



HAL
open science

Production par les pairs dans la science citoyenne : une approche centrée sur la communauté à travers l'exemple de la science personnelle

Katharina Kloppenborg

► To cite this version:

Katharina Kloppenborg. Production par les pairs dans la science citoyenne : une approche centrée sur la communauté à travers l'exemple de la science personnelle. Computer Science [cs]. Université Paris Cité, 2023. English. NNT : 2023UNIP7302 . tel-04754221

HAL Id: tel-04754221

<https://theses.hal.science/tel-04754221v1>

Submitted on 25 Oct 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Université Paris Cité, en cotutelle avec **The Alan Turing Institute**
ED Frontières de l'Innovation en Recherche et Éducation (474)
Inserm SEED Évolution et ingénierie de systèmes dynamiques (U 1284, UMR-S 1284)

Peer Production in Citizen Science

A Community-Centered Approach on the Example of Personal Science

Par Katharina KLOPPENBORG

Une thèse de doctorat en

MATHÉMATIQUES ET SCIENCES INFORMATIQUES

Dirigée par

Ariel LINDNER et Bastian GRESHAKE TZOVARAS

Présentée et soutenue publiquement

le 10/11/2023

Membres du jury

Mélanie DULONG DE ROSNAY	Directrice de recherche	CNRS – Centre Internet et Société	Présidente du jury & examinatrice
Benjamin Mako HILL	Associate professor	University of Washington	Rapporteur
Katarzyna WAC	Full professor	Université de Genève	Rapporteuse
Ame ELLIOTT	Design Director, PhD	Superbloom, ancien. University of California, Berkeley	Examinatrice
Bastian GRESHAKE TZOVARAS	Senior researcher	The Alan Turing Institute	Co-directeur de thèse
Ariel LINDNER	Directeur de recherche	Université Paris Cité/Inserm	Directeur de thèse

Résumé

Titre: Production par les Pairs dans la Science Citoyenne : Une Approche Centrée sur la Communauté à travers l'Exemple de la Science Personnelle

Mots clés: Travail Collaboratif Assisté par Ordinateur, Interaction Homme-Ordinateur, Science Citoyenne, Science Personnelle, Recherche Participative, Conception Participative, Expérience Utilisateur

La science citoyenne englobe un large éventail de pratiques dans lesquelles la collaboration en ligne pour la production de connaissances joue un rôle important. Cependant, l'étude des formes de collaboration en ligne autres que le crowdsourcing dans la science citoyenne est restée largement inexplorée. Cette thèse vise à combler cette lacune en étudiant la production par les pairs comme un type de collaboration dans les communautés de pratique en ligne de la science citoyenne. Tout d'abord, la théorie de la production par les pairs est opérationnalisée en tant que modèle de travail et est utilisée pour analyser la collaboration dans des études de cas de science citoyenne. S'ensuit un processus complet de conception participative pour un cas d'application donné, qui implique la communauté de pratique de la science personnelle. Ce processus aboutit à la création du « Personal Science Wiki » (Wiki de la recherche personnelle), un espace en ligne destiné à consolider les connaissances communautaires par le biais d'une production par les pairs. Ensuite, une étude d'utilisabilité et de tri des cartes permet d'identifier et de résoudre des problèmes spécifiques liés à la mise en œuvre du wiki, et fournit des informations sur les modèles mentaux et les exigences en matière de contenu concernant les connaissances liées à la recherche personnelle. Les enseignements tirés du processus de conception participative sont généralisés sous forme de recommandations sur le processus pour la conception de solutions de production par les pairs et de systèmes de gestion des connaissances avec des communautés de pratique.

Summary

Title: Peer Production in Citizen Science: A Community-Centered Approach on the Example of Personal Science

Keywords: Computer-Supported Collaborative Work, Human-Computer Interaction, Citizen Science, Personal Science, Participatory Research, Participatory Design, User Experience

Citizen science encompasses a wide range of practices where online collaboration for knowledge production plays a significant role. However, the study of forms of online collaboration other than crowdsourcing in citizen science has remained largely unexplored. This thesis aims to fill this gap by investigating peer production as a form of collaboration in online citizen science communities of practice. First, peer production theory was operationalized as a working model and used to analyze collaboration in citizen science case studies. This was followed by a comprehensive participatory design process for a specific use case involving the personal science community of practice. This process resulted in the creation of the “Personal Science Wiki”, an online space for consolidating community knowledge through peer production. Subsequently, a usability and card sorting study identified and resolved issues with the wiki implementation, and provided insights into mental models and content requirements regarding self-research knowledge. The lessons learned from the participatory design process were generalized as process recommendations for designing peer production solutions and knowledge management systems with communities of practice.

Résumé substantiel

Dans le contexte d'une thèse rédigée en anglais en France à l'Université Paris Cité, nous incluons un résumé plus long (12 000 caractères) qui reprend le déroulement de la thèse en français

La collaboration en ligne est devenue une partie intégrante de la vie quotidienne, avec une croissance constante des plateformes de médias sociaux et la formation de communautés en ligne pour le soutien et l'échange de connaissances. De nombreuses plateformes travaillent avec des contenus générés par les utilisateurs, et le travail à distance a été facilité par les avancées technologiques récentes.

Deux formes prédominantes de collaboration en ligne sont le crowdsourcing et la production par les pairs basée sur les communs. Le crowdsourcing implique de déléguer des micro-tâches spécifiques à de grands groupes de personnes, généralement des tâches faciles à réaliser pour les humains mais difficiles pour les ordinateurs, comme la reconnaissance de motifs ou d'objets. En revanche, la production par les pairs basée sur les communs fonctionne comme un mode de production distribué qui est facilité par des communautés auto-organisées. Dans ce modèle, les tâches varient en complexité et en taille, et la création de tâches est intégrée aux efforts de la communauté. Des exemples notables de production par les pairs basée sur les communs incluent Wikipedia et des logiciels open-source comme Linux. Des variantes existent également, comme on peut le voir sur des plateformes comme TripAdvisor ou Google Maps, où la production par les pairs est « hébergée par une entreprise », ce qui signifie qu'une entreprise gère les droits de propriété, la gouvernance et la gestion. La croissance de la collaboration en ligne et de la technologie des capteurs accessibles a propulsé le domaine de la science citoyenne, englobant diverses pratiques impliquant le public dans la production de connaissances scientifiques. La science citoyenne va des contributions bénévoles à la collecte de données ou à l'annotation dans des projets dirigés par des scientifiques professionnels. Cela peut réduire les coûts ou augmenter l'échelle des efforts. La science citoyenne est aussi adjugée comme une citoyenneté active liant science, démocratie et politique publique. Les projets de science citoyenne sont classifiés basées sur les niveaux de participation du public, la plus répandue étant les projets « contributifs » impliquant des tâches de crowdsourcing. La production par les pairs basée sur les communs a été suggérée comme une approche alternative de collaboration en ligne en science citoyenne, avec le potentiel de faciliter un engagement plus approfondi et varié. Cependant, les applications de la production par les pairs dans le domaine de la science citoyenne sont restées rares jusqu'à présent.

La science personnelle, issue du mouvement « Quantified Self » (quantification de soi), implique que des individus utilisent des méthodes empiriques pour explorer des questions personnelles, en particulier liées à la santé. Grâce aux pratiques d'auto-suivi, les individus découvrent des solutions pour des problèmes de santé, contribuant à l'autonomisation personnelle et étant parfois le catalyseur d'initiatives de recherche dirigées par les patients. Cela est illustré par des cas dans la recherche sur le diabète ou la maladie de Parkinson. La communauté de la science personnelle valorise le soutien mutuel par les pairs, mais doit faire face à des défis pour accumuler des connaissances partagées, indiquant un besoin d'outils améliorés pour faciliter la collaboration tout en respectant les valeurs de la communauté. La participation active des individus tout au long du cycle de recherche et la présence d'une communauté en ligne active font de la science personnelle un domaine fascinant pour étudier la collaboration en ligne dans la science citoyenne axée sur les citoyens.

Cette thèse vise à explorer la production par les pairs comme une approche collaborative en science citoyenne, en utilisant la science personnelle comme étude de cas. Elle aborde les éléments clés des plates-formes de production par les pairs en science citoyenne et examine leur mise en œuvre dans les plates-formes existantes. Ensuite, cette compréhension est appliquée pour concevoir une approche de production par les pairs pour la construction collaborative de connaissances en science personnelle, en commençant par enquêter sur les obstacles à l'adoption des pratiques de science personnelle et en développant une solution grâce à une conception participative et centrée sur l'utilisateur. Ce faisant, cette recherche contribue également aux connaissances sur la production par les pairs, la gestion des connaissances et la conception participative au sein des communautés de pratique entre pairs.

Initialement, nous élaborons un modèle opérationnel basé sur la théorie de la production par les pairs, qui présente sept éléments fondamentaux de la production par les pairs dans le contexte de la science citoyenne, tels que sont expliqués dans le chapitre 2 de cette thèse. Ces éléments englobent les éléments « objet de recherche commun », « gamme de tâches », « granularité et modularité », « auto-sélection équitable », « contrôle de la qualité », « trajectoires d'apprentissage » et « coordination directe et indirecte ». Ce modèle sert de cadre pour analyser et concevoir des projets collaboratifs en ligne. Ensuite, nous appliquons ce modèle à trois plates-formes variées de science citoyenne : iNaturalist pour l'observation de la biodiversité, Public Lab pour la recherche DIY sur la justice environnementale, et Zooniverse pour le crowdsourcing et la mise à l'échelle. Les résultats confirment nos attentes, en révélant que Public Lab est étroitement aligné aux principes de la production par les pairs, Zooniverse présentant moins de tels éléments, et iNaturalist se situant entre les deux. Ces études de cas illustrent non seulement comment les caractéristiques de la production par les

pairs sont mises en œuvre sur les plateformes de science citoyenne, mais mettent également en lumière les motivations et les compromis inhérents à ces mises en œuvre de production par les pairs. De plus, elles permettent une distinction plus claire entre le crowdsourcing et la production par les pairs. Ces idées aboutissent à un guide de conception pour la production par les pairs dans la science citoyenne, destiné à soutenir les chercheurs et les praticiens dans la prise de décisions et dans l'incorporation d'éléments de production par les pairs dans leurs entreprises collaboratives, si cela est souhaité.

Par la suite, dans le chapitre 3, nous appliquons cette connaissance pour élaborer une approche de production par les pairs au sein d'une communauté exemplaire de science citoyenne « bottom up » (ascendante) : la communauté de pratique en sciences personnelles. Pour explorer les problèmes et les solutions possibles, nous utilisons une approche de conception centrée sur l'utilisateur, en suivant le cadre du double diamant du « design thinking ». Cela signifie que tout d'abord, nous identifions les parties prenantes et développons 13 membres archétypaux de la communauté de sciences personnelles en tant que « personas ». Ces personas sont basées sur des entretiens avec des auto-chercheurs menés par l'équipe juste avant cette étude. A travers ces entretiens nous extrayons en plus les motivations, les frustrations et les idées des auto-chercheurs. Celles-ci nous les regroupons en différentes catégories telles que la communauté, le partage et l'apprentissage, les problèmes d'accessibilité ou les demandes de fonctionnalités. Lors de réunions d'équipe avec les parties prenantes de la communauté, nous utilisons ces catégories et les « personas » comme points de départ pour les discussions afin de hiérarchiser les problèmes et les domaines d'intérêt. Cela conduit à une focalisation sur des approches centrées sur la communauté, car la cohésion communautaire est identifiée comme un moteur de motivation à long terme réussi. La problématique mise en évidence est le manque d'un moyen facile d'accéder aux connaissances au sein de la communauté, qui serait complémentaire et plus accessible que les réunions ou les fils de discussion sur les forums. Par la suite, nous plongeons dans une phase d'idéation et de prototypage, impliquant notamment la création d'une maquette d'une plateforme sociale en sciences personnelles. Le concept et la structure de cette plateforme sont ensuite transformés en un format de type wiki dans la deuxième itération du prototypage. Cette transition privilégie le déploiement rapide et les tests en temps réel d'un produit minimal viable par la communauté, tout en incorporant dès le départ des fonctionnalités de production collaborative. Après avoir reçu des retours positifs de d'autres parties prenantes de la communauté, le Wiki des Sciences Personnelles est mis en œuvre et rendu accessible à la communauté. Le contenu initial est généré par l'importation de plus de 370 présentations des événements « Show and Tell » des archives de Quantified Self. Les retours sont continuellement recueillis à travers des pages wiki dédiées, un canal Slack et lors de réunions

communautaires hebdomadaires. Ils sont ensuite régulièrement intégrés à la plateforme. Un petit groupe d'utilisateurs commence à contribuer régulièrement aux pages, ce qui permet au wiki d'accumuler environ cent pages de contenu au cours des sept premiers mois.

Animés par le désir d'explorer l'utilisabilité du wiki à travers le flux d'utilisateurs pour un public plus large et incités par le nombre croissant de pages de wiki qui semblent ne pas correspondre au système de catégories existant, nous avons mené une étude utilisateur, qui est détaillée dans le Chapitre 4. Cette étude est composée de deux segments principaux encadrés par un premier entretien avec les participants de cette étude, qui couvre les expériences des participants en matière de sciences personnelles, leur familiarité avec les wikis et leurs informations démographiques. Le premier segment de l'étude implique un test d'utilisabilité où les participants ont pour tâche de localiser des éléments d'information spécifiques sur le wiki, tels que les appareils pour enregistrer les données de sommeil ou les personnes ayant contribué au suivi des activités. Par la suite, les participants sont encouragés à naviguer librement sur le wiki afin de concevoir un projet imaginaire centré sur le suivi du sommeil et un sujet de leur choix. Le deuxième segment consiste en un exercice de tri de cartes, utilisé pour découvrir les modèles mentaux que les participants possèdent en ce qui concerne les informations liées à la recherche personnelle. Dans cet exercice, les participants sont invités à organiser et à catégoriser 45 titres de pages du Personal Science Wiki en catégories qui leur semblent logiques.

Un total de 21 participants ont été recrutés, avec des expériences variées en matière de recherche personnelle et dans la communauté des sciences personnelles. Tous les participants ont participé à la tâche de tri de cartes, tandis que les deux sessions de tests d'utilisabilité ont été menées avec cinq participants chacune. La première itération des tests d'utilisabilité a révélé des difficultés dans les tâches de recherche d'informations de base, entravant certains utilisateurs dans l'achèvement des missions ou entraînant des retards prolongés. Des ajustements ultérieurs ont été apportés, conduisant à un taux de réussite de 100 % dans la deuxième itération des tests d'utilisabilité. De plus, cette deuxième itération a mis en évidence des problèmes d'accessibilité liés aux pages importées des présentations « Show and Tell ». Les résultats ont suggéré que le format narratif s'est avéré peu optimal pour extraire rapidement des informations pertinentes concernant la planification d'études à partir d'une vaste gamme de présentations et pour identifier les présentations pertinentes.

Les données du tri de cartes ont été analysées quantitativement et complétées par une évaluation qualitative des commentaires des participants pendant l'étude. Les résultats quantitatifs ont identifié six regroupements thématiques, englobant les variables à suivre (y compris des sous-regroupements axés sur divers sujets de santé tels que la santé mentale, l'alimentation, la nutrition et le développement personnel), les enseignements tirés des projets,

les méthodes d'analyse des données, les entités et les interventions, les outils de suivi et la communauté des chercheurs personnels. Les informations qualitatives ont mis en évidence la tendance des participants à envisager plusieurs architectures d'information potentielles simultanément, en fonction de la tâche et du groupe d'utilisateurs. De plus, les participants ont exprimé le souhait d'introduire des hiérarchies pour guider progressivement les utilisateurs vers des informations pertinentes.

À partir du code utilisé dans l'analyse, nous avons développé un package Python open-source appelé « cardsort », destiné aux chercheurs en expérience utilisateur. Ce package propose des fonctions d'analyse de regroupement hiérarchique, de visualisation de dendrogrammes et d'extraction d'étiquettes de regroupement à partir des données de tri de cartes.

Enfin, la discussion dans le Chapitre 5 apporte des éclaircies sur le développement de systèmes de gestion des connaissances au sein des communautés de pratique en sciences citoyennes, ainsi que sur la conception participative de plates-formes de production par les pairs plus généralement. Elle propose des résumés concis sur les enseignements tirés sous forme de recommandations de processus, venant en aide aux chercheurs et praticiens confrontés à des défis similaires.

Dans l'ensemble, cette thèse présente le Personal Science Wiki en tant qu'infrastructure pour produire de manière collaborative une ressource de connaissances partagées au sein de la communauté des sciences personnelles. Le processus de réflexion de conception a révélé des obstacles à une plus large participation dans la recherche personnelle, et l'étude utilisateur informe la conception des structures d'information et des critères de contenu pour les ressources de connaissances en sciences personnelles à plus grande échelle. Le processus de conception a également produit des enseignements sur la conception participative et la gestion des connaissances basée sur la communauté, mettant en évidence à la fois les synergies et les défis de l'intégration de la production collaborative et de la conception participative. En fin de compte, cette thèse contribue à la compréhension de la production collaborative en tant que méthode de collaboration dans les sciences citoyennes de manière plus générale, par l'étude de cas et en extrayant les éléments essentiels tout en discutant des motivations et des compromis.

Acknowledgements

A PhD thesis is not written in isolation, and I owe a lot to the people who accompanied me along the way. First, I would like to thank my supervisors Bastian Greshake Tzovaras and Ariel Lindner for entrusting me with this opportunity, for accompanying me throughout all steps, challenges and successes of this journey, and for helping me learn a lot. A big thank you also goes to the other members of the Peer Produced Research Lab. Mad Ball, who spent countless hours discussing, co-authoring, implementing, and advising me on this project despite not having an official supervision role, and Enric Senabre Hidalgo for many discussions, input, and suggestions.

