rejected simply because of potential conflicts of interest among crowd participants. Instead, it will be important for journals and research communities to discuss how misconduct can be prevented and detected without undermining projects' ability to engage crowd members who care deeply about particular topics and who seek to contribute to high-quality research that has important societal implications.

15.2 COMPENSATION AND SHARING OF PROJECT OUTCOMES

Crowds can make invaluable contributions to scientific research. In return, organizers have to ensure that crowd members are treated with respect and can also benefit from their participation.

15.2.1 Compensation for Time and Effort

Crowd members are typically unpaid, even though similar work is compensated financially in other settings such as on *Amazon Mechanical Turk* or when done by professional scientists as part of their jobs (Sauermann & Franzoni, 2015). While this may seem unfair, there is a general understanding that compensation in crowd science is primarily non-financial – projects should provide several other types of rewards that participants value and receive in return for their contributions (see Table 14.1). To the extent that participants are free to join a project and leave at will, and that project organizers are transparent about both the tasks and the rewards that can be expected, this should result in outcomes that are advantageous for everyone involved. Of course, there may be cases where participants seem to invest too much time in projects without getting paid, e.g., when they care deeply about certain topics or if they develop a sense of personal obligation and are afraid to drop out even though the time commitment becomes problematic (Beck et al., 2023; Bunderson &

Thompson, 2009). Similarly, sophisticated gamification and algorithmic management approaches may induce participants to spend more time than they had initially intended (Schelenz et al., 2020). Although there is little empirical evidence on these issues, they should be studied in future work, and project organizers should take them seriously.

Although it is typically understood that crowd members do not get paid, it is important to consider implications for the size and composition of the crowd. As noted throughout the book, crowd diversity is often important, e.g., when relying on the broadcast search paradigm to identify outlier solutions, when relying on crowd wisdom to gain representative insights into societal preferences, or when using community production approaches to integrate ideas and complementary perspectives of participants. We already discussed the issue that achieving diversity can be difficult if participation imposes financial costs that are difficult to bear for lower-income individuals (section 4.3). Related problems may emerge from the lack of financial compensation for time: Projects may find it difficult to attract lower-income individuals who need to earn money to make a living, but also busy individuals who have very high "opportunity costs of time". There is no easy solution, but organizers should consider whether and how such selection effects matter for them and if they can be mitigated. A clear recommendation – and even duty – is for organizers to avoid unnecessary costs and to use contributors' time responsibly (Trouille et al., 2019). Although this may seem obvious, it requires organizers to think carefully about where crowd contributions are really needed, how goals can be achieved without "wasting" participants' time, and how new technologies such as AI can make work more efficient (see section 15.3).

15.2.2 Sharing of Project Outcomes

Project organizers also need to decide on the sharing of tangible benefits that may result from projects, as well as ownership of outputs such as data or publications. Some observers are concerned that professional scientists enjoy an inherent power advantage that allows them to appropriate a disproportionate share of these benefits (Resnik et al., 2015).

There will not be universal agreement on what is fair, especially given that different participants may contribute for very different reasons. But it is useful to recognize that there is not a single fixed output that needs to be shared in a zero-sum approach: Crowd science projects can generate a range of benefits that are not mutually exclusive and perhaps even complementary (Franzoni & Sauermann, 2014). For example, an environmental monitoring project may result in scientific publications that are particularly valuable for professional researchers who seek to attain tenure at an academic institution, while crowd contributors can use the data to better understand their natural environments or advocate for sustainability policies. Generating both benefits does not stand in competition. Indeed, having the results published in a peer-reviewed article may even increase the strength of the evidence and its ability to shape policy responses. Similarly, a project seeking to understand disease mechanisms can generate academic impact that is particularly valuable for professional scientists but also spur downstream research and medical treatments that benefit crowd members who are patients or patient relatives.

Of course, some benefits are limited or stand in conflict, and this is where tensions can arise. A common case is the ownership and disclosure of data. As discussed in Chapter 7, there is a general expectation that data generated by crowd members are also accessible to participants and the public. This can take different forms depending on the particular nature of the data and related interests. Some projects publish microdata immediately, others publish data with a delay to give professional scientists time to publish papers, and yet others publish only aggregate data (e.g., visualizations of biodiversity data on maps). Some projects also tie access more explicitly to contributions. The project *IPRoduct*, for example, charges external users for data access but gives usage credits to crowd contributors depending on the volume of contributions they have made.