I would like to thank the members of my thesis advisory committee, Benjamin Mako Hill, Vineet Pandey, and Molly Clare Wilson for guiding me over the last three years and providing me with much useful feedback, developing methods with me, helping me prepare submissions, giving me strategic advice, and encouraging me, much of this beyond the obligations of the TAC. I would also like to thank the members of my thesis jury committee, the reviewers Mako (as mentioned above) and Katarzyna Wac, as well as the examiners Ame Elliott and Mélanie Dulong de Rosnay for their support during this final step. My thanks go also to Martijn de Groot for his willingness to serve on the jury, even though ultimately scheduling conflicts intervened. There have been many other people who have supported me directly or indirectly during different stages of this project. My thanks go to Fotis Psomopoulos who mentored me during the Open Life Sciences program, and to Kirstie Whitaker and Georgia Aitkenhead who gave me my first opportunity to work in a citizen science project and to apply open science practices to user research. My thanks also go to Gary Wolf and Steven Jonas from Quantified Self for insightful discussions and support in importing the Show and Tell talks into the Personal Science Wiki. I would also like to thank all participants in the Open Humans self-research chats, and users of the wiki for sharing their feedback and opinions, notably DG and Richard. I would also like to thank all those who volunteered their time to participate in my user research study, whose names have to be kept anonymous. Thanks also go to the reviewers of the cardsort Python package from pyOpenSci, Alexandre Batisse, Semidán Robaina, and khynder who helped me improve the code significantly. I would also like to thank Lionel for helping me with the IRB application for my study, Muki for helping me develop the narrative structure of this thesis, and Cléa for proofreading.

Next, I would like to thank the members of the CorrelAid Paris student club. Notably I would like to thank Liubov, to whom I also owe many other things, including proofreading my dissertation, and making the contact that made me find this PhD opportunity in the first place.

Thanks goes to the team and project partners of the iNaturalist and Paris-Bikes projects, and to the many other great people I met and collaborated with in the context of CorrelAid.

I would also like to thank the administrative staff of LPI, notably Béatrice, Yaneth, and Dule who helped me overcome the administrative difficulties working and doing a PhD in a foreign country.

I would also like to thank all the other people who helped me feel at home here, and I hope they will forgive me for not listing them all by name. To everyone not mentioned above who I met in and around LPI who I had the pleasure to share countless lunches, and conversations with, and who became friends. To the other PhD students who I shared many experiences with and who became friends. To other people I met along the way outside of research contexts, and to my friends from previous phases of life who are still part of my life. To Hugo for spending every day and building a home with me, and also to his family. Finally, I would like to thank my parents for always being there for me, teaching me values, and supporting me in my choices.

As a last note, since this is a thesis about online collaboration, I would also like to acknowledge the countless people that contributed to the masses of content I consumed during this time which helped me with many things, from articles on Wikipedia, to coding tutorials, or ASMR pomodoro videos.

Table of Contents

Résumé	III
Summary.....	IV
Résumé substantiel.....	V
Acknowledgements	X
Table of Contents.....	XII
List of Tables	XV
List of Figures	XVI
List of Abbreviations	XVII
Data Availability.....	XVIII
1. Introduction.....	1
1.1 From Crowdsourcing to Peer Production – Variants of Online Collaboration	2
1.2 Citizen Science – Thriving through Online Collaboration	5
1.3 Personal Science – An Example of Citizen Science in the Wider Sense	8
1.4 Research Questions and Approach.....	10
2. Operationalizing Peer Production for Citizen Science	12
2.1 Background: Peer Production	12
2.1.1 Characteristics of Peer Production	13
2.1.2 Peer Production in Citizen Science.....	16
2.2 Methods	17
2.3 Working Model of Peer Production.....	19
2.4 Case studies	24
2.4.1 iNaturalist.....	27
2.4.2 Public Lab	28
2.4.3 Zooniverse.....	30
2.5 Discussion	31
2.5.1 Comparison by Peer Production Element, Motivations and Trade-Offs	31
2.5.2 Limitations, Conclusion, and Future Work.....	36
3. Designing a Peer Production Approach for Personal Science	39
3.1 Background: Personal Science.....	39
3.1.1 Emergence of Personal Science: From “Sensor-Mania” to Self-Research.....	39
3.1.2 Extracting the Common from Individual Practices: Frameworks, Motivations, and Topics in Personal Science	41

3.1.3	Personal Science’s Relationship with Scientific Principles and Practices	43
3.1.4	Barriers and Research Gaps	45
3.2	Methods	47
3.3	Results	49
3.3.1	Stakeholder Identification.....	49
3.3.2	Problem Identification	54
3.3.3	Prototyping.....	56
3.3.4	Personal Science Wiki	59
3.4	Discussion	64
4.	<i>Usability of the Wiki Approach and Mental Models of Personal Science Knowledge ..</i>	73
4.1	Background: Usability and Mental Models	73
4.2	Methods	75
4.2.1	Usability Test.....	75
4.2.2	Card Sorting.....	77
4.3	Results	81
4.3.1	Description of Study and Sample	81
4.3.2	First Usability Test Iteration	83
4.3.3	Changes based on Results.....	85
4.3.4	Second Usability Test Iteration	91
4.3.5	Card Sorting.....	94
4.3.6	Development of the “cardsort” Python Package	102
4.4	Discussion	103
5.	<i>Discussion.....</i>	110
5.1	Community Knowledge Management in a Citizen Science Community of Practice	113
5.1.1	Reflections on Challenges	113
5.1.2	Limitations and Future Work	121
5.2	From Participatory Design to Peer Production	123
5.2.1	Reflections on Challenges	123
5.2.2	Limitations and Future Work	130
5.3	Conclusion	131
	<i>Bibliography.....</i>	134
A.	<i>Appendix.....</i>	<i>i</i>
A.1	Links to Platform Features Referenced in the Case Studies	<i>i</i>
A.2	Screenshots of Platform Features	<i>iv</i>
A.2.1	Communal Validation iNaturalist.....	<i>iv</i>
A.2.2	Reuse Features on Public Lab	<i>v</i>
A.2.3	Support Features for New Users.....	<i>vi</i>
A.3	Peer Production in Citizen Science Design Guide	<i>vii</i>
A.4	List of Personas	<i>x</i>

A.5	Community Rose-Bud-Thorn and Prioritization (Copy from Miro Board)	xix
A.6	Ideation (Copy from Miro Board)	xxiv
A.7	Screenshots of Personal Science Community/Project Platform	xxvii
A.7.1	Homepage mockup	xxvii
A.7.2	Actions when logged in (mockup)	xxviii
A.7.3	Project page mockup (top)	xxix
A.7.4	Project page mockup (bottom)	xxx
A.7.5	Topic page mockup (User content tab)	xxxii
A.7.6	Topic page mockup (Tool ratings tab)	xxxiii
A.7.7	Topic page mockup (Wiki tab)	xxxiii
A.8	List of Cards for Card Sorting Task	xxxiv
A.9	Usability Tests	xxxvii
A.9.1	List of Issues from the First Usability Test Iteration	xxxvii
A.9.2	List of Issues from the Second Usability Test Iteration	xxxviii
A.9.3	Comparison of Results from Usability Test Iterations 1 and 2	xxxix
A.10	User-Generated Labels for Clusters of Cards (Summary)	xl
A.11	Process Recommendations	xlvi
A.11.1	Process Recommendations for Designing Knowledge Management Systems for and with Communities of Practice in Citizen Science	xlvi
A.11.2	Process Recommendations for the Participatory Design of Peer Production Systems	xlviii
A.12	Articles	l
A.12.1	A Peer Production Model for Citizen Science: Comparative Analysis of Three Online Platforms	l
A.12.2	Peer-Producing a Common Knowledge Resource for Personal Science	lxxiv

List of Tables

Table 2.1 Eight characteristics of peer production as conceptualized by Kostakis and Bauwens (2020).....	16
Table 3.1 An exemplary persona representing an archetypal user type in the personal science community	53
Table 4.1 Tasks of the usability tests.....	76
Table 4.2 A selection of cards used for the card sorting exercise.....	78
Table 4.3 Subcategories created on the wiki after the first iteration of usability tests	91

List of Figures

Figure 1.1 Levels of participation in scientific research adapted from Shirk et al. (2012), and percentage of European citizen science projects in these categories (Hecker et al., 2018) ...	7
Figure 2.1 Working model of peer production with examples from Wikipedia.....	20
Figure 2.2 Schematic representation of knowledge production in the case studies	26
Figure 3.1 Conceptual framework of activities in personal science (Wolf & De Groot, 2020)	41
Figure 3.2 An adaptation of the double diamond design process (Chu, n.d.)	48
Figure 3.3 Screenshot of a part of the Miro board, showing statements from interviews clustered by topic, and color-coded according to the “rose-bud-thorn” method.....	55
Figure 3.4 Mockup of a profile page for the Personal Science Platform concept. Source of UI components: https://contrauikit.com/	58
Figure 3.5 An early version of the Personal Science Wiki homepage, showing the main category structure “Tools”, “Topics”, “Projects”, and “People”	61
Figure 3.6 An early version of the “Oura Ring” page, a page of the category “Tool”, including a “Tool Infobox” template on the top right, and a “Linked content on this wiki” template on the bottom of the page	63
Figure 4.1 Screenshot of an exemplary card sorting session. The left column (“Cards”) contains all cards that have not yet been sorted. All other columns are categories created and filled by the participant.....	79
Figure 4.2 Screenshot of the updated user interface of the Personal Science Wiki homepage after the first iteration of usability tests.....	87
Figure 4.3 Screenshot of the updated “Oura Ring” page, used as an example for a Tool page	89
Figure 4.4 Dendrogram visualizing the results of hierarchical cluster analysis of the card sorting outputs of all 20 participants.....	95
Figure 4.5 A screenshot of the documentation of the “cardsort” Python package (https://cardsort.readthedocs.io/).....	102
Figure 5.1 PhD project process overview.....	112

List of Abbreviations

CBPP Commons-based peer production

FOSS Free and open source software

Data Availability

Supplementary materials are published under the public Creative Commons Attribution 4.0 International license and can be accessed using the following DOI:

doi:[10.5281/zenodo.8250058](https://doi.org/10.5281/zenodo.8250058)

1. Introduction

Collaborating and sharing content online have become an integral part of daily life. Social media platforms have experienced a steady growth in their user base, from 2.7 to 4.6 billion between 2017 and 2022, with an expected additional growth of one billion users in the next five years (Dixon, 2023). Thanks to numerous TikTokers and Youtubers, it is possible to access tutorials for almost any topic, ranging from viral dances to server-side programming. Online magazines attract thousands of people every week to vote on matters like the best user-generated captions for cartoons (Jain et al., 2020), and even entire orchestras have been casted online (Adair, 2011). Regarding more serious matters, hashtags like #MeToo and #BlackLivesMatter helped to mobilize large crowds for a common cause (S. J. Jackson et al., 2020). In the workplace, the Covid-19 pandemic greatly accelerated remote work, leading to the proliferation of digital tools for online collaboration (Kniffin et al., 2021). These tools range from video conferencing and online course management to real-time collaboration platforms that facilitate activities such as brainstorming, planning, design, and document editing, thereby supporting further growth of online collaboration (Battisti et al., 2022; Vo et al., 2022). On social media platforms like Facebook and Reddit, online communities have formed where people offer support to one another and exchange knowledge in various areas spanning work, hobbies, or health (Evans et al., 2017; Gilmour et al., 2020; Kou & Gray, 2019).

Even prior to these recent developments, groups of individuals have come together online to engage in collaborative efforts for creation or learning, to achieve common goals, or for personal use-value or fulfillment. Group chat systems such as IRC (Internet Relay Chat) have existed since the late 1980s (Reid, 1991), followed by the emergence of online forums in the first half of the 1990s (Loutonen, 1995). One of the earliest examples of collaborative production online is the development of free and open-source software (FOSS). Having grown with the propagation of the internet, this movement gained wider public attention through the GNU project and introduction of the General Public License in 1984, initiated by Richard Stallman, as well as the development of the Linux Kernel by Linus Torvalds in 1991. Together, they allowed for running an operating system composed entirely of free software for the first time (Bretthauer, 2001).

The open online encyclopedia Wikipedia, which had its first edit in 2001, came to be one of the most successful examples of platforms with user-generated content of all time, with over 61 million articles in total by June 2023, equivalent to about 23,000 print volumes ("History of Wikipedia," n.d.; *Pages to Date*, 2023). In 2006, the Time magazine named "You" as the

person of the year, symbolizing the millions of individuals who contribute content online, underscoring the growing importance of user-generated content as a societal phenomenon in the beginning of the twenty first century (Grossman, 2006).

Since then, this trend has not stopped to accelerate. Global user bases contribute to large platforms by providing reviews for restaurants or videos, supporting projects through funding, or prototyping solutions for various issues during hackathons (Granados & Pareja-Eastaway, 2019; Navarrette, 2020). In recent years, the emergence of web platforms for citizen science has demonstrated significant potential in enabling volunteers to contribute to scientific knowledge (Haklay et al., 2021). In terms of scale, the platform Zooniverse leads the way, with over 2.6 million registered volunteers supporting science projects¹. From fields like biodiversity monitoring to protein folding, this practice extends continuously to encompass areas such as health, wherein patients actively participate in research facilitated by online collaboration methods (Kullenberg & Kasperowski, 2016; Swan, 2009).

1.1 From Crowdsourcing to Peer Production – Variants of Online Collaboration

The availability of interactive tools on the internet has allowed the emergence of various forms of online collaboration, where groups of individuals come together to create something collectively using digital platforms. With the growth of these phenomena, researchers have sought to understand and differentiate forms of online collaboration, for example to understand how to design sociotechnical systems that promote contribution (Hawthornthwaite, 2009).

In the realm of open participation and mass collaboration on the internet, associated with phenomena like collective intelligence, the open movement, and the growth of user-generated content, two forms of organizing online collaboration dominate discussions: crowdsourcing and peer production. Sometimes the terms are used interchangeably, or one is considered a subset of the other, encompassing a wide range of online collaboration activities, including idea generation, microtasking, public participation, citizen science and journalism, as well as open-source software, and wikis (Hawthornthwaite, 2009; Hossain & Kauranen, 2015). However, other perspectives suggest that crowdsourcing and peer production are distinct types of online collaboration that vary along multiple dimensions.

¹ <https://www.zooniverse.org/>, last accessed 07.09.2023

The term crowdsourcing was coined by Howe (2006) to describe the practice of outsourcing tasks to large crowds of individuals through an open call for participation. Crowdsourcing typically involves well-defined and discrete microtasks that contribute data points to a shared dataset. These tasks are characterized as being easily performed by human annotators, but hard for computers, such as pattern or object recognition in images. Crowdsourcing can include small monetary rewards per task, as seen on platforms like the human intelligence task marketplace Amazon Mechanical Turk, or it can be free of charge, as usually the case in citizen science projects. In other cases, participation in crowdsourcing tasks may be required to access certain services, as exemplified by Google's reCAPTCHA, which asks users to identify images to distinguish humans from bots (Benkler, 2016).

Hawthornwaite (2009) uses the term "lightweight peer production" for crowdsourcing, where the weight metaphor relates to contributors' efforts, commitments, and interaction with each other. In this model, participants engage in rule-based tasks that are pre-specified by a project lead. These tasks are discrete, standalone, and do not require coordination between contributors. They are typically of equal size and complexity, requiring minimal learning or preparation, with clear instructions provided by the project organizer. Crowdsourcing has gained immense popularity due to its effectiveness in minimizing costs and scaling up projects, particularly when tasks involve explicit, easily formalized, and routine knowledge inputs that can be pre-specified by task designers, in order to harness large numbers of contributors (Benkler, 2016; Navarrette, 2020).

The term commons-based peer production (CBPP) was introduced by Benkler (2002) to describe the organizational models observed in emerging phenomena at that time: The FOSS movement had gained momentum, in particular through the development the widely used Linux operating system, and Wikipedia had become one of the most successful collaborative online project in the beginning of the twentieth century (Benkler, 2006). An early characterization by Raymond (1999) employed the metaphor of a "cathedral" to describe traditional proprietary software development as a centralized and hierarchical structure. In contrast, he likened open-source software development to a "bazaar," emphasizing its decentralized and open nature, where anyone could freely access and contribute to the development process. Benkler (2006) defines CBPP as a new mode of production, facilitated by the internet, characterized by self-organizing distributed communities collaborating on a common project without managerial commands or monetary incentives. The term "commons" references Ostrom's (1990) concept of non-proprietary resources, highlighting that CBPP projects operate with open and shared resources and outputs.

In CBPP, individuals self-identify and self-select tasks of varying size and complexity. Unlike in crowdsourcing, these tasks are not externally designed but are part of the community's work (Benkler, 2016). Taking the example of Wikipedia, contributors have the freedom to choose any task, ranging from correcting a spelling mistake to creating an entire article. Hawthornthwaite refers to this as "heavyweight peer production", emphasizing characteristics such as high complexity, interdependence of contributions, greater learning efforts, increased collaboration, and long-term commitment to the community. CBPP encompasses not only the production itself but also project governance and quality control by peers (Hawthornthwaite, 2009). With these characteristics, CBPP has been recognized as beneficial in situations where requirements for knowledge, resources, and solutions are uncertain. Its capacity to attract contributors with diverse motivations and skills is highlighted, making it suitable for projects that require experimentation and innovation to address complex issues by harnessing creativity, tacit knowledge, and diversity of experiences of contributors (Benkler, 2016). In practice, however, demographic differences within the group of contributors, such as gender or status in Wikipedia or FOSS (Kostakis et al., 2021), are apparent, revealing challenges in effectively engaging a truly diverse community. One explanation for this inequality on Wikipedia is conflict-intensive editing policies that can discourage women from participating (Collier & Bear, 2012). The problems of disadvantaging non-dominant populations are not limited to policy- and coordination-rich CBPP approaches. They also arise in crowdsourcing, where responses from multiple participants are often aggregated to produce an average or majority vote, potentially rendering minority opinions invisible (Noble, 2012).

The characterization of crowdsourcing and CBPP as lightweight and heavyweight peer production suggests that these practices exist at two ends of a spectrum. Crowdsourcing involves anonymous and discrete micro-contributions to support a project organizer's goal, while CBPP entails a more community-oriented approach where contributors collaborate on various tasks, share resources and outputs, and participate in project governance (Hawthornthwaite, 2009). Similarly, Benkler (2016) introduces the concept of "firm-hosted" peer production as a variant of CBPP, exemplified by platforms like the travel information platform TripAdvisor. In this version, governance and management are controlled by enterprises rather than the community, but it shares characteristics such as self-selection and varying task sizes with CBPP. In practice, projects often incorporate elements from both collaboration modes, such as easy predefined tasks for beginners or casual contributors in CBPP, as well as pathways for engagement beyond microtasks in crowdsourcing (Hawthornthwaite, 2009; C. Jackson et al., 2018).

In this thesis, the terms CBPP and “peer production” will be used interchangeably to refer to the heavy-weight, commons-based variant of online collaboration, while “crowdsourcing” will be used to describe the lightweight, micro-task mode.

1.2 Citizen Science – Thriving through Online Collaboration

A domain that has flourished due to advancements in online collaboration, as well as sensor technology in smartphones and computational power, is citizen science. Citizen science is an umbrella term for a wide range of practices which revolve around engaging the public in scientific knowledge production (Haklay et al., 2021).

The decision to adopt a citizen science approach can be driven by different motivations, and even the term itself originated in the 1990s from two separate perspectives. Bonney (1996) uses it to describe volunteer contributions to natural sciences, such as ornithology. This type of participation has played a vital role in reducing costs for large-scale research projects by leveraging the potential of global contributor bases for data collection across expansive geographic areas and for the annotation of large amounts of data (Kullenberg & Kasperowski, 2016). This form of citizen science has made significant contributions to the proliferation of citizen science in scientific literature, spanning fields such as biodiversity monitoring, geography, astronomy, or microbiology (Bautista-Puig et al., 2019; Kullenberg & Kasperowski, 2016).

On the other hand, Irwin (1995) conceptualizes citizen science from a social science and normative perspective, considering public participation in science as a form of active citizenship, explicitly linking it to democracy and public policy. Citizen science projects closely associated with this tradition, also known by names like participatory action research or community-based participatory research, are often initiated by local communities seeking scientific evidence to address issues they have identified and to advocate for their rights (Haklay et al., 2021). Common topics include environmental justice, such as air and water pollution, or the preservation of species and natural resources. The involvement of professional scientists in these projects varies, and may be entirely independent of research institutions (Kullenberg & Kasperowski, 2016).

The boundaries of citizen science have been a subject of scientific discourse, trending towards a multifaceted view of citizen science (Kasperowski & Kullenberg, 2018). This broader understanding of citizen science extends to other practices in which individuals engage with science, such as DIY science, biohacking, or the maker movement (Ferretti, 2019). Given the expansive nature of the concept and its increasing significance in research agendas and funding structures (Strasser et al., 2018), efforts have been made to develop typologies for

characterizing and classifying different types of citizen science, as well as principles to guide the design of citizen science projects.

For instance, the European Citizen Science Association has published ten principles that outline their interpretation of good practice in citizen science. These principles emphasize factors such as active involvement, mutual benefits, recognition of citizen scientists, and propose evaluation criteria including scientific output, data quality, participant experience, and wider impact (ECSA (European Citizen Science Association), 2015).

Frequently citizen science typologies classify projects based on the phases of scientific knowledge production that citizen scientists can participate in. Drawing inspiration from Arnstein's ladder of citizen participation in politics (Arnstein, 1969), Shirk et al. (2012) developed a widely used framework that describes five levels of citizen science based on degree of participation (see Figure 1.1). The phases that include active engagement of the public in the research process range from "contributory" projects, where professional scientists invite volunteers to contribute to data collection or annotation, to "collaborative" and "co-created" projects, where citizen scientists are involved in multiple stages of research, including study design and interpretation. Additionally, there are "collegial" projects, where research is conducted by individuals without professional credentials, with varying degrees of institutional recognition. Expanding upon this approach, Schrögel and Kolleck (2018) split degrees of participation into three dimensions: an epistemic dimension, which – similar to Shirk et al. – considers the role of citizen scientists in generating knowledge; a normative dimension, which relates to their inclusion in decision making and governance processes in science; and reach, which assesses the extent to which the involved public includes experts versus the general public.

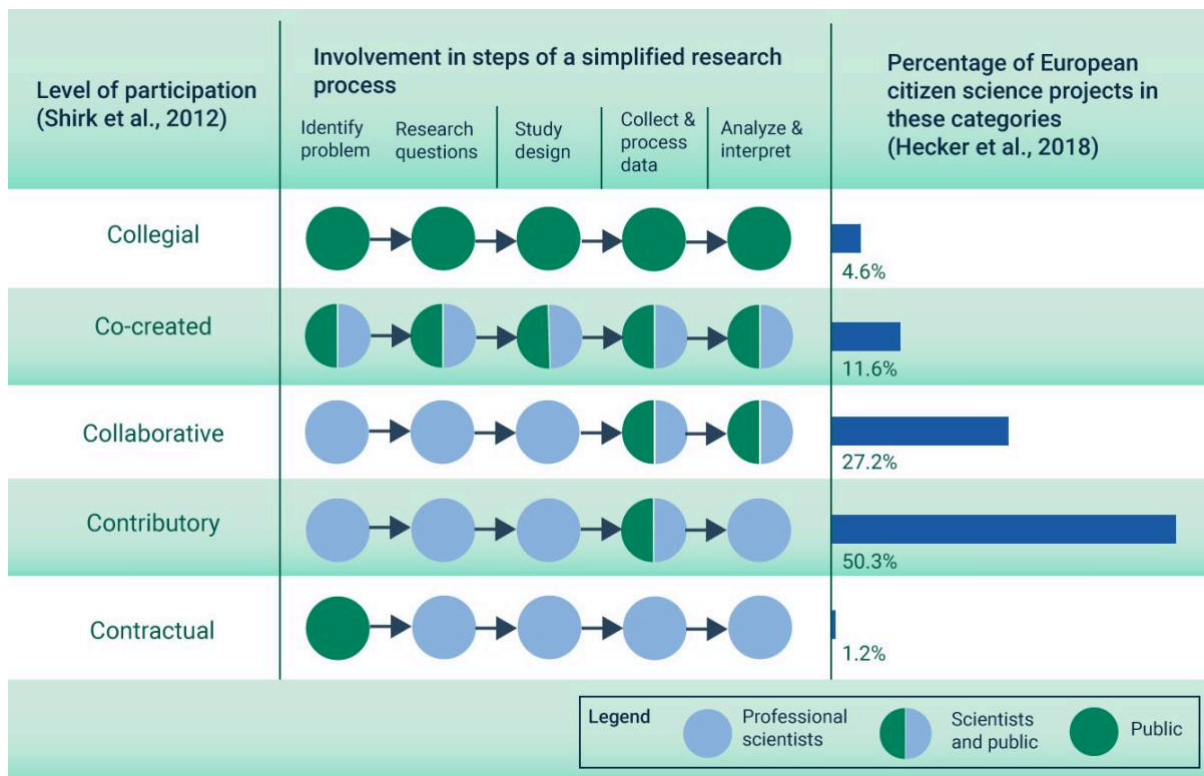


Figure 1.1 Levels of participation in scientific research adapted from Shirk et al. (2012), and percentage of European citizen science projects in these categories (Hecker et al., 2018)

A recent study surveying European citizen science projects found that the majority of citizen science initiatives fall into the category of “contributory” projects (Hecker et al., 2018), the equivalent of which is called “crowdsourcing” in Schrögel and Kolleck’s model (see Figure 1.1). The use of the word “crowdsourcing” seems suitable since the largest part of publications from citizen science highlight projects that utilize online platforms to engage large numbers of contributors (Kullenberg & Kasperowski, 2016). Similarly, the largest part of meta research about citizen science in publications focusing on computer-supported collaborative work focuses on projects using crowdsourcing platforms (e.g. (Mugar et al., 2014; Reeves et al., 2017; Rosser & Wiggins, 2018)), while there is still a need to explore effective support for other types of citizen science with online tools (Law et al., 2017).

Peer production has been suggested as an alternative mode of online collaboration in citizen science, with the potential to enable more autonomous citizen science by facilitating deeper and more varied engagement. Chen (2019) refers to CBPP characteristics like the treatment of scientific knowledge as a commons, flexible task design to attract contributors with a wide range of skills and motivations and the potential to redistribute power, to help citizen scientists “gain legitimacy as qualified knowledge producers”. Mahr and Dickel (2019) draw comparisons with amateur birdwatching in the nineteenth century to make the case for more autonomous

citizen science with a less pronounced lay-expert divide through “peer produced citizen science”.

To date, there have been few works that explore the application of CBPP in citizen science explicitly. Fuster Morell (2021) have examined several citizen science projects from a peer production perspective, focusing on aspects such as governance, licensing and impact. However, there is currently a lack of systematic approaches that specifically address the epistemic dimension, which refers to how peer production can be effectively implemented in citizen science to facilitate the collaborative creation of scientific knowledge.

1.3 Personal Science – An Example of Citizen Science in the Wider Sense

One notable example of citizen science in the wider sense is personal science (Heyen, 2020). Personal science has been defined as “the practice of using empirical methods to explore personal questions”, primarily focusing on health or well-being topics (Wolf & De Groot, 2020). Individuals frequently start practicing self-research because they are confronted with a personal issue that they want to solve, manage, or understand. For example, one day Lindsay Meyer experienced sudden hearing loss on her left ear. She utilized a smartphone app to track the restoration of her hearing alongside medical appointments, enabling her to observe the effectiveness of medication at home and detect any diminishing effects before consulting with her physician (Meyer, 2011). Sara Riggare, who lives with Parkinson's disease, employed a smartphone app to track her finger tapping speed and medication intake over multiple days. This enabled her to identify fluctuations in medication effectiveness and adjust dosages in collaboration with her neurologist, thereby mitigating dips (Riggare & Hägglund, 2018). Personal science is also applied in situations beyond chronic conditions and medical emergencies. For example, in the case of Jacob Eg Larsen, who sought to understand the causes of his sporadic headaches. Although initially challenged by establishing a baseline and appropriate tracking method, Jacob discovered that the pills he took for headaches were contributing to the problem, which helped him to successfully minimize his pain (Larsen, 2018). Similarly, Denise Lorenz, driven by sleep problems, gained insights into the factors affecting her sleep quality through a year-long project where she tracked various variables (Lorenz, 2014).

Personal science practices originated long before the development of modern tracking devices. A historic example is physician and professor Santorio Santorio who extensively experimented on himself and developed dedicated devices, particularly for studying metabolism in the early seventeenth century (Eknoyan, 1999). In contemporary times, the

proliferation of wearable tracking technologies and personal data sharing on the internet has exposed and enabled an increasing number of individuals to engage with sensor technologies and data in their daily life. In this context, the Quantified Self movement emerged in the early 2000s (Lupton, 2016). Hobbyist users and creators of self-tracking tools with a common interest in gaining “self-knowledge through numbers” started to share and discuss first-person accounts of their self-tracking projects. From California the movement spread worldwide, reaching over a hundred meetings until 2019 (Wolf & De Groot, 2020). In recent years, personal science has garnered attention in sociological research by scholars seeking to understand practitioners’ motivations (Senabre Hidalgo et al., 2022), or the phenomenon’s relationship with science (Heyen, 2020) and broader cultural, social, and political dynamics (Lupton, 2016).

The aforementioned examples illustrate the impact personal science can have on individuals’ lives by aiding in the identification of solutions or causes for health-related concerns and promoting self-empowerment through increased awareness (Lupton, 2016). Moreover, personal science offers valuable tools for self-care practices, enabling individuals to take proactive measures towards their well-being (Riggare, Stamford, et al., 2021; Wac, 2022). Because of these reasons, personal science has been suggested as a potential public health instrument (Heyen, 2020; Wolf & De Groot, 2020).

In addition to its impact on individual health, personal science has demonstrated its potential as a driving force behind patient-led research, conducted within patient communities beyond the single patient, which has gained momentum in recent years (Kempner & Bailey, 2019). Personal experiences and observations can serve as the foundation for larger research projects (Roberts, 2004). An example of this is Sara Riggare, as introduced previously, whose involvement in co-creating research projects and advocating for patient engagement stems from her own experiences living with a chronic condition and engaging in personal science (Riggare, Stamford, et al., 2021; Wannheden et al., 2023). Similarly, Dana Lewis, who became a self-tracker following her diabetes diagnosis as a teenager, collaborated with others to develop OpenAPS, an open source artificial pancreas system that has enhanced the lives of numerous individuals with diabetes (D. M. Lewis, 2020).

Peer support is highly valued in the personal science community (Wolf & De Groot, 2020). Practitioners frequently share their experiences and offer feedback and support through dedicated online and offline meetings, forums, subreddits, chat rooms, or blogs (Halavais, 2013; Lupton, 2016). Platforms like Open Humans provide tools to facilitate data imports from various sources and analysis (Greshake Tzovaras et al., 2019).

However, the online collaboration is still far from perfect. Despite the existence of communities for more than 15 years and communication through the mentioned channels, entry barriers have been observed. Individuals tend to craft their methods as they run their projects, and most commercially available apps are not flexible enough to cater well to the needs of people aiming to do personal science. Moreover, there is no systematic way of accessing community knowledge (Wolf & De Groot, 2020). Similarly, a lack of accumulation of a shared knowledge resource has been recognized by Heyen (2020). To make personal science more accessible, tools must be developed to support the sharing and reuse of methods, as well as the translation of common features into reusable research designs (Wolf & De Groot, 2020). This requires the development of mechanisms that foster collaboration while respecting the values and harnessing the collective intelligence of the personal science community.

The active involvement of individuals in the entire research cycle of personal research projects, from planning to interpretation, along with the presence of an active online community that highly values peer support, combined with the recognized issues mentioned above, makes personal science an intriguing research subject for online collaboration in citizen-driven citizen science.

1.4 Research Questions and Approach

The aim of this thesis is to enhance the understanding of peer production as a collaborative approach in citizen science, taking personal science as an exemplary case of bottom-up research. At the intersection of computer-supported collaborative work (CSCW), citizen science, participatory design, and science and technology studies, the following research questions are addressed:

1. *What are the key elements of peer production platforms and how are they implemented in a citizen science context?*

The first research question aims to outline the characteristics of peer production in citizen science contexts and to examine the implementation of these characteristics in existing citizen science platforms. To accomplish this, peer production theory will be translated into a working model. This model will then be applied to case studies of citizen science platforms to comprehend and illustrate how peer production is implemented in these contexts. Additionally, these case studies aim to provide insights into the motivations and challenges associated with adopting peer production features (Chapter 2).

Subsequently, this knowledge will be applied to a specific use case, involving the design and implementation of a peer production approach to support collaborative knowledge building within the personal science community. This will be guided by the following research question:

2. What are the barriers to the widespread adoption of personal science practice, and how can they be addressed with a peer production approach?

The second research question will be addressed using a participatory design thinking approach. User research will first help identify and prioritize issues within the personal science community that are suitable for resolution through a peer production approach. A prototype of a peer production solution will then be developed and refined through iterative design iterations (Chapter 3). A subsequent user research study will focus on usability and on providing deeper insights into user expectations and mental models related to practical knowledge in personal science (Chapter 4).

The contributions of this dissertation include the co-creation of a knowledge management system with the personal science community, further understanding of knowledge management requirements and challenges specific to personal science, which can be generalized for other communities of practice. Lessons learned from the application of the peer production approach will contribute insights into participatory design and the implementation of peer production within communities of practice. Additionally, this thesis contributes to the broader understanding of peer production in citizen science contexts, offering illustrations and guidelines to assist practitioners and researchers in designing collaboration approaches for their projects.

2. Operationalizing Peer Production for Citizen Science

Note: Parts of this chapter have been derived from my prior research article, which is included in Appendix A.12.1.

Commons-based peer production (CBPP), as outlined in chapter 1.1, refers to a mode of organizing collaborative online production. Prominent examples include free and open source software (FOSS) like Linux, and Wikipedia. CBPP is characterized by the self-organization of distributed communities who collaborate on a common project without the need for managerial commands or monetary incentives. The input and output resources are shared as part of a knowledge commons.

2.1 Background: Peer Production

Since the observation of the “bazaar”-like collaboration in FOSS by Raymond (1999) and the coining of the term CBPP by Benkler (2002), the phenomenon of peer production has captured the interest of research, industry, and public sector: Firms such as IBM or Google are highly involved in open source projects, platforms like YouTube or TripAdvisor rely on complex user-generated content (Benkler, 2016), and cities like Helsinki experiment with peer-producing public services (Botero & Saad-Sulonen, 2013). The fascination can be partly explained by the unlikely success of some FOSS projects and Wikipedia: Individuals come together online to create complex knowledge products that outperform some commercial alternatives, without explicit coordination and monetary rewards, which contradicts conventional notions of how enterprises function. Linux was even labeled the “impossible” public good by Kollock (1999). As a result, peer production has sparked interest, seeking to understand how to harness its potential for innovation (West & Gallagher, 2006). A range of research works has examined the peer production phenomenon from different perspectives, aiming to characterize it, distinguish it from other forms of online collaboration (see chapter 1.1), understand contributors' motivations, and identify factors that influence quality and project success. For an extensive review of past and present research directions on CBPP, refer to Benkler et al. (2015).