The general expectation of open data needs to be balanced with concerns regarding privacy and potential abuse of data. Privacy concerns are most obvious if the data relate to humans (e.g., in the social or medical sciences), but also if the data relate to observations of endangered species of plants or animals (see Chapter 7). Concerns also arise if data can be abused by interest groups, if selective disclosure provides misleading impressions, or if data are easily misinterpreted (Doche, 2021; Resnik et al., 2015). Such concerns may warrant certain restrictions, e.g., that data are made accessible on demand to users with legitimate interests or users who have documented that they have required data protection mechanisms in place. Projects should also take advantage of existing licensing mechanisms such as Creative Commons licenses to avoid the costs of coming up with customized solutions.

Another important decision is the allocation of scientific credit and authorship. Most projects that involve crowds in selected stages, such as data collection, assign authorship to the professional scientists who run the project but acknowledge crowd contributors in acknowledgment sections or on project websites (see Box 15.1). Incidentally, it should not be assumed that all contributors want to be acknowledged personally, e.g., they may not want friends or family to know that they are supporting research on controversial topics or that they are spending scarce time and resources for research purposes. As such, organizers should explicitly ask contributors for their consent before disclosing identities.

BOX 15.1 ECSA PRINCIPLE #8

Principle #8: Citizen scientists are acknowledged in project results and publications.

-Ten Principles of Citizen Science (European Citizen Science Association, 2015).

Some projects name crowd members as co-authors under a collective pseudonym (e.g., Eiben et al., 2012; Polymath, 2012). If particular crowd members have made particularly high-value contributions, then they are sometimes listed as individual co-authors (e.g., Lintott et al., 2009). Individual co-authorship is typically granted to crowd members who engage fully in research projects and participate in writing or even take the lead in setting up and implementing projects (e.g., Wellington-Oguri et al., 2020).

Although additional co-authors will somewhat dilute the credit given to any one author, this discount is typically less than proportional. This means that authorship is not a zero-sum game (Bikard et al., 2015; Maciejovsky et al., 2009), although it is not clear whether and how these findings generalize to authorship by crowd members. More importantly, it is not clear that all crowd members desire to be named as co-authors; some may not value this particular reward, while others recognize that authorship also entails responsibility in the case of mistakes and misconduct (Rennie et al., 1997).

Authorship decisions should not be taken lightly because of important existing norms within scientific communities and explicit guidelines established by journals. The official requirements for authorship are typically quite high, suggesting that most crowd members will not qualify (see Box 15.2). That being said, recent work has shown that in practice even many professional scientists listed as co-authors do not meet these requirements (Sauermann & Haeussler, 2017). Given the considerable scope for the assignment of authorship, project organizers should discuss openly who might reasonably expect to be listed on an article.

BOX 15.2 ICMJE AUTHORSHIP CRITERIA

The ICMJE recommends that authorship be based on the following four criteria:

1. Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND
2. Drafting the work or revising it critically for important intellectual content; AND
3. Final approval of the version to be published; AND
4. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

-Defining the roles of authors and contributors (International Committee of Medical Journal Editors, 2020).

Finally, some project results may also have concrete financial value that needs to be split one way or another. Although such projects are rare, one could imagine this might be relevant in the case of biomedical projects that yield new therapies, projects in the social sciences that yield new marketing tools, or space projects that identify asteroids that can be mined for raw materials.[2] Some projects share financial benefits by giving prizes to crowd members who generate outlier contributions, especially if projects are organized as contests (Chapter 9). If crowd members are directly involved in producing commercially valuable inventions that are patented, they usually must be named as inventors who have rights to share financial profits. We also saw in Chapter 5 how some crowdfunding platforms allow contributors to participate in the financial success of projects. Although a detailed discussion of the legal and ethical issues involved in managing intellectual property and the distribution of financial returns is beyond the scope of this book, interested readers can consult specialized sources such as Scassa and Chung (2015).

Many of the decisions discussed in this section are very difficult to make, and what can be considered fair depends on various factors including relevant norms in the respective fields, the goals of the organizers, as well as the characteristics and goals of crowd members (Box 15.3). One general recommendation is transparency: If decisions have already been made, they should be communicated and explained when recruiting crowd members so that

[2] https://www.zooniverse.org/talk/15/46052.

interested people can decide whether they are willing to contribute. In other cases, decisions are best made over time as it becomes clearer what contributions are made by whom. Projects should then implement mechanisms to openly exchange ideas and make decisions in a participatory manner. This may include exchanges in discussion forums, live-streamed Q&A sessions with organizers, or the solicitation of input in regular mailings and newsletters. Some projects also have boards of selected crowd members who serve as representatives of the broader crowd. These boards are informed about decisions that matter for the crowd, can provide timely feedback, and may have decision rights.[3] Such boards are useful when deciding on the sharing of project outputs but may also provide helpful feedback on other opportunities to improve the organization and operation of projects.

BOX 15.3 ETHICAL OBLIGATIONS IN CROWD SCIENCE

Every project has two sets of ethical obligations. One set is to science, such as to conduct research with integrity and to share results and data with the scientific community. Another set is to project participants, such as to steward data for the benefit of those who contributed it and to share back results and data in forms they can use. It may not always be possible to satisfy both sets of obligations simultaneously. Ethical principles, such as respect, reciprocity, transparency, and accountability, can help guide the identification of ethical dilemmas and their resolution, which will be unique to the circumstances of each project.

-Caren Cooper, Professor of Forestry and Environmental Resources, personal communication.

15.3 DECIDING ON THE ROLE OF AI: AUTOMATION, AUGMENTATION, AND MANAGEMENT

Artificial intelligence can increasingly take over research tasks such as image classification, data analysis, and problem-solving (Wang et al., 2023). Should organizers still ask unpaid crowd members to spend their time on these tasks? What should be the relationship between AI and crowd contributors?

[3] One example is the Eterna Players Alliance, see https://eternagame.org/epa.

Generally speaking, AI can play three different roles in crowd science projects (see Figure 15.2): It can take over some of the tasks traditionally performed by crowd members (*automation*), it can support crowd members in performing their tasks (*augmentation*), and it can manage or organize projects (*algorithmic management*) (Agrawal et al., 2023; Kellogg et al., 2020; Sauermann & Koehler, 2024). Projects can use AI in multiple ways at the same time, and new applications within these three categories will emerge as the capabilities of AI continue to improve.

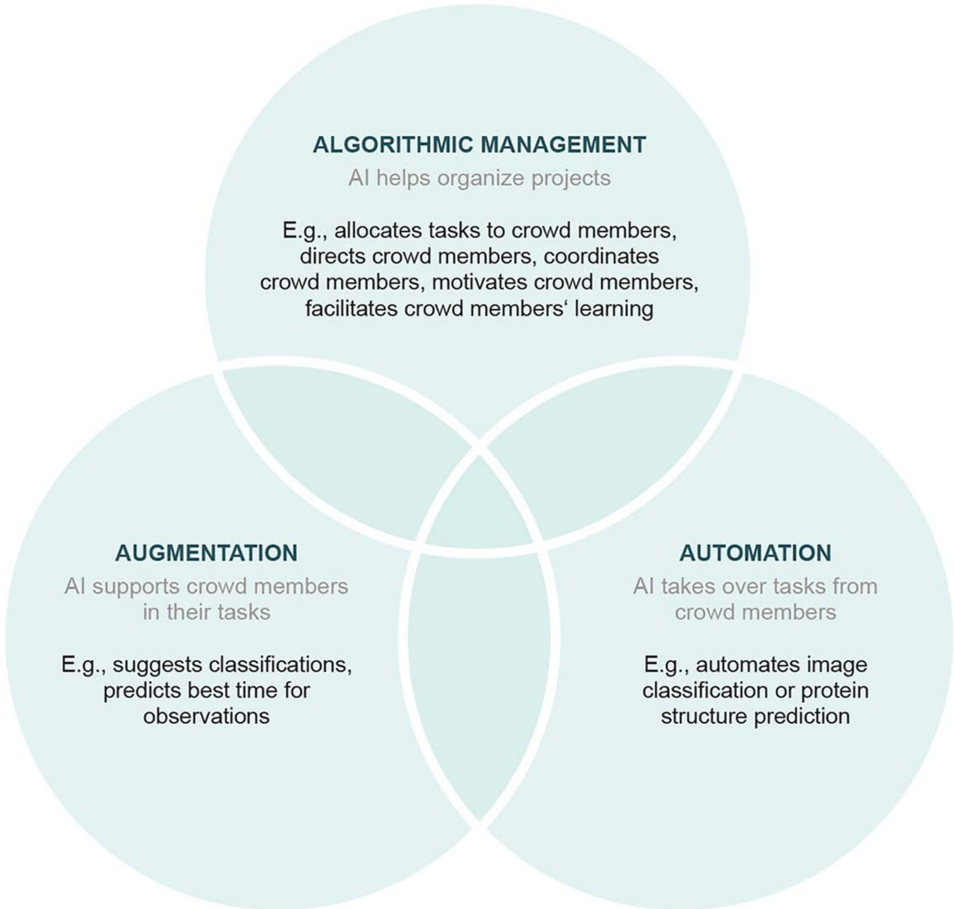


Figure 15.2 Three uses of AI: automation, augmentation, and algorithmic management