2.1.1 Characteristics of Peer Production

An important observation is that, amidst outstanding projects like Linux and Wikipedia, the vast majority of peer production projects do not gain momentum: Each day, many attempts at new peer production projects are initiated, but most of them struggle to attract a contributor base or sustain themselves in the long run (Foote et al., 2023). In fact, even among FLOSS projects that have managed to create successful products, the median number of contributors is one (Schweik & English, 2012a). Consequently, in the absence of a large crowd of contributors, principles like Linus' law – "given enough eyeballs, all bugs are shallow" (Raymond, 1999) – which imply that FOSS projects have fewer bugs due to the large number of people inspecting the code, do not apply. Additionally, in projects that do grow significantly, a power law distribution of contributions has been observed across various types of peer production projects: approximately 80 percent of the work is accomplished by the most active one percent of contributors, followed by a long tail of contributors with minimal contributions (Matei & Britt, 2017; Schweik & English, 2012a).

Why some projects thrive while others do not is still not fully understood. (Foote et al., 2023) refer to the general difficulty of building successful online communities, and suggest exploring the potential of features that support indirect coordination of work. Others seek to comprehend contributor motivations in the absence of clear extrinsic incentives, such as monetary exchange. For instance, von Krogh et al. (2012) provide an overview of motivation research in peer production and identify the presence of diverse intrinsic motivations, including factors like altruism or hedonic pleasure, as well as internalized extrinsic motivations like the value of the product for personal use, learning, reputation, and also sometimes extrinsic motivations like career advantages or payment. While no individual motivation is definitively associated with project survival, it has been observed that projects catering to a diverse range of motivations show higher success rates (Schweik & English, 2012a), suggesting that peer production projects should be designed to support these various motivations (Benkler, 2016).

Other efforts have attempted to delineate the qualities and conditions that define a project or infrastructure as peer production. Benkler (2016) identifies three characteristics that make peer production practices conducive to innovation: Firstly, the decentralization of both task conception and execution, rather than relying on management for task formulation and allocation. Secondly, as mentioned earlier, the capacity to attract a diverse array of individuals with varying motivations and skills. And thirdly, the separation of project governance and management from property and contracts. This entails treating inputs and outputs as open commons, utilizing open licenses (for a review of peer production licenses, see Dulong de

Rosnay (2021)), and fostering participatory and meritocratic governance rather than relying on contracts. Benkler notes that in the firm-based variant of peer production, property and contract usually still exist, which can entail tensions between contributors and proprietors.

Dulong de Rosnay (2013) develops a framework describing architecture models of peer production online communities, encompassing both technical and governance architecture. Consistent with Benkler's (2016) reasoning, she examines the centralization or decentralization of governance and ownership, where peer production infrastructures involve users in decision-making processes and have resources collectively owned by the peers who produce them. Regarding technical architecture, centralization refers to the presence of either centrally controlled or decentralized servers at the hardware level, as well as the extent of central control over platforms at the software level.

Kostakis and Bauwens (2020) summarize eight defining characteristics of peer production infrastructures, presenting a “grammar” of peer production (see Table 2.1). The first aspect involves the presence of *distributed networks*, which is essentially achieved by utilizing the Internet, although a significant portion of the physical and virtual infrastructures of the modern internet are controlled by central hubs (Starosielski, 2015).

Second, the produced objects are considered *commons* (Ostrom, 1990), making them freely available for use and remixing, provided that the adapted versions carry the same open license. This is particularly convenient for digital goods, as the marginal costs of reproduction are low in comparison to material commons.

The third characteristic is *equipotentiality*. This concept draws inspiration from the term “anti-credentialism”, used by Wikipedia's founder Jimmy Wales to describe a fundamental principle of the platform. It implies that no formal credentials, such as a university degree, are required to determine someone's capability to perform a task. Instead, in theory, anyone can choose to contribute to tasks, and their ability is evaluated based on the quality of the work they produce.

The next characteristic is *holoptism*, which contrasts with Foucault's (1977) *panopticism*, where only a central power has access to all information. In holoptism, all users and contributors in peer production systems have access to all relevant information, such as user contribution histories, feedback, and project metrics and aims.

Another key aspect is *stigmergic cooperation*. Stigmergy is a term borrowed from biology, coined by Grappé (1959) to describe how insects like termites coordinate work to build complex structures by leaving traces in the environment to inform other insects about tasks that need to be done. In online collaboration, this refers to the availability of digital traces that

enable indirect coordination of work (Elliott, 2006), eliminating the need for direct communication and facilitating self-selection of tasks.

The sixth characteristic encompasses *modularity, granularity, and low-cost of integration*. According to Benkler (2006), these attributes serve as facilitators for stigmergic coordination in a peer production system, where tasks are organized into easily-assembled modules. Incorporating modules of various sizes and complexities accommodates different motivations, skills and time capacities, and small modules can reduce entry barriers.

The next characteristic is *heterarchy*, as described by Crumley (2015). It means that while peer production projects are often less rigidly structured and controlled than firm-based production models, they are not devoid of structure or hierarchy. Instead, they aim to adopt dynamic hierarchies, with roles assigned based on merit, for example, to ensure quality control by deleting or refusing contributions that may threaten system integrity. These roles are carried out by maintainers in FOSS or editors in Wikipedia, for instance.

The final characteristic is *cosmolocalism*. The concept signifies that the “light” digital products become global knowledge commons, while “heavy” resources, such as servers or other machines or infrastructures, should be shared locally in places driven by communities (Ramos, 2016). The authors emphasize that their list does not claim to be exhaustive, but presents some essential rules and components of peer production systems.

<i>Characteristic</i>	<i>Definition</i>
Distributed networks	“Networks in which autonomous agents can freely determine their behavior and linkages without the intermediary of obligatory hubs”, example: Internet
Commons	“Shareable resources that are [voluntarily and cooperatively constructed and] governed according to the principles and norms of the productive community”
Equipotentiality	“Everyone can potentially cooperate in a project, and, thus, in principle no authority can pre-judge the ability to cooperate”
Holoptism	“Holoptism [...] is the implied capacity and design of peer production processes that allows participants free access to all the information about the other participants [...] in terms of their existence and contributions.”
Stigmergic cooperation	“Stigmergy is the phenomenon of indirect communication among agents and actions [...], mediated by Internet-based technologies”

Modularity, granularity, and low cost of integration	“Tasks, products and services are organized as modules, that fit with other modules [...]. Granularity is a property of creating the smallest possible modules [...] to lower the threshold of participation [...] Further, it should be easy to put the various contributions (the modules) into the final product.”
Heterarchy	“Peer production is neither hierarchy-less, nor structure-less [...], but usually characterized by flexible and dynamic hierarchies and structures based on merit that are used to enable participation.”
Cosmolocalism	“What is light (knowledge) becomes global commons, and what is heavy (machinery) is local and shared.”

Table 2.1 Eight characteristics of peer production as conceptualized by Kostakis and Bauwens (2020)

2.1.2 Peer Production in Citizen Science

The potential of peer production approaches in citizen science to foster deeper participant engagement and support autonomous research has been raised in literature, as outlined in Chapter 1.2. In practice, many citizen science projects already utilize peer production tools like GitHub to openly share source code (e.g. Anton et al. (2021)), wikis (e.g. Opryshko and Nazarovets (2021)) or wiki-like systems (e.g. Breen et al. (2019)). Furthermore, in terms of authorship, Peters et al. (2019) observe a trend towards collective writing in citizen science, as a “form of peer production and publishing” enabled by digital infrastructures, which challenges traditional notions of ownership and authorship, pointing towards an expanding role taken by citizens.

Fuster Morell et al. (2021) developed a framework of commons qualities in citizen science, focussing on socio-technical and macro-structural factors. This framework includes dimensions related to research and institutional governance, knowledge and technological policy, as well as impacts and social effects. It encompasses factors often associated with peer production, such as the use of open licenses and open data, FOSS tools, and decentralized infrastructure. Additionally, it goes beyond these factors to consider economic transparency and the sustainability model of the institution, as well as wider impacts in areas like environmental or policy impact, gender equality, and inclusion. Specifically regarding citizen science, they expand the model to include openness for participation in several research steps, and transdisciplinarity.

Applying the framework to five case studies in the digital mapping domain (Ebird, Geowiki, iNaturalist, Public Lab, Safecast), Fuster Morell et al. find that most platforms exhibit peer production characteristics, such as open data and licenses, decentralized technical infrastructures, and the use of open-source tools. All platforms operate on a non-profit or pro-bono basis, but they lack transparency regarding their financial resources. In terms of aspects regarding research specifically, all examined platforms demonstrate features that enable the integration of community feedback at multiple stages, implying a certain openness of the research process beyond data collection. Moreover, all case studies play roles in the scientific landscape, such as environmental monitoring, providing monitoring infrastructure, or addressing sustainability issues. Some projects show policy impact, but most do not have a transdisciplinary focus. While social responsibility is addressed concerning digital rights and privacy in most platforms, factors related to the inclusion of marginalized communities or gender equality are lacking.

Fuster et al.'s framework represents initial steps in understanding CBPP practices in citizen science, with a focus on macro-level factors related to impact and sustainability in the whole ecosystem. However, further understanding is needed at a “micro-level”, regarding an understanding of platform design features that facilitate peer production in citizen science.

To address this gap, I developed a *working model of peer production* that specifically examines knowledge production processes in citizen science, aiming to complement the existing framework with a perspective that considers platform interaction features. I analyze the knowledge production processes and presence of peer production features in three case studies, and illustrate key collaboration characteristics with specific platform features. Additionally, by comparing citizen science projects that employ different collaborative approaches, including crowdsourcing, I aim to uncover motivations for adopting peer production in citizen science, also identifying situations where alternative organizational methods may be more suitable. In doing so, this study takes the initial steps towards enabling informed decision-making regarding collaborative approaches in citizen science, and aims to provide design guidelines for researchers and practitioners to assist implementation of peer production in citizen science.

2.2 Methods

The working model of peer production is informed by peer production theory and literature on adjacent concepts. In an effort to create a concise list of characteristics that model the

production part of peer production, i.e. how knowledge is collaboratively produced online by volunteers respecting peer production principles, literature was searched that specifically describes, analyzes, or illustrates elements of this production process. Notably, Kostakis and Bauwens' (2020) "grammar of peer production" was leveraged to this end. The model does not utilize the complete list of peer production characteristics as presented by Kostakis and Bauwens . Instead, this list was modified to suit the context of citizen science and interaction design focusing on collaborative knowledge production. Literature on adjacent concepts, like stigmergic collaboration (Dipple et al., 2012), or legitimate peripheral participation (Lave & Wenger, 1991) was consulted to add further depth to relevant elements. Moreover, since the model was adapted to the citizen science context, it takes into account particularities of the knowledge and processes in a research context. For easier understanding, examples from the hallmark peer production platform Wikipedia were added to illustrate each peer production characteristic. The model also strives to highlight differences between peer production and crowdsourcing practices, to provide assistance in distinguishing between these often confounded modes of production. For reasons of readability, if not specified differently, by the term "peer production", this work refers to "full" or "commons-based" peer production (CBPP) (Benkler, 2016). Since the model focuses on the knowledge production in particular, other dimensions relevant to CBPP are considered less explicitly. For a framework for peer production in citizen science focused on governance, policy and impact, see Fuster Morell et al. (2021).

The case studies were selected using purposive sampling (Campbell et al., 2020) based on the following criteria: (1) All cases are citizen science projects, adhering broadly to the principles of citizen science (ECSA (European Citizen Science Association), 2015), (2) the projects use a digital platform for a large part of their work, where volunteers participate to create knowledge online in a distributed manner, (3) the platforms are in active use, with an active, preferably large user base, and (4) the cases are heterogeneous in terms of their participatory approaches and motivations to engage volunteers. Besides, the choice of cases was influenced by the availability of secondary literature.

To identify projects potentially relevant for analysis, project databases were scanned², as well as issues from 2016 to 2020 of the journal "Citizen Science: Theory and Practice"³, and projects analyzed in a survey on the European citizen science landscape by Hecker et al. (2018). In order to derive insights on heterogeneity of participatory approaches before analysis, the "About" sections of the project platforms and secondary literature were

² eu-citizen.science, citzenscience.gov, scistarter.org, p2pvalue.eu

³ <https://theoryandpractice.citizenscienceassociation.org/>

considered. Regarding the projects present in Hecker et al. (2018), annotations informing about different levels of participation based on Shirk et al. (2012) were already provided by the authors.

For the analysis, the working model of peer production served as a checklist that was applied to each case study by inspecting the online platforms, and complemented by supplementary literature if available. For each platform, the principal researcher created a user account and walked through the information architecture to inspect all primary pages and the interaction possibilities present. To aid understandability, the common research object and how it is collaboratively produced were summarized in a schematic knowledge production process. In the following, the presence and implementation of each peer production characteristic from the model was explored based on features available to users on the platforms. Two other researchers explored sub-selections of elements of the peer production model in the case studies as reliability-check, results of which were compared and discussed to inform analysis and interpretation. If secondary literature on specific design decisions was available, this was also used to inform the analysis. The initial data collection was completed between February 2021. Links to the features listed in the following are available in Appendix A.1.

2.3 Working Model of Peer Production

The working model of peer production, introduced in this chapter, consists of seven key characteristics of peer production platforms. These characteristics are exemplified using examples from Wikipedia.

The model focuses on the collaborative knowledge production process, while paying less attention to aspects such as governance, intellectual property, or impact acknowledge that these aspects tend to be closely interconnected, and to be regarded as *full* commons-based peer production, they need to be taken into account. The model is tailored to the context of citizen science, considering research knowledge and processes.

The purpose of this model is to function as a tool for citizen science researchers and practitioners, enabling them to systematically analyze the collaborative nature of their online projects using a peer production perspective. Additionally, it aims to help identify specific platform features associated with this CBPP. The goal is to enhance the comprehension of the presence and trade-offs of design alternatives, and thus support informed decision-making regarding the implementation of peer production features.

The characteristics of the working model of peer production are: Common research object, range of tasks, granularity and modularity, equipotential self-selection, quality control, learning

trajectories, and direct and indirect coordination. An illustration of the model can be found in Figure 2.1. Links to sources for the Wikipedia examples are in Appendix A.1.








Peer production characteristic	Wikipedia example
Common research object 	Open encyclopedia
Range of tasks 	Creating, editing, discussing articles
Granularity and modularity 	Articles, sections, sentences, references, typos, ...
Equipotential self-selection 	Users choose what and how much they want to edit
Quality control 	Talk pages for feedback, rollback function to undo changes
Learning trajectories 	Manuals, suggestions of easy tasks for beginners
Direct and indirect coordination 	Flags like “citation needed”, red links, talk pages

Figure 2.1 Working model of peer production with examples from Wikipedia

The first and central feature of the model is the **common research object** that is collectively produced. The term is inspired by the “research objects” by Bechhofer et al. (2010) who refers to aggregations of digital files that are produced in the course of a research project. The common research object is a function of the goals of the project, and one project can have one or more of these objects. Since they are something that is created collaboratively, these objects are usually a composition of many parts (see “granularity and modularity”). Common

research objects form the basis of all kinds of modes of online collaboration in citizen science, including crowdsourcing. Though not strictly part of the production process itself, there are two important aspects to note here: First, in CBPP, the collectively created artifacts are “commons”, i.e. they are published under public or copy-left licenses and thus can be publicly accessed and reused, which is an important part of the value proposition for contributors (Kostakis & Bauwens, 2020). In a citizen science context, this can translate to open science practices, like making datasets available to the public, and publishing in open access journals. Second, in a peer production approach, ideally there are ways for contributors to decide or influence the nature of these objects. However, general approval of the purpose and use-value of the project is usually a starting motivation for new contributors. Hence, disapproval on a high level most likely leads to non-participation and potentially the dissolution or non-forming of a community (Chang & Yang, 2009). In Wikipedia, the common object produced is an open encyclopedia.

The **range of tasks** describes what types of work are accessible to users, i.e. tasks of which quality, size, and complexity. Characteristic for CBPP is the availability of a wide range of tasks, including creative ones, like the conception of new tasks or solutions (Benkler, 2016). This does not mean that there are no simple, low-engagement tasks, or contributors that never engage in any but these. In fact, neatly-defined microtasks can be an important entry point for newcomers (see “learning trajectories”). Some contributors might continue to work on a wide range of tasks, while others might specialize on specific ones. Nevertheless, the accessibility of tasks catering to a wide range of motivations and skills, without a strict distinction between task designers and task executors (see “equipotential self-selection”), is an important distinguishing feature between peer production and crowdsourcing. In the context of citizen science, it is also critical to explore which parts of the research cycle the tasks accessible to the public translate to: Are volunteers able to contribute to data collection or processing, the determination of the research agenda, hypothesis or protocol generation, analysis, or interpretation (Shirk et al., 2012)? This can be an opportunity to reflect on epistemic and social goals of the citizen science project and how they are embedded in, and if and how they are serving these goals. On online platforms, the range of tasks can be informed by exploring the interaction possibilities available to users, and the information visible with regards to processes, edit history, agenda, and open tasks, similar to the “holoptism” quality listed by Kostakis and Bauwens (2020). In Wikipedia, the range of tasks includes, amongst many more, creating, editing, or discussing articles, stewarding topics or pages.

Granularity and modularity refers to how tasks and the research object are broken down into smaller tasks and objects. Related is the cost of integration, which describes the effort required to integrate small elements into larger modules that make up the research object

(Benkler, 2006). Having very small modules that can be addressed with little time, effort, and skill can lower the threshold of participation, while the possibility to address larger, complex tasks can be a motivating factor for experienced contributors (Benkler, 2016). In Wikipedia, the modules of the encyclopedia are articles, which in turn are composed of sections, sentences, etc. The visual and markup editors allow low-effort integration of edits or adding new pages into the system. Tasks such as creating a consistent narrative or putting articles in the right categories can equal higher integration effort.