Perhaps the most often discussed use of AI is as a tool to automate tasks that were historically performed by humans, such as image classification or protein structure prediction. Such applications often require the use of human-generated training data, and humans may still be needed to handle special cases that are too difficult for AI. Nevertheless, automation means that AI is reducing the need for crowd members to get involved. This raises the concern that automation jeopardizes non-scientific benefits of crowd involvement, such as citizen enjoyment and learning (Box 15.4). As noted in an insightful paper by *Zooniverse* organizers, however, automation within a given project does not mean that crowd members stop doing science – they can participate in other projects and tasks where their contributions are really needed (Trouille et al., 2019). Consistent with this idea, several *Zooniverse* projects were retired once enough training data for AI had been generated, enabling new projects to recruit those participants and increasing the overall volume of scientific research. Similarly, the project *Foldit* has shifted attention from protein structure prediction to protein design, an area where human intelligence and creativity still dominate the capabilities of AI.[4]

BOX 15.4 AI IN CROWD SCIENCE

The challenge is how to facilitate human and machine learning in a way that the two do not simply counter one another. For instance, ML systems simply automating volunteers' tasks may remove opportunities for productive learning among volunteers. However, if ML gradually takes over low-level tasks, it might allow volunteers to focus on and learn more intricate tasks as the technology efficiently manages routine responsibilities.

-Kevin Crowston, Professor of Information Science, personal communication.

A second role of AI is to augment crowd members' capabilities and make their tasks easier. In *eBird*, for example, an AI-driven identification tool increases the speed and accuracy of data collection by making suggestions regarding the species of birds observed by participants (Kelling et al., 2013). In such cases, the AI does not replace crowd members but can reduce the effort required while increasing quality or speed. Another example of augmentation is when algorithms predict the best time or place to observe certain objects or phenomena, such as the Northern Lights (Case et al., 2016). This makes observations easier for crowd members and reduces the risk that they waste their time at the wrong place or time. Augmentation will typically make humans more productive and may even reduce barriers for participation, e.g., when the knowledge

4 https://fold.it/portal/node/2008706.

requirements to make high-quality contributions to projects such as *eBird* are reduced. But augmentation is not trivial and can also have negative side effects. For example, humans sometimes find it difficult to understand why AI makes certain recommendations, reducing their willingness to incorporate AI suggestions (Lebovitz et al., 2022). Relatedly, some supporting AI may make tasks less interesting and reduce opportunities for learning, e.g., when crowd members just have to take pictures and are not challenged to think about what animal or picture they saw. Such challenges can be addressed through thoughtful design, e.g., by keeping humans in the loop or letting AI explain what features of an object led it to suggest a certain classification.[5]

Third, we already discussed in prior chapters the role of AI as a manager that can help organize projects with respect to aspects such as task allocation, coordination, and motivation (Chapters 13 and 14). Using AI in this role does not undermine the role of crowd members – indeed, it will often enable projects to involve a larger and more diverse crowd. Of course, using AI to manage projects also creates challenges such as the potential loss of interactions between professional scientists and citizens. Similarly, if algorithms are trained to optimize purely for scientific performance, they may undermine other benefits such as the personal enjoyment or learning of participants (see also our discussion of gamification in section 14.1).

There is a great deal of ongoing research on the role of AI in science, including a special collection of the journal *Citizen Science: Theory and Practice*.[6] Although our discussion in this section only touches upon some of the key issues, we hope that it clarifies that organizers have different choices regarding whether and how to employ AI. Those choices will naturally depend on the technical capabilities of AI in a particular domain, as well as the resources organizers have available. More importantly, however, those choices will also depend on the goals that organizers are trying to achieve (Koehler & Sauermann, 2023): Organizers who focus on increasing scientific productivity may tend to seek efficiency gains from automation while also leveraging AI to augment and manage as long as this increases scientific output. Organizers who (also) care about public engagement and citizen learning may be less likely to use AI for automation, opting instead to keep humans in the loop and supporting the work of crowd members using augmentation. Thus, deciding on

[5] Whether a particular application of AI should be classified as automation vs. augmentation depends on how one defines the relevant "task". See Sauermann and Koehler (2024) for a conceptual discussion and illustrations in the context of crowd science.

[6] https://participatorysciences.org/2023/07/18/call-for-abstracts-ai-and-the-future-of-citizen-science/.

whether and how to use AI requires projects to clarify their goals, recognizing that goals may differ across stakeholders and may change over time.

15.4 PRIVACY, SAFETY, AND INSTITUTIONAL OVERSIGHT

Several regulations and guidelines protect the interests of human subjects in research, such as patients participating in clinical trials, students participating in the evaluation of educational technologies, or employees participating in academic surveys. These regulations aim to ensure the safety of participants and the privacy of personal data while balancing remaining risks with potential benefits from the research. In the USA, most human subjects research performed by academic researchers is reviewed by Institutional Review Boards (IRBs), and many other countries have similar mechanisms in place.

The application of such regulations to projects that involve crowds as contributors rather than study subjects is somewhat of a grey zone. Some definitions of "human subjects research" clearly focus on the role of humans as objects being studied, meaning that they do not cover cases where crowd members perform research activities. Others define human subjects more broadly, e.g., as "a living individual about whom an investigator conducting research obtains data through intervention or interaction, or identifiable private information" (Cooper et al., 2019). This definition would also apply to participants who provide personal information when registering on crowd science platforms or who submit their geographic location as part of data collection efforts. A discussion of specific applicable rules and regulations is beyond the scope of this book, but interested readers can consult more focused treatments such as Freyberg et al. (2020). Nevertheless, we wish to highlight three more general points (summarized in Table 15.1).

First, a key element of human subjects protection is "informed consent". This means that subjects are informed about all relevant aspects of a study and freely decide whether to participate. IRBs sometimes waive informed consent if it would jeopardize the research itself, e.g., if knowing that they are being studied or what researchers are trying to find out would lead participants to change their behavior. Such waivers will typically not apply to crowd contributors since they are not the ones being studied (although projects should consider potential conflicts of interest with respect to specific topics or findings; see section 15.1.2). Thus, organizers should provide potential participants with reasonably complete information about the tasks to be performed, the expected costs for participants (e.g., materials, travel), any potential risks (e.g., with data collection in hazardous conditions), as well as the planned use of data and results (see section 15.2.2). A non-representative sample of projects studied by Cooper et al. (2019) suggests that only a small minority currently

Table 15.1 Selected types of projects and recommendations regarding institutional oversight

	Institutional research (led by professional scientists at universities, government institutes, etc.)			**Non-institutional research**
Subject being studied	Humans	Humans	Not humans	All subjects
Crowds involved as researchers	No (Not covered in this book)	Yes	Yes	Yes
Examples	• Human subjects respond to survey • Human subjects submit own blood/DNA samples	• Crowd members report social behavior of others • Crowd members process and analyze MRI images of children	• Crowd members collect water quality data • Crowd members process images of galaxies	• Local residents monitor biodiversity • Patients collect and analyze data on their own diseases and treatments
Recommendations	• Follow traditional Institutional Review Board (IRB) process	• Follow traditional IRB process for human subjects part • Check with IRB regarding crowd involvement • Get informed consent from crowd members • Limit collection of personal data; let crowd members decide how data are used and disclosed	• Check with IRB regarding crowd involvement • Get informed consent from crowd members • Limit collection of personal data. Let crowd members decide how data are used and disclosed	• Get informed consent from crowd members • Limit collection of personal data; let crowd members decide how data are used and disclosed • Try to get access to IRB to get feedback or approval

Source: Based on Cooper et al. (2019).

have informed consent in place. At the same time, platforms such as *SciStarter* seem to be moving in the right direction by providing key information about tasks and expected costs routinely in their project listings.

Second, care has to be taken with the collection of personally identifiable information such as crowd members' names as well as personal data such as the volume of their contributions or their physical locations. A general principle is that projects should not collect information they do not need. However, it may not always be clear what information will be needed for future uses of project results, and some personal data may be very useful for increasing project efficiency or improving the user experience (e.g., to match tasks and contributors or facilitate training). Personal information may also be required to generate or share benefits with participants, e.g., to acknowledge their contributions in published research papers, to send them study results, or to alert environmental agencies to problems that are reported in particular locations. Cooper et al. (2019) argue that projects should allow contributors to decide individually what data they are willing to provide or allow to be collected about them, and how the data can be used. This could be part of the informed consent process, although such customized solutions also introduce additional administrative complexities and costs that need to be considered.