Equipotential self-selection relates to which tasks are accessible to regular platform users, and to what extent they can choose and self-assign tasks. “Equipotential” is a compound word of “equal” and “potential” and refers to the idea that contributors do not have to provide any formal credentials a priori, like a university degree, to work on any task, and their ability to do so is then judged a posteriori by the quality of their work (Kostakis & Bauwens, 2020). This does not mean that anybody is allowed to do any task at any time: For example, rights to perform tasks that could endanger the integrity of the system if not well done, are usually granted after a contributor has gained trust within the community after a certain amount of prior work (“meritocracy”) (Stevenson, 2020). On Wikipedia, users are allowed to create or edit articles of their choice, without the need to prove expertise with formal entry credentials, like a degree in a relevant field. They can also decide how much and which parts of an article they would like to edit, without waiting for anyone to assign them what to work on. For advanced roles, access is granted based on prior work, including for example a requirement of having at least 500 edits for reviewer roles, or 3000 edits for page mover roles.

The **quality control** characteristic covers the mechanisms in place to judge the quality of user contributions and to refuse or remove contributions that are of low quality or endanger system integrity. In CBPP this is done by the community, also referred to as “communal validation” (Kostakis & Bauwens, 2020). For quality control tasks that go beyond signaling of undesired contributions, like deleting content or blocking user accounts, contributors generally need to be granted rights by the community, decisions which are often based on some type of merit-system (see “equipotential self-selection”). Needs for quality control depend on the common research object produced. While in FOSS projects breaking running code might be a big concern, in citizen science concerns might be related to reliability and validity of results. On Wikipedia, users can give feedback on the “Talk” page of an article, and there is also a rollback function to go back to former states. Experienced contributors can apply for advanced roles in quality control, like becoming stewards for specific pages and topics and watch in more detail over their development, reviewers, page movers, or administrators.

Learning trajectories refers to how newcomers learn to do tasks, and which possibilities they have to learn and perform more advanced tasks. While peer production literature generally does not list learning or teaching as a central point, rather referring to peer production's quality of attracting users of different expertise and motivation (Benkler, 2016), learning and upskilling are an important part of building and sustaining a community (Lave & Wenger, 2002), and established peer production projects usually have an extensive repertoire of manuals, how to's, and requirements for different roles. A related concept is "legitimate peripheral participation" (LPP) (Lave & Wenger, 1991), which describes how newcomers participate in communities of practice by first doing small tasks with limited responsibility and gradually learn to become a more central part of the community by collaborating with experts. Mechanisms that support this process have been discussed in the context of peer production projects like Wikipedia (Antin & Cheshire, 2010; Halfaker & Taraborelli, 2013), FOSS (Gasson & Purcell, 2018), and citizen science (Mugar et al., 2014). In citizen science, learning is susceptible to having an even more central role than in other peer production projects: Beyond learning as a means to create a certain output, citizen science projects are often, at least partly, motivated by increasing scientific literacy, with dedicated meta research focusing on learning outcomes (Roche et al., 2020; Vohland et al., 2021). On Wikipedia, there are many guides to teach newcomers, for example the "Manual of Style", and to document consensus on design guidelines. New users have the possibility to pick micro-tasks, like editing spelling errors, before starting bigger tasks, and can thus learn by practice. There are also community guidelines in favor of treating newcomers or other users who might make mistakes with patience and benevolence ("Assume good faith").

Direct and indirect coordination of work is a central condition and quality of peer production, and relates to features that help coordinate work, e.g. that signal open tasks, as well as features that allow for direct communication between users, like chats or forums. Besides direct coordination, referring to features where users communicate directly with each other, e.g. in chats or forums, indirect coordination plays an important role in peer production settings. Indirect coordination online is also called "stigmergic collaboration", making use of a metaphor from biology: Animals like termites manage to build complex structures by coordinating work by leaving traces of pheromones in the environment (Dipple et al., 2012). In peer production, the existence of those kinds of "traces" is necessary to signal open work without needing a manager to assign tasks. They can, for example, take the form of tags or flags for specific tasks, or more generally by making the current state of the work visible and transparent, so contributors can derive open tasks by themselves (Kostakis & Bauwens, 2020). Foote et al. (2023) discovered no significant relationship between communication

networks and success of CBPP projects, suggesting that direct communication might be partly replaced by stigmergic collaboration, indicating that it plays a subordinate role in CBPP.

In Wikipedia, for direct coordination, there are talk pages for articles and users. Features to signal open tasks are, for example, links in red color that indicate that a page that is linked in another page has not been created yet, section headings followed by little or no text, or flags like “citation needed”, or “stub”, which can be integrated into articles.

2.4 Case studies

To address the research question “*What are the key elements of peer production platforms and how are they implemented in a citizen science context?*” and to evaluate the working model of peer production, we apply it to three case studies.

In accordance with the selection criteria outlined in section 2.2, all of the cases are citizen science projects that use an online platform for a large part of their knowledge production, have an active community, and represent a broad scope of different motivations and approaches for volunteer engagement. The resulting sample is, in alphabetical order: iNaturalist, Public Lab, and Zooniverse.

- **iNaturalist** (<https://www.inaturalist.org>) is a social network and online platform for sharing, mapping and identifying biodiversity observations around the world. While collaboratively building a biodiversity database, they frame their primary aim as “connect[ing] people to nature”. iNaturalist began in 2008 as a Master’s final project at the UC Berkeley’s School of Information and is now a joint initiative between the California Academy of Sciences and the National Geographic Society, with almost 5.7 million registered users and over 130 million uploaded observations as of September 2022.
- **Public Lab** (<https://publiclab.org>), short for Public Laboratory for Open Technology and Science, is a community, non-profit organization and online platform, aiming to empower people to address environmental justice issues through community science and open technology. They focus on the collaborative development, sharing, reuse and adaptation of DIY scientific tools intended to enable community investigation of environmental concerns. Public Lab was formed after the BP oil disaster at the Gulf of Mexico in 2010, when residents documented damage in a grassroot mapping effort using weather balloons (Breen et al., 2019). As of September 2022, there were over 2,100 registered users, who contributed numerous topic pages, reports, and manuals for do-it-yourself environmental monitoring projects. In April 2023, Public Lab announced that due to economic reasons, they would be discontinuing staff support

and closing their online store. They are now striving to sustain operations through a volunteer-run model⁴.

- **Zooniverse** (<https://www.zooniverse.org>) is a platform for crowdsourcing citizen science. Volunteers assist professional researchers from all kinds of domains, by collectively classifying data for their projects. Zooniverse developed from the Galaxy Zoo project and is now a collaboration between the University of Oxford, the University of Minnesota - Twin Cities (UMN) and Chicago's Adler Planetarium. With more than 2.5 million registered users, and almost 700 million classifications as of September 2022, it is one of the biggest online platforms for citizen science.

As a preparatory step, to aid understanding of the following analysis, we derived a schematic representation of the primary knowledge production process on each platform, which is visualized in Figure 2.2. In the following, these processes will be interpreted through a peer production lens by applying the working model, and each characteristic will be mapped to concrete platform features, if available. References for the case studies can be found in Appendix A.1.

⁴ <https://publiclab.org/notes/jmacha/04-14-2023/update-from-the-board-of-directors>, last accessed 11.08.2023

Knowledge production in the case studies

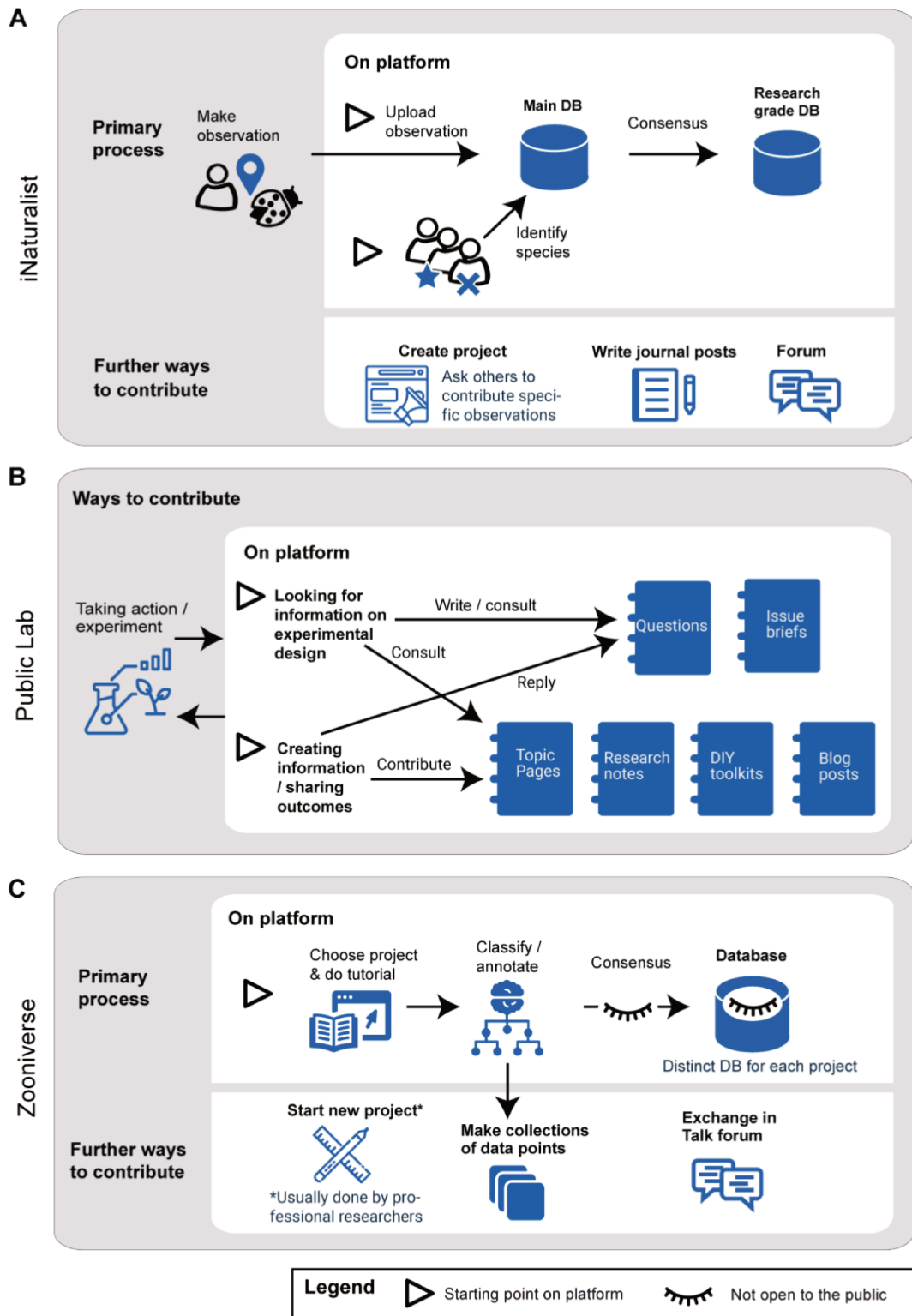


Figure 2.2 Schematic representation of knowledge production in the case studies

2.4.1 iNaturalist

Common research object: The common research object of iNaturalist is a biodiversity database comprising recorded sightings of species, complemented with metadata such as location, time, and photographs. The database is intended for non-commercial reuse, but contributors have the option to apply licenses for their own photos. While most database entries are visible to the public, the precise location might be obscured in some cases to protect endangered species or for privacy concerns..

Range of tasks: In iNaturalist, participants mainly contribute either by uploading new observations, or by adding species annotations to existing observations. Additional tasks include writing journal posts, discussing in a forum, and creating data collection projects that encourage users to provide observations specific to certain areas or species. Users in the curator role can edit the taxonomy, create and edit wiki pages, resolve flags on taxa and user content, hide comments and suspend users for violating community guidelines.

Granularity and modularity: In iNaturalist the main tasks are of small size and well-defined. The smallest task would be to annotate existing data points, followed by uploading new observations. Integration of the main modules is automatic: observations are automatically added to the database and provide the data pool for future annotations. Once the species has been collectively identified (see quality control), the observation is automatically added to the Global Biodiversity Information Facility (GBIF) database (GBIF: The Global Biodiversity Information Facility, 2022).

Equipotential self-selection: Contributors can select from the range of tasks mentioned above. They are free to decide the type and quantity of observations they would like to annotate or add to the database, without automatic assignment, and anyone can start a data-collection project on the platform. There is a curator role that can be granted by iNaturalist staff for users who have engaged continuously over several months: curators have additional rights, e.g. to edit iNaturalist's taxonomy or to hide comments that violate community guidelines.

Quality control: There is a communal validation process for species identification, using the following mechanism (Boone & Basille, 2019): New observations are automatically tagged with "needs ID". As the observations and annotations are generally publicly accessible, users can see other users' annotations, and can agree, disagree, or make a guess more specific. For example, if the person uploading the observation specified it as "ladybird", other users can

either confirm this identification, specify what species of ladybird it is or disagree by identifying it as a different insect. The resulting annotation is called “community taxon” (see Figure A2.1. in Appendix A.2.). To achieve research grade, the ID needs to be supported by at least two users, and either have a community taxon at species level or lower. This research grade database is publicly accessible under an open license but some metadata, like specific location, can be obscured, to protect the privacy of underage users, or to protect endangered species. In addition to voting on the species, users can also add comments.

Learning trajectories: To learn how to contribute to the database, there is a “Getting started” guide with tutorials on uploading observations and species identification. Users are free to address bigger tasks, like creating their own projects, or offline data-collection events, called “bioblitz”, for which there are also help pages, or become curators after having collected experience through regular engagement.

Direct and indirect coordination: There are features to coordinate work, like “needs ID” tag in the communal validation process, projects that call for specific observations, or filters to help users identify observations in areas of their expertise. For direct communication, there is a forum, as well as comment and blog functionality.

2.4.2 Public Lab

Common research object: In Public Lab, the research object is a catalog of experimental designs and project reports in the domain of Do-It-Yourself environmental science. Unlike on Zooniverse and iNaturalist, there is no data collection or annotation mechanism on the platform. Instead, artifacts include collections about DIY environmental monitoring and knowledge transfer, like topic pages, similar to wiki pages, e.g. on air quality, and research notes, similar to blog posts (e.g. “How to Build a Bucket Air Monitor”). There are artifacts for problem solving, like issue briefs, in which users explain their issue to support from other users, or more general question elements that other users can reply to. Artifacts are publicly shared and openly licensed by default, although exceptions may occur if appropriate in context, e.g. if shared information risks the safety of individuals (Rey-Mazón et al., 2018).

Range of tasks: Reflecting the diversity of research artifacts, Public Lab users can work on a range of tasks that can be split roughly in two categories: looking for information on experimental design, and sharing information or outcomes (see Figure 2.2. B). To look for information, users can create dedicated artifacts, i.e. questions and issue briefs, or consult other existing artifacts on their topic of interest. To share outcomes or other information, users can create or contribute to topic or project pages, research notes, DIY toolkits, and blog posts.

They can replicate other users' experiments ("activities"), comment and reply to questions, issue briefs, or research notes.

Granularity and modularity: The range of tasks comes with varying granularity, ranging from small edits on topic wiki pages to uploading larger building blocks such as experimental designs. Integration of modules is achieved by interlinking contributions on Public Lab through tags and backlinks. These tags need to be added to an artifact to link it to a topic or artifact category, to add backlink functionality ("i did this" / "seeks:replications", "activity:", "replication:", "activity:infragram") to integrate their artifacts / make them findable. Tags are pre-specified if an artifact is created by clicking on "add an activity", "I did this", "ask a question" from a related page (see Figure A2.2. in Appendix A.2.).

Equipotential self-selection: Similar to iNaturalist, Public Lab users have access to all content to self-select open tasks they are most interested in or add new content to their liking. Upon application, users can take on moderator or administrator roles.

Quality control: Due to the free, textual form of the research artifacts, there is no algorithmic quality control that measures consensus like in iNaturalist or Zooniverse. Rather, feedback is generally in written form of comments to other artifacts, or in the form of new blog entries, when users replicate each other's activities and report their protocol and how it worked in their case.

Learning trajectories: For new users, there are so-called issue brief artifacts to remove barriers and encourage users to get started (see Figure A2.3.a in Appendix A.2.), "first-time-posters" tag, templates and forms for artifacts, and helpful instructions in default texts of text boxes (see Figure A2.3.b in Appendix A.2.). There are also question objects to help resolve specific issues. It is possible to replicate existing experiments or ask other users to replicate one's own experiment to get feedback and learn from one's own or other people's experiences. More experienced users can apply for moderation or administration roles.

Direct and indirect coordination: There are several features that help signal open work, like the "I did this" button (see Figure A2.2. a in Appendix A.2.), that appears on pages tagged with "activity", which depicts an invitation for other users to replicate the experiment, and at the same time serves to connect the original and replicated activity. Other ways to signal that help is needed are dedicated artifacts like "questions" or "issue briefs" (see Figure A2.2.b and A2.3. a) in Appendix A.2.). For direct communication, there is a comment functionality under all types of artifacts (see Figure A2.3.b in Appendix A.2.).

2.4.3 Zooniverse

Common research object: For projects on Zooniverse, the main research objects are large datasets of images, videos or text in need of human annotation, which are typically provided by professional researchers. Projects span a wide range of topics and users are asked to annotate individual data points such as telescope images of galaxies, create transcriptions of historic diary pages, or identify noises of deep sea animals from acoustic samples. The complete datasets are not visible to volunteer contributors, and project organizers have proprietary rights to the data for a period of about two years, after which they are thought to make the datasets publicly available.

Range of tasks: The main task type is the annotation of a data point according to the instructions given for each individual project. Beyond this, users can make collections of data points they classified, and the platform offers forums for each project as well as talk pages for each individual data point (see Figure 2.2. C). These talk pages can be used for leaving comments, tags, adding data points to collections, and for participating in discussions for quality control and learning (see respective paragraphs below). Committed users can ask to become moderators of talk forums for specific projects.

Granularity and modularity: Individual annotation tasks are typically small, but depending on the project, they can differ in complexity and duration, e.g. ranging from selecting from predefined options to transcribing documents. Within one project, the granularity of annotation tasks is of similar size. Modularity is given by the automatic integration of user contributions to the database after annotation.