Third, relevant stakeholder groups should get together to discuss appropriate institutional oversight for crowd science activities. As noted in Table 15.1, crowd science projects that study human subjects are already under the oversight of IRBs or comparable institutions, but this applies primarily to the human-subjects part. There are few explicit regulations regarding the involvement of crowd members as researchers, and IRBs may need to learn how to assess the associated risks and benefits. Existing mechanisms also mostly apply to projects that are operating within formal organizations such as universities or government institutes; projects run by patients or local communities are typically not required to go through IRB processes. Although this may be seen as an advantage by those who are skeptical of established institutions, a lack of oversight may lead to unnecessary risks, may compromise quality, and may limit the scientific impact of the work.[7] We recommend that even projects that do not have to get formal approval seek input from IRBs or similar institutions to ensure they treat both subjects and crowd members as ethically and safely as possible. Projects initiated outside of formal institutions may do so by collaborating with professional scientists who can provide access to IRBs through their home institutions. We recognize that such a setup is not ideal because the responsibility for adhering to formal IRB agreements would likely rest on the professional collaborators, who may have limited control over what happens in projects that are led by others. Thus, broader discussions around oversight mechanisms for crowd science projects operating in different institutional environments are needed.

[7] Among others, many journals have IRB approval as a condition for reviewing or publishing articles. See https://theplosblog.plos.org/2008/07/to-irb-or-not-to-irb/.

16. Conclusion and project index

The wide range of case examples we discussed throughout the book illustrates how crowds can make important contributions to scientific research across fields and across all stages of the research process. Tables 16.1a, b, c, and d provides a complete index of all projects we discussed, including web links for readers who are interested in learning more. Of course, these examples cover only a tiny part of the rapidly expanding project landscape.

We are excited to see the growing interest in crowd science among professional scientists and citizens, as well as among other stakeholders such as funders and policymakers. We hope that our book will inspire readers to further explore the potential of crowd science, while also providing a strong conceptual foundation to analyze who the crowds are, what they are contributing, and why their involvement can help make projects more effective (Chapter 2). The tools developed in Chapter 3 and illustrated in subsequent chapters can guide scientists as they think about whether and how to involve crowds in their research. Our website www.sciencewithcrowds.org includes additional helpful resources as well as contact information to stay in touch and share experiences or questions. We look forward to hearing from you!

Table 16.1a Project Index - part 1

A–F

Project name (Chapters)	**Primary task performed by crowd members** (Primary research field)
A Healthier Southern Denmark (4, 14)	**Crowd selects health research projects for funding** (Medical science) https://www.tv2fyn.dk/ess
Amazon Mechanical Turk platform (5, 8, 15)	**Crowd performs broad range of usually simple tasks** (Various) https://www.mturk.com
Aurorasaurus (7, 11)	**Crowd collects data on Northern Lights** (Space weather) https://www.aurorasaurus.org
Bat Detective (14)	**Crowd classifies bat calls in sound recordings** (Biology) https://www.batdetective.org
BITEs (Brokering Innovation through Evidence) (11)	**Crowd co-develops short summaries of research findings** (Medical science) https://warwick.ac.uk/fac/sci/med/about/centres/clahrc/impact/bites
Cornell Birdcall Identification (6)	**Crowd develops algorithms for analyzing soundscape recordings** (Biology) https://www.kaggle.com/competitions/birdsong-recognition/overview
CSI-COP (7)	**Crowd collects data on cookies and GDPR compliance of apps** (Computer science, law) https://csi-cop.eu
CurieuzeNeuzen (1, 2, 5, 8, 11, 12, 13)	**Crowd develops and implements project to measure air quality** (Climate science) https://curieuzeneuzen.be
eBird (1, 2, 7, 11, 13, 14, 15)	**Crowd collects data on birds** (Biology) https://ebird.org/home
Epidemium platform (2, 4, 8, 11, 12, 13)	**Crowd designs and implements data-driven cancer research projects** (Medical science) http://epidemium.org
Epidemium NeOS (13)	**Crowd performs data-driven research on environmental risk factors for cancer** (Medical science) http://epidemium.org https://app.jogl.io/project/835?t=needs
Epidemium ORL/IA (2, 4, 8)	**Crowd performs data-driven research on ENT cancer induced by human papillomavirus (HPV)** (Medical science) http://epidemium.org https://app.jogl.io/challenge/orlia
Eterna (4, 9, 10, 11, 12, 13, 15)	**Crowd designs RNA structures** (Biochemistry) https://eternagame.org
ExCiteS Kenya (4, 7)	**Crowd designs and implements project to monitor plant species** (Biology) https://uclexcites.blog/2019/05/29/citizen-science-and-botanic-knowledge-among-herders-and-farmers-in-kenya/
Exoplanet Research Workshop (10)	**Crowd analyzes data on exoplanets and writes up results in academic papers** (Astronomy) https://exoplanetresearch.com
Exoplanet Watch (8, 10)	**Crowd analyzes telescope images and creates light curves of exoplanets** (Astronomy) https://exoplanets.nasa.gov/exoplanet-watch/about-exoplanet-watch/overview/
Experiment.com platform (2, 5)	**Crowd funds scientific research projects** (Various) https://experiment.com
Fathom Fund (5)	**Crowd contributes to evaluating research proposals by providing crowdfunding** (Various) https://meopar.ca/research/fathom-fund/
Foldit (1, 2, 9, 15)	**Crowd solves complex protein folding problems** (Biochemistry) https://fold.it

Table 16.1b Project index - part 2

G–P

Project name (Chapters)	**Primary task performed by crowd members** (Primary research field)
Galaxy Zoo (2, 3, 8, 12, 14)	**Crowd classifies telescope images of galaxies** (Astronomy) https://www.zooniverse.org/projects/zookeeper/galaxy-zoo/
Galaxy Zoo Quench (8)	**Crowd analyzes data on galaxies** (Astronomy) https://quench.galaxyzoo.org
Gill Lab (5)	**Crowd funds research on ecosystem change** (Climate science) https://contemplativemammoth.com/2014/12/03/crowd-funded-science-thoughts-after-185-people-gave-us-10733-for-research/
Glyph (2, 8)	**Crowd identifies commonalities between letters in different scripts** (Linguistics) https://glyph.shh.mpg.de
iNaturalist platform (2, 7)	**Crowd collects data on various animals and plants** (Biology) https://www.inaturalist.org
InnoCentive platform (now Wazoku Crowd) (2, 9)	**Crowd helps solve problems in science and innovation** (Various) https://www.wazokucrowd.com
IPRoduct (15)	**Crowd collects data on IPR protection of products** (Social science) https://iproduct.io/app/public/page/home
JPL Infographics (11)	**Crowd transforms NASA data into infographics for the broader public** (Space science) https://www.jpl.nasa.gov/news/jpl-infographics-site-wants-you-and-your-creativity
Marblar (11)	**Crowd ideates and selects application ideas for scientific discoveries** (Various) https://techcrunch.com/2012/10/22/dust-off-that-science-marblar/?guccounter=1
Moores Lab (5)	**Crowd funds research on sustainable materials** (Chemistry) https://meopar.ca/project-aims-to-turn-problematic-invasive-green-crabs-into-a-sustainable-solution/
Mosquito Alert (7, 11)	**Crowd collects data on invasive mosquitoes** (Biology) https://www.mosquitoalert.com/en/
NASA Solar Flare Prediction (9)	**Crowd develops algorithms for predicting the occurance of solar flares** (Heliophysics) https://journals.sagepub.com/doi/10.1177/0001839217747876
OIS Research Framework Development (10)	**Crowd co-develops and writes a conceptual article on Open Innovation in Science** (Social science) https://ois-research-conference.org
Open Insulin (5)	**Crowd supports developing accessible insulin, including through crowdfunding** (Medical science) https://openinsulin.org https://experiment.com/projects/open-insulin
Open Research Behind Closed Doors (6)	**Crowd co-creates methodology for study on persons deprived of liberty** (Human rights studies) https://gmr.lbg.ac.at/wp-content/uploads/sites/12/2021/10/factsheet_en_final.pdf
Österreich forscht platform (1)	**N/A (project catalogue)** (Various) https://www.citizen-science.at
PACT: TARGet Kids! Parent And Clinician Team (6, 13)	**Crowd co-creates clinical trials (**Medical science) https://www.targetkids.ca/pact
Parent Trial (6)	**Crowd co-creates clinical trial related to preventing obesity in children** (Medical science) https://doi.org/10.1186/s13063-021-05305-6
PATIO: Patient Involvement in Oncology (6)	**Crowd co-creates prostate cancer research** (Medical science) https://www.applied-diagnostics.at/patio/#initiative