Equipotential self-selection: Users choose which projects they want to contribute to based on their interests, and the quantity of data points they want to process, within the limits of available data. Beyond this, users do not self-select tasks as the data points are automatically assigned to the user one at a time. To engage further, users can take part in discussions on projects or individual data points using the aforementioned talk pages. Users can become talk forum moderators after being granted the rights by the project leads. Creating new projects requesting annotation is usually reserved to professional scientists.

Quality control: In Zooniverse, quality control consists in several users classifying the same data points, which are then aggregated to a consensus answer (Kosmala et al., 2016). Users cannot see annotations of other users and quality control is done by project leads without further input by the contributors. However, post-classification, the user can access the data

point's talk page to provide feedback or discuss with other users who have annotated the same data point.

Learning trajectories: For each project, the project organizers offer tutorials to instruct users on how to annotate for that specific project. Additional engagement can occur through activities such as discussions on talk pages, by adding hashtags to data points or creating collections. Users also have the opportunity to take on more advanced roles, such as becoming a moderator in a project talk forum. The assignment of these advanced roles is handled by the project leads.

Direct and indirect coordination: There is no coordination between users in the main data processing workflow, since annotations of other users are hidden. However, after annotating, users can access a page dedicated to the respective data point, where they can add tags and comments, and see meta-information other users entered. For further communication there is a forum attached to each project.

2.5 Discussion

The present chapter introduced a working model summarizing key elements of peer production in the context of citizen science and used it to analyze how peer production elements are implemented in three citizen science case studies. In the following, for each element of the model, I compare the case, discussing potential motivations, benefits, and trade-offs. Appendix 1.C contains a design aid, with design guidelines based on each peer production element, including a summary of motivations and trade-offs.

2.5.1 Comparison by Peer Production Element, Motivations and Trade-Offs

1. Common research objects: The common research objects are tightly coupled to the goals of the projects. In iNaturalist, this is primarily a biodiversity database that is open to anyone, and has been reused in many research projects⁵. The project's main, societal goal ("connecting people to nature") is indirectly represented through the database, encouraging people to add to it by exploring biodiversity in their local environment. In Zooniverse, the main purpose of volunteer engagement is to assist researchers scaling up their projects, by having them annotate datasets according to fixed protocols research teams provide. Researchers are asked to make their data public after a proprietary period, which gives them time to finish their project, while having exclusive rights over their data. The common research object can thus

⁵ <https://forum.inaturalist.org/t/published-papers-that-use-inaturalist-data-wiki-3-2022-and-2023/34753>, accessed 29.04.2023

not be considered a commons. This approach keeps a lay-expert divide between professional researchers and lay contributors and can potentially lead to conflicts in case the project organizers use the value created by contributors in other ways than initially promised (Chen, 2019). Public Lab wants to empower individuals and local communities to address environmental justice issues in their surroundings, which results in common research objects that are not in the form of databases, but a collection of methods, discussions and artifacts providing support for people who want to create and run their own research projects. To aid this goal, all material is published under open licenses for open reuse. Similar to the reasoning of Benkler (2016), these examples indicate that a peer production approach with open, reusable and potentially less structured research objects might have been chosen when projects' goals include supporting citizens in developing methods to address their own issues, as opposed to goals related to upscaling.

2. Range of tasks: Next, the range of tasks represents the steps that are necessary to create the research objects, and other surrounding tasks available to contributors to fulfill the projects' goals. In citizen science contexts, it is also important to explore which parts of the research cycle are represented in the tasks open to the public. In iNaturalist, contributors mainly engage in data collection (adding new observations), and data annotation (identifying species). They can influence which data points are being collected, by simply providing observations of their choice, or going a step further and creating data collection projects encouraging other users to provide specific observations. A downside is that this can possibly lead to the introduction of sampling bias: Di Cecco et al. (2021) identify spatial, temporal, and taxonomic biases issuing from user observation patterns, resulting from users' tendency to specialize in some species or groups, rarely observing a species twice, recording observations during particular times of day, and particular locations. Nevertheless, the value of the approach for biodiversity research has been accorded to the number of observations, speed of updates, diversity, and spatial distributions, which has led to the observation of species in locations where they had not been previously discovered (Hochmair et al., 2020). While not a direct part of the platform's workflow, users are also free to download the data for their own research questions and analyses.

In Zooniverse, participation is mainly contributory, with users engaging primarily in data annotation. Volunteers can contribute to analyses by leaving comments in talk pages and discussion boards, and can influence the improvement of annotation schemes by adding tags to data points they annotated (C. Jackson et al., 2018). This approach leaves full control in the hands of the research team leading the project, who are in charge of providing an unbiased dataset and help ensuring independent annotations by randomization. While they can profit

from comments and user-generated tags, it remains in their hands to decide which feedback they want to integrate and how.

In Public Lab, tasks are related to sharing knowledge and supporting each other around their own research projects, which can empower bottom-up research or “collegial” projects (Shirk et al., 2012). Tasks are mostly text-based and open-ended.

In a CBPP approach, resources are public and contributors can engage in a wide range of tasks, which translates to participation in many or all phases of the research process. In the case studies, participation in many phases can empower people to learn how to address their own issues with research methods, but lead to the introduction of sampling biases in one case. The importance of different project goals can influence the decision about the range of tasks, e.g. weighing off the risk of sampling bias against the potential of discovery of unexpected data points.

3. Granularity and modularity: Regarding granularity and modularity, Zooniverse and iNaturalist follow a similar approach: In both cases, volunteers contribute mainly annotations to individual data points (and alternatively new data points in the case of iNaturalist) that are automatically integrated into an existing database. In Public Lab, where tasks are mostly text-based, granularity varies more, and aggregation of these less-structured tasks into modules can require manual effort, for example curation and re-structuring of texts, or tagging to connect individual contributions into a larger body of knowledge. There are some mechanisms to reduce these efforts, like the use of templates or automatic assignment of tags.

These examples illustrate that large-scale aggregation can be easier if contribution is restricted to a system of pre-specified, rule-based microtasks. Microtasks can also make it easier to engage a big number of people quickly. On the other hand, while bigger, more open modules might be less suited for punctual engagement and can have a higher cost of integration, they have potential to leave more space for creativity and the development of new ideas and projects.

4. Equipotential self-selection: When it comes to equipotential self-selection, Zooniverse follows the most restrictive approach. There is a clear distinction between project leads, usually credentialed academic researchers, and volunteers who predominantly process data. Credentials serve as an argument of high-quality research, and project leads are expected to come with an advanced research project that only needs annotation, unlike for example in Public Lab, where developing research projects is a core part of the work on the platform. Volunteers in Zooniverse are free to choose which projects they want to contribute to and how many data points they want to label, but data points are automatically assigned to them. As explained above (see “(2) range of tasks”), random assignment of data points can help prevent

the introduction of bias, which is an existing issue in iNaturalist data, where users are free to add data points of their interest, and are also free to start data collection projects to encourage others to add data points according to self-chosen criteria on a larger scale. On the other hand, the possibility of self-selecting which observations a user wants to annotate serves an important purpose: While on Zooniverse, in theory, any user should be capable of annotating any data point according to the provided protocol, in iNaturalist, in order to identify species, a certain expertise is needed, that not all users have. Thus, in order to obtain detailed and true identifications, there is an interest in providing experts of certain families of animals or plants, with ways to self-select these. In Public Lab and iNaturalist, self-selection is facilitated by visibility of all content and data points to contributors.

In summary, the implementation of this element of peer production requires weighing off the advantages and disadvantages of different design decisions: equipotential self-selection could hinder quick and unbiased processing of data in research projects that have been designed beforehand, but can allow for profiting from the specific expertise present in the community, and can support the development of early stage research projects through free exchange and trial-and-error.

5. Quality control: Needs for quality control vary depending on project goals and qualities. When following a peer production approach, this process is performed by the community, often by advanced community members. In Zooniverse and iNaturalist, quality control of annotations is algorithmic. In the former, consensus is calculated from several user annotations for each data point. This is done by the research team and hidden from volunteers. Annotations of other users are invisible, to ensure the independence of responses. Nevertheless, users do have indirect ways to report quality issues, or improve protocols by adding tags to observations or by commenting in talk pages (C. Jackson et al., 2018).

In the case of iNaturalist, the process is visible and open to the community: the community taxon becomes gradually more precise, and each step can serve as a filter for experts to identify observations in their areas of expertise. In a study focussing on termines, the classification quality of iNaturalist data has been found to be “excellent” (Hochmair et al., 2020). In Public Lab, due to the open-ended nature of tasks, communal validation is way less structured: Users usually give written feedback in the form of comments or replies to questions, or they can share modified versions of existing protocols.

In summary, from an epistemic perspective, the decision about a quality control process with the community or not can follow the balancing of the importance of independent results against enabling a larger number of users to contribute, detect errors and areas of improvement, or to guide experts to specific tasks (cf. Linus’s Law from open source software development: “Given enough eyeballs, all bugs are shallow” (Raymond, 1999)). From another perspective,

allowing people to participate in quality control, can provide opportunities for learning, as seen in the next element of the model.

6. Learning trajectories: Learning in the context of citizen science projects can encompass a wide range of topics: From learning to use a citizen science platform in order to contribute to a project, to becoming an advanced community member contributing to more complex tasks, to learning research methodology up to creating own projects, or getting factual knowledge about scientific subjects. Given this diversity, the present analysis of learning trajectories does not claim to provide a complete picture of all learnings involved. The case studies focus on explicit learning paths and features on the platforms that support newcomers to become contributors and then advanced contributors, and on how the goals and research phases open to the public influence these.

On Zooniverse, project leads provide tutorials for their project that teaches volunteers how to annotate their dataset. Similarly, on iNaturalist, an extensive collection of guides is available that help newcomers learn how to contribute to the database, and more advanced users e.g. how to create projects, run data collection (“bioblitz”) events, or what roles like “curator” involve.

On Public Lab, supporting learning is a core aim of the project, in order to empower individuals to address local issues themselves, using research methods. There are artifacts like “issue briefs”, that explicitly encourage people to reach out to the community describing their issue, even when they do not know how to get started with their project. Research protocols and DIY research tool construction tutorials are supposed to be shared, adapted, and re-used.

Learning in communities of practice is often achieved by allowing newcomers to consult existing work and process histories, so they can observe norms of practice. This is also referred to as “legitimate peripheral participation” (Lave & Wenger, 1991). Although the case studies are very different, they all value practice and engagement in the respective community: In Public Lab, iteration, creativity and trial-and-error are cited as key values of research (Breen et al., 2019). In iNaturalist and Zooniverse, users can take more advanced roles after a certain amount of contributions (e.g. “curator” in the former, and “project moderator” in the latter). In Zooniverse, since annotations of other users are hidden, contributors make use of indirect traces of work, like tags or comments to learn norms of practice (Mugar et al., 2014).

In general, supporting volunteers running their own research projects translates into very different requirements to platform features than when learning primarily aims to support volunteers how to perform a pre-defined task within a research project. Reflecting which learning possibilities exist through explicit learning material or practice, can serve to understand how a project’s implementation is aligned with its epistemic and societal goals. Projects following a crowdsourcing approach can reflect if and how contributors are enabled

to make creative contributions beyond the main workflows, which has been found to have potential to enable valuable contributions, such as the improvement of protocols through new tagging systems (C. Jackson et al., 2018) in the case of Zooniverse.

7. Direct and indirect coordination: Finally, direct and indirect coordination refers to features that allow to signal and coordinate open work through signs, or to direct communication features like forums. Indirect “stigmergic” coordination features allow to guide users to tasks of their competence or interest, which is an important part of peer production systems. In Zooniverse, as discussed above, data points are assigned randomly to guarantee independence of annotations, so the main workflow does not provide much indirect collaboration by choice. In iNaturalist there are filters and flags like “Needs ID” to help contributors identify areas of their expertise, which is beneficial due to the need of expertise for annotation. In Public Lab the interconnection of artifacts is important to guide novices to knowledge they need for their projects, and experienced users to questions or incomplete artifacts where their support is needed. Indirect coordination is achieved through an extensive tagging system, linking of different versions of experiments, flags like “I did this” or “replication needed”, and the use of wiki technology for consensus pages for relevant topics.

All case studies have features for direct communication, like forums, or comment sections. When designing indirect coordination features, one can deliberate if it would be more advantageous to enable contributors to discover open work themselves (peer production), or to assign work (crowdsourcing). The prior can guide contributors to tasks of their expertise and interests, and potentially help them to define new tasks, while the latter leaves more control in hand of the project leads and can e.g. help to guarantee independence of annotations. Direct communication features, as part of or aside the main workflow, seem to be implemented throughout different collaborative approaches, allowing for contributors to easily and informally get in touch with other users or the research team, which can in some cases point to new scientific discoveries (Lintott et al., 2009).

2.5.2 Limitations, Conclusion, and Future Work

The presented approach has some limitations. First, the case studies consider the main platforms of the citizen science projects at a static point in time. Further participation may occur outside of these platforms, for example, on code-sharing or instant messaging platforms, or at online or in-person community events. Looking at the status quo only also ignores differences in platform design over time, including features that have been tried and discarded. Additionally, existence of features does not necessarily equal usage. Future research could complement this study by analyzing usage statistics, platform development over time, or by interviewing long-term community members. Second, since the case studies analyze the

status quo of interaction possibilities on the platforms, it is not possible to prove if differences in metrics like number of participants, depth of engagement, learning etc., can be traced back to the adoption or non-adoption of a peer production approach. It also remains unexplored to what extent it is possible or beneficial to only add one or a few elements of peer production, independent of other features. Future work could address this by systematically studying project-relevant metrics before and after implementation of peer production features. Third, the sample size of the case studies is very small. Since citizen science is an umbrella term for a wide range of practices, the generalizability of the model to other citizen science contexts remains to be explored.

Despite these limitations, the working model of peer production provides a heuristic solution that, by quickly walking through interaction possibilities of online platforms, allows for inspecting peer production qualities of existing projects, and getting indications of what a peer production approach translates to in terms of platform features, and how they relate to engaging online communities into different phases of research. In doing so, the model goes beyond approaches ordering projects into categories, such as the levels of public engagement in citizen science by Shirk et al. (2012). Complemented by literature focusing on other dimensions of peer production, like governance, policy, or impact, such as the framework by Fuster Morell et al. (2021), this work paves a way for design guidelines for peer production, also by making palpable what, in detail, distinguishes peer production from crowdsourcing. Additionally, applying the model to case studies whose approaches are closer to crowdsourcing than peer production, allowed to illustrate which features make something peer production or not in an unprecedented level of detail, allowing to bring attention to potential levers of change, including deliberations about feasibility and trade-offs of a peer production approach in different citizen science contexts.

This study does not attempt to advocate that every citizen science project should follow a peer production approach. Citizen science is highly diverse, including a wide range of motivations and practices that likely benefit from a diverse range of collaborative approaches. Nevertheless, the working model of peer production can serve as a tool to help reflect design decisions, and empower citizen science practitioners to choose an approach suited to their epistemic and societal goals.

The case studies aimed to provide a new perspective by illustrating and discussing different collaborative approaches under the lens of peer production. While many of the elements of peer production presented here are intertwined, the case studies indicate that the implementation of some peer production elements independent of others might be possible,

indicating a certain fluidity between crowdsourcing and peer production, or firm-hosted and commons-based peer production.

Further work is necessary to explore the potential of peer production, which has been interpreted as a transformative practice (Kostakis & Bauwens, 2020) to enhance the transformative potential of citizen science, a quality for which this heterogeneous field is frequently discussed (Strasser et al., 2018), and for which peer production has been suggested as a promising direction (Chen, 2019; Mahr & Dickel, 2019; M. A. Peters et al., 2019).

By introducing a literature-based working model of peer production, this study has broken down peer production theory to specific platform features, and by applying it to case studies it has explored present implementations, feasibility and tradeoffs of peer production in online citizen science. The lessons have been summarized into a design guide for peer production in citizen science, with the aim to support researchers and practitioners with the decision-making about and implementation of a CBPP approach (see Appendix A.3.).

Take Home Messages

- The “working model of peer production” can be used to identify peer production features on citizen science online platforms, to reflect on user participation possibilities and to support the informed choice of participatory approaches
- Three case studies revealed that existing citizen science platforms implement peer production and crowdsourcing elements to different extents.
- The choice of a suitable participatory knowledge production approach in online citizen science depends on the project’s motivations and priorities, and careful considerations of the advantages and disadvantages of peer production and crowdsourcing.

3. Designing a Peer Production Approach for Personal Science

In the previous chapter, I operationalized peer production theory into a working model for citizen science contexts. This model was then employed in three case studies to exemplify peer production elements along with specific platform features. Moreover, the case studies provided insights into motivations and trade-offs associated with applying peer production elements in such contexts. Based on my operationalization for peer production in citizen science, the focus then shifted towards exploring the potential implementation of peer production within the personal science community. This citizen science community frequently exchanges online and values peer support, but no peer production platform exists just yet.

3.1 Background: Personal Science

As outlined in chapter 1.3., personal science has been defined as “the practice of using empirical methods to explore personal questions” (Wolf & De Groot, 2020). Individuals often engage in this practice because they want to improve their health or well-being, ranging from managing chronic diseases to increasing productivity. Data collection methods range from low-tech approaches like pen-and-paper, to specialized wearable sensors.

3.1.1 Emergence of Personal Science: From “Sensor-Mania” to Self-Research

The concept of personal science evolved from the growing prevalence and academic discourse around self-tracking, which has been defined as “practices in which people knowingly and purposively collect information about themselves, which they then review and consider applying to the conduct of their lives” (Lupton, 2016). Although self-tracking became more widespread with advancements in accessible sensor technology, the practice itself is not new. Various terms have been used over time for the phenomenon of individuals monitoring aspects of their daily life and health. Early versions of wearable computers began to be used as early as the 1970s, and around the 1990s the concept of “lifelogging” started to gain attention (ibid.). Lifelogging revolves around the idea of creating complete records of a person’s everyday life, for example through the use of wearable cameras. From continuously logging data to create a personal life archive, goals in this domain shifted to collecting data for goal-directed purposes (Rapp et al., 2018). The explosion of ubiquitous computing, the Internet of Things (IoT) ecosystem and the availability of wearables and other self-tracking

gadgets led to a period of “sensor-mania”, with a focus on the possibilities of these new tracking devices (Swan, 2012). Within this development, the concept of “personal informatics” emerged within Human-Computer Interaction research, defined as “a class of systems [...] that help people collect and reflect on personal information” (Li et al., 2010). Research in this domain has concentrated on health and wellness domains, design for behavior change and self-improvement, understanding individual users’ tracking needs, and exploring the use of commercial trackers as well as custom tools (Epstein et al., 2020).

One of the most prominent movements in the self-tracking domain is Quantified Self, a term coined by journalists Gary Wolf and Kevin Kelly in 2008 to describe hobbyist groups that gathered to discuss their self-tracking projects under the slogan “self-knowledge through numbers” (Wac, 2018). Originating in California, the movement has since spread worldwide, with around 110 meetings in thirty countries recorded up until 2019 (Wolf & De Groot, 2020). It has received extensive media coverage (Hepp et al., 2021), and has been subject of research, in relation with topics such as personal informatics, health care (Feng et al., 2021), and its role as a cultural phenomenon (Lupton, 2016). Practitioners of Quantified Self engage in data collection to assess and influence various aspects related to their quality of life, including their physical and psychological well-being, social interactions, and environmental context (Wac, 2018). Unlike generic recommendations such as “move more,” which do not consider individual contexts, engagement with Quantified Self has been described as “data-driven and very personal” (ibid.). This approach contrasts with the earlier days of self-tracking, characterized by rather passive sensor-centric engagement (Swan, 2012), by emphasizing consciousness, individual empowerment and agency (Jin et al., 2022; Lupton, 2019).

Within this development, the notion of “personal science” emerged. Originally coined by psychology professor and self-experimenter Seth Roberts (2004), personal science emerged as a concept to understand self-tracking practices as “self-research”, in the context of empirical knowledge production (Heyen, 2016). It has been interpreted as a type of “n-of-1” research (De Groot et al., 2017), encompassing activities for science-based knowledge production by citizens and laypersons related to their own health, occurring in the interplay between scientific inquiry and self-reference (Heyen & Dickel, 2019). The term is closely associated with Quantified Self, and has been used to characterize self-research activities presented during Quantified Self community events (Heyen, 2020; Wolf & De Groot, 2020). Personal science sets itself apart from simple forms of self-tracking by the observation that those who engage in personal science are frequently not satisfied with commercially available methods or passive tracking for monitoring or optimization. The distinction lies within a more conscious engagement with the practice and data in personal science: Self-researchers are motivated by personal questions, which determines what kind of data is interesting to them,

and which methods are necessary to collect this data. This process may lead them to bottlenecks, resulting in the need to adapt or develop alternative methods to address their inquiries, often drawing upon methods from scientific research (Heyen, 2016; Senabre Hidalgo et al., 2022; Wolf & De Groot, 2020).

3.1.2 Extracting the Common from Individual Practices: Frameworks, Motivations, and Topics in Personal Science

Motivated to further characterize personal science and support people in adopting this practice, Wolf and de Groot (2020) developed a conceptual framework for personal science. Drawing on their experiences from over a decade of community events, the authors identified five common activities found in personal science projects: Questioning, designing, observing, reasoning, and discovering (see Figure 3.1.).

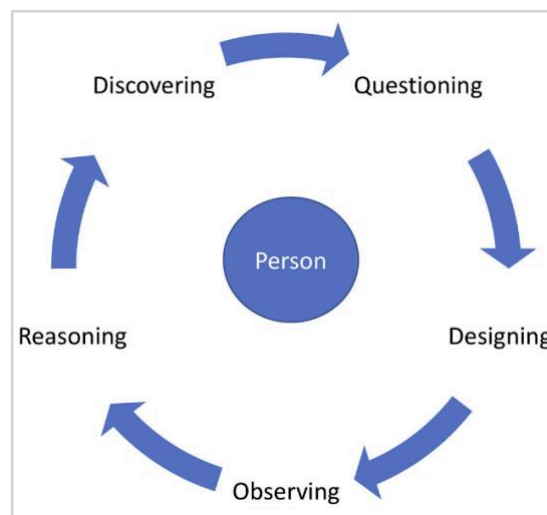


Figure 3.1 Conceptual framework of activities in personal science (Wolf & De Groot, 2020)

Questioning involves the development of research questions. The research domain is the individual's own life. These questions are personal, self-reflective, and address aspects such as experiences and emotions. They are chosen deliberately and hold direct relevance to the individual asking the question.

Designing pertains to the development of research methods for the self-research project, characterized by varying degrees of complexity and formality depending on the individuals' requirements and skills. Study designs can range from simple observations of changes of a variable over time to complex experimental setups or interventions.

Observing is the act of collecting data to address the research question. The data collected is personal and specific to the individual conducting the research, who deliberately gathers their

own data. Methods for data collection can be digital or analog, including active entry of data or passive recording with sensors. The data represents factors such as physical or mental states, social or environment factors.

Reasoning encompasses data analysis, but also extends to the individual's control over the research process. This includes shaping research questions, methods, seeking help when needed, and weighing the risks and benefits of research and actions. Data is often organized in tabular format, and visualization and analysis techniques are selected based on the characteristics of the data and research question.

The term *discovery* is used here in the sense of "learning". This encompasses the process of consolidating the insights gained from research into actions in daily life. It also involves sharing and discussing the results either in public or within the community. The process of discovery can lead to new questions and spark the beginning of a new self-research cycle.

In a recently published work-in-progress publication, Wolf (2022) refines the framework by removing the explicit design step, which is now implicitly incorporated in the other steps. Results are assigned to each step on a conceptual level: Questioning results in a topic, observing in protocols and data, reasoning yields insights, and discovering leads to actions. Additionally, more specifications have been added to each remaining step, with the aim to create a toolkit for personal science. The author emphasizes that the purpose of this framework is not to provide a step-by-step manual, but to offer a high-level framework that provides orientation and supports troubleshooting. This includes elaborations of concepts and techniques considered helpful for each step. For example, regarding the "observing" step, which focuses on what to track and how to track it, the publication provides detailed information on characteristics of suitable phenomena for self-tracking, including features of these, and suggests proxies in cases where the direct phenomenon is not observable.

In 22 interviews with self-researchers, Senabre Hidalgo et al. (2022) focused on identifying factors that motivate practitioners to continuously engage in personal science, as well as the topics they address. They discover that intrinsic motivations play a significant role, in particular the improvement of personal conditions, either relating to specific health conditions or general well-being and lifestyle, as well as the enjoyment and curiosity in engaging in data, technology, and research activities.

Other motivations relate to community or social factors, like engaging with a community of peers who share similar goals and values, as well as contributing to empirical self-knowledge by sharing own experiences and learning from others. Extrinsic motivations, which were found to play a more subordinate role in most cases, include the acquisition of skills and experience for the professional career, opportunities for business or product development, or demonstrating results in specific areas.

Regarding the research topics pursued by the interviewed individuals, they covered various areas such as specific pathologies, chronic conditions, and health risk factors. Additionally, they explored everyday topics including diet, activity, sleep, menstrual cycle, and mood. Some individuals delved into more technical and niche subjects like neurotech, while others examined broader factors beyond health and well-being, such as quality of life and personal finance.

3.1.3 Personal Science's Relationship with Scientific Principles and Practices

Further research has aimed to contextualize the knowledge generated in personal science within the broader framework of scientific principles: Heyen (2016, 2020) conducted an extensive multi-sited ethnography targeting Quantified Self communities in Germany, Switzerland and the United States, in order to explore self-research from a sociology of knowledge perspective. He explores the knowledge that is produced by self-research practice, and the goals and methods of this type of knowledge production, in order to address the question about the appropriateness of using the term personal "science" to describe these practices. Heyen terms the knowledge acquired through self-tracking activities as "self-expertise", characterized by self-relatedness, practical use value, and verification through the application of empirical methods. It is distinguished from other forms of self-knowledge solely based on experience because it is produced in a methodologically controlled manner. Moreover, it is considered a form of non-certified expertise, since it is not officially recognized or certified by an institution.

Both Heyen (2016) and Senabre Hidalgo et al. (2022) discuss self-research in the context of the *Mertonian norms*, which are imperatives describing foundational values of science. These norms encompass four institutional imperatives characterizing science: communism or communality, universalism, organized skepticism, and disinterestedness (Merton, 1973).

The first norm, *communism or communality*, refers to the idea of common ownership of scientific knowledge by everyone. Both Heyen and Senabre et al. see this point at least partly fulfilled, arguing that publicly sharing practices and results, frequently including personal and private data, is an important value and motivator within the community. However, Heyen adds the constraint that knowledge acquired during self-research might be too personal to attribute it to a community. This aspect, he suggests, could be a reason for the absence of a common stock of knowledge in the community.

Second, *universalism* refers to the "impersonal" character of science, meaning the requirement that claims of truth and validity should not depend on the researcher and any of their social attributes. Instead, the same methods should lead to the same results for everyone. According to the authors, this principle also applies partially in the context of

personal science. Personal science and the related community events are open to everyone, and in theory, attributes like ethnic group, gender or social milieu do not play a role for the objectiveness of methods. However, Heyen adds that truth and validity claims beyond the individual might not be relevant, or are at least not contested in many cases. Additionally, the lack of collective knowledge production at that time supports this argument.

Thirdly, *organized skepticism* implies that scientific knowledge should be open to criticism and systematic scrutiny. With the constraint of a lack of an institutionalized process like peer review and lack of a common knowledge stock of interest beyond the individual, skepticism seems to be a value in the personal science community: This is evident in the form of critical questions that are frequently raised during meetups. The community actively addresses doubts or errors in protocols or results, and active, non-judgmental listening is a valued practice.

The fourth point, *disinterestedness*, emphasizes that researchers should work for the common benefit, rather than their personal advantage. It is not directly equal to altruism, but rather highlights the importance of integrity by refraining from using illicit methods for personal gain. This norm seems to partially conflict with self-research, because this practice is performed with personal interest in mind, e.g. improving one's own quality of life. However, the potential damage of falsifying data would primarily affect the individual researcher, making fraudulent gain less applicable in this case. In a broader sense, Senabre et al. argue that the community values of transparency and open sharing, the pursuit of objectivity, and the motivation to benefit peers through sharing are arguments for the application of disinterestedness in personal science.

Heyen concludes that although the term personal "science" for self-research rests ambivalent with regards to the central own-use value, and self-directedness of the practice, its use can be justified, because self-researchers attempt to create verified knowledge by use of scientific methods and criteria.

Apart from discussions regarding scientific characteristics of personal science in general, the movement has been set in relation to other phenomena: Frequently, a line is drawn between personal science and *single-subject* or *n-of-1* research. In *n-of-1* research, often applied in medicine, an individual person serves as the research subject in a strictly controlled trial setup (Kratochwill & Levin, 2015). Although both practices involve studying a single individual, and self-research has also been labeled as *n-of-1* research (Wiggins & Wilbanks, 2019), they differ in other important aspects: First, in personal science, the individual not only serves as the subject, but also takes the role of the researcher. It is thus suitable to speak not only of *n-of-1*, but "n-of-me" research (Wolf & De Groot, 2020). Second, single subject research typically takes place in clinical settings and is conducted by clinical researchers, while personal science is usually conducted in informal, non-institutional settings. Finally, *n-of-1* trials aim to

simultaneously benefit the research subject personally while also producing generalizable knowledge that can be applied to other patients. In personal science, while a secondary aim is often to benefit peers by sharing results and supporting them in their own practice, primary goals are generally addressing personal issues of the individual in daily life, often focusing on questions that are not treated in clinical research at all (Wolf & De Groot, 2020).

Heyen (2016) situates personal science between *prosumption/produsage* (Bruns, 2008) and citizen science, in the sense that knowledge and data are produced and consumed by the self-tracker simultaneously, since they generate it for their own self-use.

Personal science has been discussed with regards to its relationship with *citizen science* more generally, as well as *patient-led research*. Since in personal science non-professionals perform most, if not all steps of research, it has been interpreted as a form of extreme citizen science (Chiaravalloti et al., 2022; Heyen, 2016). However, some differences exist between personal science and citizen science in the stricter sense, particularly concerning the relationship between personal science and science in general: In personal science, the individual conducting the research is also the subject of the research, topics and questions are determined by the individual and do generally not address a research agenda of a scientific discipline, and the knowledge aimed for is practical self-usage in most cases, and not generalizable knowledge (Wolf & De Groot, 2020).

Finally, it has been argued that although citizen science in the stricter sense differs from personal science in certain aspects, it can be considered as citizen science in a more recent, wider definition of the term: This definition emphasizes the involvement of non-professionals in research, as well as inclusiveness and broader public participation in science (Senabre Hidalgo et al., 2022; Wolf & De Groot, 2020). In this broader context, personal science is seen as a "new mode of public engagement with science" that fosters the development of self-expertise (Heyen, 2020).

3.1.4 Barriers and Research Gaps

Personal science has been discussed for its potential impact on individuals' health in context of individual motivations, as a public health instrument, and as a driving force for patient-led research when motivated by publicly-minded motivations (see Chapter 1.3.). In order to further the understanding of these different potentials, some barriers and research gaps need to be addressed.

Wolf and de Groot (2020) identify four barriers to the widespread adoption of personal science: Firstly, they mention *underdeveloped methods*. They identify a lack of shared best practices on how to formulate research questions, how to develop protocols, collect data, analyze and

learn from one's own data, leading to individuals "handcrafting" their methods every time. The authors take a step towards addressing this barrier by translating common features into a reusable framework of personal science practice, which is revisited and extended by Wolf (2022), as detailed above.

Secondly, they highlight that *self-tracking tools* often lack functionality for personal science. Proprietary tools might not even allow exporting data. Additionally, tools designed for specific personal questions might be too expensive, inflexible in their functionality, or simply unavailable. Similarly, Wac (2018) observes a discrepancy between what people "do track" and what self-tracking tools "enable them to track", pointing out a lack of technologies for tracking psychological states and social relationships, which form important pillars of quality of life. Rapp et al. (2018) and Feng et al. (2021) further emphasize a research gap concerning the interpretation and sense-making in personal informatics technologies. Choe et al. (2014) identify common pitfalls in Quantified Self projects and derive recommendations for tool designs considering issues of current tools. These guidelines stress the importance of tools that provide early feedback to identify what to track, support experimental setups, maximize benefits of manual tracking, and promote self-reflection.

The third and fourth barriers identified by Wolf and de Groot refer to more systemic issues, one being a claim for more *recognition and social support*, especially from healthcare professionals, to encourage personal science practice and acting upon the results, and finally, the importance of having *time and power* to do personal science and *act on discoveries*, which addresses broader issues of democratization of scientific practices. With regards to social support, Senabre et al. (2022) point to lack of studies on collaboration in self-tracking, despite indications for the importance of cooperative dynamics. Similarly, Feng et al. (2021) call for studies of group- and community-level implications of Quantified Self. Finally, as outlined in chapter 1.3., despite the existence of active communities and valuing of peer support, accumulation of a shared knowledge base for personal science is so far lacking (Heyen, 2020).

Other aspects that need to be considered include the lack of rigorous controls in self-research experiments compared to clinical studies (Wac, 2018), as well as ethical issues that can arise when personal science projects are disseminated in scientific journals. These ethical concerns may include privacy issues, the burden of tracking, the relevance of the research beyond the individual, and the need for appropriate ethical review processes (Riggare, Hågglund, et al., 2021).

This study aims to contribute to the deeper understanding of barriers related to knowledge sharing and community support in personal science and explore how these can be addressed using a peer production approach.

3.2 Methods

This chapter is based on the design thinking methodology. As a “human-centered approach to finding unexpected solutions to complex problems” (TaHERi et al., 2016), it aims to match users’ needs with technological feasibility and business strategy (Brown, 2008). Having attained large popularity in industrial design (ibid.), it has also gained recognition in academic research, for example in the contexts of computer-supported collaborative work (e.g. Gumienny et al. (2013), McInnis et al. (2017), TaHERi et al. (2016)), healthcare innovation (N. Carroll & Richardson, 2016), and citizen science (Goi & Tan, 2021).

In this research study, design thinking will be applied using the “double diamond” design process model, developed by the UK Design Council (2007) as a “simple graphical way of describing the design process” (see Figure 3.2). It aims to lead from a general problem statement to specific solutions, via two parts – or “diamonds”. The first diamond, representing the problem space, has a “divergent” research phase, in which the range of potential problems is discovered at large, and a “convergent” insights or definition phase, in which promising problems or pain points are selected and specified. The second diamond, addressing the solution space, departs from the selected problem definition, starting with a divergent ideation or brainstorming phase, which are then developed and tested as prototypes. The whole process is not strictly linear, but iterative, which means that phases are thought to be repeated, influenced by results of prior iterations, until a satisfactory solution is found.