Table 16.1c Project index - part 3

P–W

Project name (Chapters)	**Primary task performed by crowd members** (Primary research field)
Planet Hunters (14)	**Crowd examines data from NASA's Transiting Exoplanet Survey Satellite** (Astronomy) https://www.zooniverse.org/projects/nora-dot-eisner/planet-hunters-tess
Plastic Detective (7)	**Crowd collects data on use patterns of singe-use plastic items** (Environmental science) https://scistarter.org/become-a-plastic-detective
Polymath (4, 9, 13)	**Crowd proposes, selects, and solves mathematical problems** (Mathematics) https://polymathprojects.org
Profs-Chercheurs (2, 7, 9)	**Crowd creates data on the impact of educational approaches on students' learning outcomes** (Education science) https://www.profschercheurs.org/fr
Quantum Moves (2, 9)	**Crowd plays games to find efficient ways for moving atoms** (Physics) https://www.scienceathome.org/games/quantum-moves-2/
Roadkill Austria (2, 10)	**Crowd reports, checks, and analyzes roadkills, and suggests roadkill-related research questions** (Zoology) https://roadkill.at/en/
Saint George on a Bike (13)	**Crowd describes elements in historical paintings** (Art history) https://www.zooniverse.org/projects/artem-dot-reshetnikov/saint-george-on-a-bike
Scheibye-Knudsen Lab (5)	**Crowd funds research on DNA damage** (Medical science) https://www.vitadao.com/projects/scheibye-knudsen-lab
Scistarter.org platform (1, 7, 14, 15)	**N/A (project catalogue)** (Various) https://scistarter.org
SDU Citizen Science platform (4)	**N/A (project catalogue)** (Various) https://www.sdu.dk/en/forskning/forskningsformidling/citizenscience
Secchi Disk (7)	**Crowd collects data on phytoplankton** (Marine biology) http://www.secchidisk.org
SETI@home (2)	**Crowd contributes computing power to search for extraterrestrial intelligence** (Astronomy) https://setiathome.berkeley.edu
SHArK: Solar Hydrogen Activity Research Kit (7)	**Crowd runs experiments on metal oxide semiconductors** (Chemistry) https://www.uwyo.edu/parkinson/shark_project.html
Snapshot Serengeti (14)	**Crowd classifies animals in images taken by camera traps** (Biology) https://www.zooniverse.org/projects/zooniverse/snapshot-serengeti
Stall Catchers (8)	**Crowd identifies vessels as flowing or stalled in videos from the brains of mice** (Neuroscience) https://stallcatchers.com/main
Synaptic Protein Zoo (8)	**Crowd identifies clusters in images of synaptic proteins** (Neuroscience) https://www.zooniverse.org/projects/reber199/synaptic-protein-zoo
Tell Us! Accidental Injuries (1, 4, 13, 14)	**Crowd develops research questions in the field of traumatology** (Medical science) https://tell-us.online/_Resources/Persistent/f/c/c/b/fccb73883edcd513a8cae1f7891401441070e1e8/Tell_us_Report2019_en.pdf
Tell Us! Mental Health (2)	**Crowd develops research questions in the field of mental health** (Medical science) https://ois.lbg.ac.at/wp-content/uploads/sites/24/2023/10/Processdocumentation_CRIS_en.pdf
VitaDAO platform (5)	**Crowd funds scientific research projects** (Medical science) https://www.vitadao.com
Waarnemingen (13)	**Crowd collects data on various species** (Biodiversity science) https://waarnemingen.be

Table 16.1d *Project index - part 4*

W–Z

Project name (Chapters)	**Primary task performed by crowd members** (Primary research field)
Wazoku Crowd platform (former Innocentive) (2, 9)	**Crowd helps solve problems in science and innovation** (Various) https://www.wazokucrowd.com
Weather Rescue At Sea (8)	**Crowd transcribes handwritten logbooks of ships** (Climate science) https://www.zooniverse.org/projects/p-teleti/weather-rescue-at-sea/about/research
Weaving Techniques (7)	**Crowd experiments with different textile-and-gold weaving techniques** (Prehistory) https://www.researchgate.net/publication/370748582_Citizen_Science_digital_und_analog_-_Archaologische_Textilforschung_am_Naturhistorischen_Museum_Wien
Zooniverse platform (1, 2, 5, 8, 11, 12, 13, 14, 15)	**Crowd classifies images or videos** (Various) https://www.zooniverse.org

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