Double Diamond DESIGN PROCESS

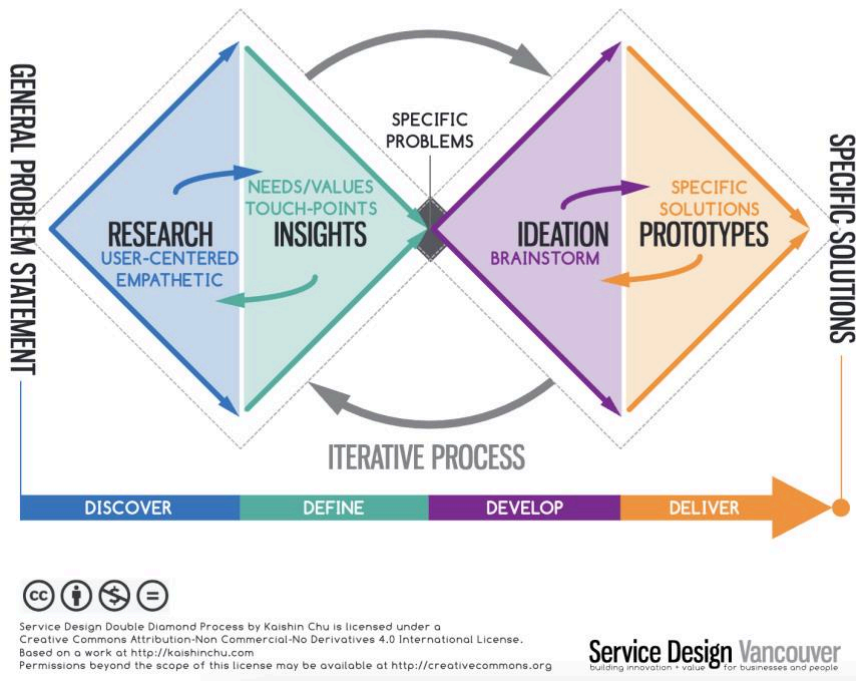


Figure 3.2 An adaptation of the double diamond design process (Chu, n.d.)

Using the double diamond model as overarching orientation, a multitude of user-centered research and design methods have been applied. Methods were chosen based on availability of resources, feasibility and efficiency, and were, in most of the steps, selected based on the results and thus the resulting requirements and open questions of the previous research or design iteration.

In order to become familiar with the problem space, as a researcher and designer initially external and not extensively familiar with the personal science community, the first steps comprised the identification of stakeholders, including considerations of who could and should realistically be included in the design process, as well as the development and prioritization of user personas. Personas are descriptions and visualizations of archetypical user types, who represent specific target groups and are thought to serve as mnemonic devices to focus on potential user needs from the start of the design process (Tschimmel, 2012). They usually include a name, photo or illustration, and other factors like specific qualities, needs, wishes and challenges of a stereotypical person, depending on the task at hand.

Another rich source of information was a set of interviews with self-tracking practitioners which were led by members of the research team before the start of the design process, and which are now published in Senabre Hidalgo et al. (2021). This article specifically focuses on the motivations of self-researchers. However, the interview transcripts also contain numerous comments about barriers, frustrations, and suggestions for improvement. Thus, from these

interviews, extracts representing motivations, ideas, or frustrations of community members were collected and clustered into topics on a visual collaboration board using Miro⁶, which then served as discussion starters with other team members and long-term community managers in order to prioritize problems and areas of intervention. In this phase, the “rose-bud-thorn” method was used. By assigning different colors, this method serves to classify statements or ideas into positive (rose), and negative (thorn) ideas, as well as ideas with potential (bud) (Crawford, 2018). This method was applied twice in this step, first to classify statements from the presumed perspective of the interviewed community members into user frustrations, motivations, and ideas for improvements, and second, during the discussion of these statements. In the discussion phase, roses represented ideas or issues to be prioritized, buds those that might be addressed with constraints or that are long-term goals, and thorns those ideas that had already been tried and did not work, or that were not thought to be feasible or desirable.

The prioritized ideas from the rose-bud-thorn activity were moved to another board, and were further discussed, and summarized into main areas of focus and intervention. Based on these results, a brainstorming of potential solution approaches was done and discussed, followed by the development of a platform prototype mockup using the collaborative interface design tool Figma⁷. This prototype was discussed with community managers, followed by a second iteration of prototype design, this time using a wiki approach. After another round of discussions, presentation to other community stakeholders, and presentation and discussion in a self-research chat, this approach was further developed and deployed in the following.

3.3 Results

3.3.1 Stakeholder Identification

The initial challenge of the design approach was to move beyond general problem statements, in order to uncover underlying, more specific issues and barriers that could be potentially addressed through designed solutions. These statements, such as “*the personal science community does not scale up*”, and “*everybody tends to start from scratch*”, were based on issues that had been observed by community managers, including the supervisor of this thesis, and served as one of the founding motivations of the doctoral project.

⁶ <https://miro.com/>, last accessed 28.07.2023

⁷ <https://www.figma.com/>, last accessed 28.07.2023

In the beginning of the PhD project, I was new to the community, and not familiar with personal science practice or community activities beyond a few months of participation on the sidelines within the context of the doctoral project. Therefore, the process began with the acquisition of a general understanding and definition of actors, community activities, and communication infrastructures:

While self-tracking is a widespread phenomenon, and communities exchange information on platforms like Facebook (Gilmour et al., 2020) or forums (Dolejšová & Kera, 2017) regarding various self-tracking topics in the health domain, this study focuses on the personal science community in a narrower sense, i.e., those who use the term and interpret self-tracking as a form of research. The two main communities in question are Quantified Self and Open Humans. Quantified Self, as outlined in chapter 3.1., is a movement bringing together people interested in “self knowledge through numbers”. The meetings of Quantified Self came to develop a focus on self-researchers presenting their projects to the community from a first-person perspective, structured by “three prime questions”: *What did you do? How did you do it? And what did you learn?* (Wolf & De Groot, 2020) The first question addresses the research question, motivation and context, the second the research design and tracking process, and the last one outlines the learnings. This “Show and Tell” talk format, focusing on the process of the project, has been found helpful for others, as well as the self-researchers themselves to understand the whole project, since narrative and logical connections have been found to not always be obvious from the start. Sharing results in this way has been found to inspire new discoveries, research cycles, and invites useful criticism (Wolf, 2022). Apart from these community meetings, Quantified Self has an online forum with an active community, including 6,000 signed up users and over 25,000 posts on 2,700 topics as of August 2023⁸. They also host an archive of meeting recordings, including over 1,000 presentations as of 2020, half of which have been transcribed, and almost 400 are publicly available online as videos (Wolf & De Groot, 2020).

Another community in the field of self-research has evolved around the **Open Humans** foundation. Founded in 2015 as an expansion of the earlier Harvard Personal Genomes Project (Ball et al., 2014), the Open Humans foundation’s purpose is to “empower individuals and communities around their personal data, to explore and share for purposes of education, health, and research”⁹. Since 2015, they have operated the Open Humans platform, an online space for personal data exploration, and participant-centered research and citizen science (Greshake Tzovaras et al., 2018). On this platform, users can create projects for institutional or personal research cases, and request data from other members. These members have full

⁸ <https://forum.quantifiedself.com/about>, last accessed 02.08.2023

⁹ Open Humans Foundation, <http://openhumansfoundation.org/>, last accessed 19.05.2023

control over their uploaded data, which means that they are able to decide who can use it and for which projects. In 2019, they count almost 7,000 members, of which almost 3,000 have loaded almost 20,000 datasets into their accounts, from personal data sources like Fitbit, 23andMe, uBiome, or Twitter (Greshake Tzovaras et al., 2018). Several studies using data from Open Humans have been published, like the bottom-up Quantified Flu study about Covid symptoms (Greshake Tzovaras et al., 2021), or TransBiome, the first study about the microbiome of neovaginas of trans women (Lehenaff et al., 2021).

Besides, Open Humans has an active slack community dedicated to personal data and self-research with over 1,100 members as of August 2023¹⁰, and organizes regular online community meetings: First, the weekly self-research chats, in which personal science practitioners discuss their projects and support each other, have involved over a hundred individuals as of 2023¹¹. Second, “Keating Memorial” Show and Tell talk events, are held annually in memory of former Open Humans director and patient-data access advocate Steven Keating who passed away in 2019, encouraging people to share their self-research projects in the format introduced by Quantified Self¹².

I further familiarized myself with community activities by consulting a range of personal science projects that were shared and recorded during Quantified Self Show and Tell talk events, and by participating in the weekly Open Humans self-research chats, where community members discuss their current project ideas and progress. Subsequently, stakeholders were explored in two aspects: real community members who could potentially be consulted during or participate in the design process, and archetypal user types represented as personas.

Stakeholders were classified based on their proximity to the core of the community. Factors considered for this classification included the duration of their involvement in community activities, whether they had taken up roles in community management (such as organizing events), their engagement in sharing their own self-research projects, and their involvement in discussions about personal science more broadly, including academic discourse on the topic. A handful of long-term community managers were identified, who presumably had high interest in the development of the personal science community and practice, and were thus considered to be likely willing to spend time on and be involved in the design process. Those were representatives of two of the biggest and most active personal science communities, Quantified Self and Open Humans, the latter of which are also direct team members of the PhD researcher. Other stakeholders classified as being close to the core included individuals

¹⁰ <https://openhumans.slack.com/stats#overview>, last accessed 02.08.2023

¹¹ <https://docs.google.com/document/d/1dCO847NygRXHX49JcFUGuBNNpGcsPCSAxaiee8E5MYc>, last accessed 08.09.2023

¹² <https://www.openhumans.org/self-research/>, last accessed 11.08.2023

who published academic articles about personal science, regularly participated in community events (such as Show and Tell talk events by Quantified Self or Self Research Chats by Open Humans), and those who engaged in frequent online discussions in the Open Humans Slack channel or the Quantified Self forum. The larger community was loosely defined as people practicing self-research who occasionally interacted with the community online. This interaction involved activities such as sharing results, projects, or questions on platforms like Open Humans, Quantified Self, or other similar platforms.

Since the general problem statements focused on the community and its growth at large, the next step involved the definition of archetypal community member types to gain an understanding of their motivations and challenges. I developed these in collaboration with my team from the Peer Produced Research Lab, whose sources of expertise came from long-term community management experience in two cases, and from a set of interviews led with community members shortly beforehand in two other cases.

Interesting dimensions for persona templates in the context of personal science were discussed and refined through several iterations. To make the task less abstract, every team member was tasked with creating a persona draft based on an interview with a real community member. These drafts then served as a foundation for group discussions, allowing us to compare and extract common points and dimensions. Once relevant dimensions were defined, each team member was asked to create three personas they considered the most crucial, in form of a name and a short description of under 300 characters – the length of a tweet. The set of personas was collectively reviewed, adjusted, and any redundant personas were removed. The final selection of “Tweet personas” was expanded to align with the previously defined template. Subsequently, the list of personas was further scrutinized from a functional standpoint to determine which user types should be prioritized in the subsequent design phase, along with the reasoning behind these choices.

The final set comprised 13 personas, out of which nine were given priority, and four were not prioritized. The persona template included a gender-neutral name with a short description as a mnemonic device, an illustration, a fictional quote and short description representing that archetype, motivations for engaging in personal science, involvement in social or community activities, challenges, as well as skills related to meta-research, data analysis, and coding. The dimensions were filled in completely or partially, based on their assumed relevance for each specific archetype. Table 3.1. shows an example of a prioritized persona, and the full list can be found in Appendix A.4.


1	Taylor the Techie									
	<p><i>"What can I do?"</i></p> <p>Taylor is a software engineer who is interested in playing with technology at large, including playing around with hardware. Taylor loves collecting data, even if they are not 100% sure what it could be used for.</p>									
Motivation	Internally motivated, excited about technology, likes to spend time on it in their freetime									
Challenges	Finding a purpose to apply their skills and interests									
Community	Self-research chats, likes to help people with their technology- and data-related questions									
Skills	<table style="width: 100%; border: none;"> <tr> <td style="width: 33%;">Meta</td> <td style="width: 33%;">research:</td> <td style="width: 33%; text-align: right;">beginner</td> </tr> <tr> <td>Data</td> <td>analysis:</td> <td style="text-align: right;">intermediate</td> </tr> <tr> <td>Coding: expert</td> <td></td> <td></td> </tr> </table>	Meta	research:	beginner	Data	analysis:	intermediate	Coding: expert		
Meta	research:	beginner								
Data	analysis:	intermediate								
Coding: expert										

Table 3.1 An exemplary persona representing an archetypal user type in the personal science community

The list of prioritized personas comprises:

- a “Techie” (see Table 3.1.),
- a “Data-Nerd”, who enjoys analyzing their own data,
- an “Improver”, who wants to use self-research insights to lead a healthier and better life,
- an “ePatient” with a chronic condition, who wants to improve their life and that of people with the same condition,
- a “Researcher”, an academic who wants to apply their methodological skills to understand their own life,
- a “Curious”, who enjoys coming up with new questions to ask and answer,
- a “Discovering Patient”, who is new to the world of data, but keen to learn which factors influence their health issues,

- a “Student”, who wants to apply methods taught in class to learn about themselves,
- and a “Hobbyist”, a retired engineer who wants to dedicate their freetime to tinkering with technology and applying it to improve and preserve their health.

Personas that were not prioritized in the further design process include:

- a “Reluctant Patient”, who is advised by their doctor to self-track, but is not interested in doing so,
- a “Scientist”, who wishes to conduct research projects using personal data collected by self-trackers,
- a “Data Donor”, who is interested in donating their extensive collection of personal data to science,
- and a “Casual Tracker”, who uses commercial tracking tools in daily life, but does not feel the need to go beyond this.

The decision of whether or not to prioritize personas was informed by the prior experiences of the team's long-term community managers. The rationale for not focusing on the "Reluctant Patient" and "Casual Tracker" personas was that successful engagement in personal science typically demands intrinsic motivation to actively experiment with technology and protocols, going beyond relying solely on ready-to-use solutions. Regarding the "Scientist" and "Data Donor" personas, these paths had been explored in past activities of Open Humans but had not received significant response. As a result, they were not given higher priority in the current design process.

3.3.2 Problem Identification

Once a general understanding of community activities and stakeholders was established, the exploration of the problem space, the first part of the double diamond process, was continued and deepened. The source for this phase of user research were the interviews with community members led by team members beforehand, whose analysis with regards to shared motivations is now published in Senabre Hidalgo et al. (2022). The goal of this activity was not an in-depth analysis of the interviews, but to extract a set of issues, motivations, and ideas formulated by community members to serve as discussion starters to identify and prioritize potential areas of intervention. The team member who led the interviews provided the PhD researcher with a list of issues related to user experience extracted from the interviews, which served as the primary basis, and was complemented by consultations of samples of the complete interviews.

The PhD researcher extracted quotes from the interviews, paraphrased and shortened them to fit on virtual post-it notes on a Miro board. Subsequently, the post-its were clustered based on their content or themes.



Figure 3.3 Screenshot of a part of the Miro board, showing statements from interviews clustered by topic, and color-coded according to the "rose-bud-thorn" method

Each card was assigned a color according to the rose-bud-thorn method: Positive experiences (roses) were represented by the color pink, negative experiences (thorns) by the color blue, and suggestions or wishes (buds) by the color green. Examples of "rose" statements included "Finding like-minded people/a community" and "Open Humans removes barriers: reusing notebooks, development environment, and API are already there." "Thorn" statements consisted of remarks such as "No time to attend community meetings" or "A lot of duplicate work happens," while "bud" statements offered ideas like "make code less intimidating at first sight" or "more documentation on how the community and [Open Humans] platform work."

The clusters that emerged were as follows: "Community and independence at the same time", "Sharing and learning", "Realizing project thanks to process help/infrastructure", "Reuse = less barriers", "Aggregation from different devices", "Platform is good, just needs to scale up",

“Accessibility, confusion where to start”, “Reasons to not use Open Humans platform”, “General problems”, “Feature requests”, and “Other”.

Using this Miro board, a team discussion was initiated to prioritize problem areas. Statements or clusters were rated as either "focus area / area with potential," "could work with constraints / no short-term goal," or "does not work / no focus." For a comprehensive list of statements with categorizations and comments, please refer to Appendix A.5.

From this discussion, the following problem areas of focus were derived:

- “Something that encourages people to share their progress”
- “A way to find what has been done / the knowledge that already exists in the community in an unstructured way” in form of “some sort of cross-referenced information system”
- “Forming long-term social motivations”
- “Analysis assistance”

3.3.3 Prototyping

To initiate the phase of ideation and exploration of the solution space, these ideas were moved to another part of the board, and complemented by related thoughts on aims, approaches and potential issues to watch out for in a subsequent discussion.

For instance, the cluster regarding “A way to find what has been done” was supplemented by specifications of what the cross-referenced information system could contain, such as “For a given topic, what methods can you use? What worked versus what did not?” or “Make processes / tacit knowledge explicit”. Potential problems were outlined as “How is our approach different from forums or reddit?” and “Problems with lists of tools: maintenance, spam, e.g. advertisement for apps from start-ups”. The whole list of this ideation phase can be found in Appendix A.6.

As a next step, in a brainstorming session, the PhD researcher developed a list of solution approaches addressing the focus areas in different ways. The initial set of ideas included:

- a custom *Personal Science Platform*, thought to serve as a social network and project platform, where people could share and find projects, as well as identify and get in touch with people with common interests;
- a *community wiki* (not specified further at this point);
- updating the *user experience and interfaces of the Open Humans platform*, to remove potential barriers for new users, and align the user flows with motivations of the previously specified personas;

- and developing reusable programming *notebooks or data management tools* for analysis assistance (not specified further at this point).

The first suggestion, the “Personal Science Platform”, being the widest in scope and potentially covering all of the problem areas, was further elaborated and designed in the form of a mockup using Figma.

Four categories of pages were envisioned to form the foundation of the platform: Pages for users, their projects, self-research tools, and topics. Similar categories were also used as metadata in the Quantified Self Show and Tell talk archive. Users were expected to have the ability to create a profile page containing tags for topics and tools of interest, a brief biography, and contact information. Whenever a user added a tag for a specific topic or tool to their profile, it would automatically generate corresponding topic and tool pages. These pages could then be manually filled with relevant information and would be automatically linked to other content on the website, such as tools, projects, topics, or individuals, that are tagged with the respective page title. Users were also envisioned to be able to document their projects on the platform, either as finished projects or in a work-in-progress or research diary mode, encouraging frequent and early sharing. Other features included the ability to rate tools and research protocols for different usage contexts, to share questions with the community, similar to Public Lab (see Chapter 2.4), and to follow other users. The platform was designed to resemble a social media platform, offering custom feeds and interconnected information.

Figure 3.3. shows a mockup of a profile page, as envisioned for the persona “Taylor the Techie”. Additional screenshots can be found in Appendix A.7.

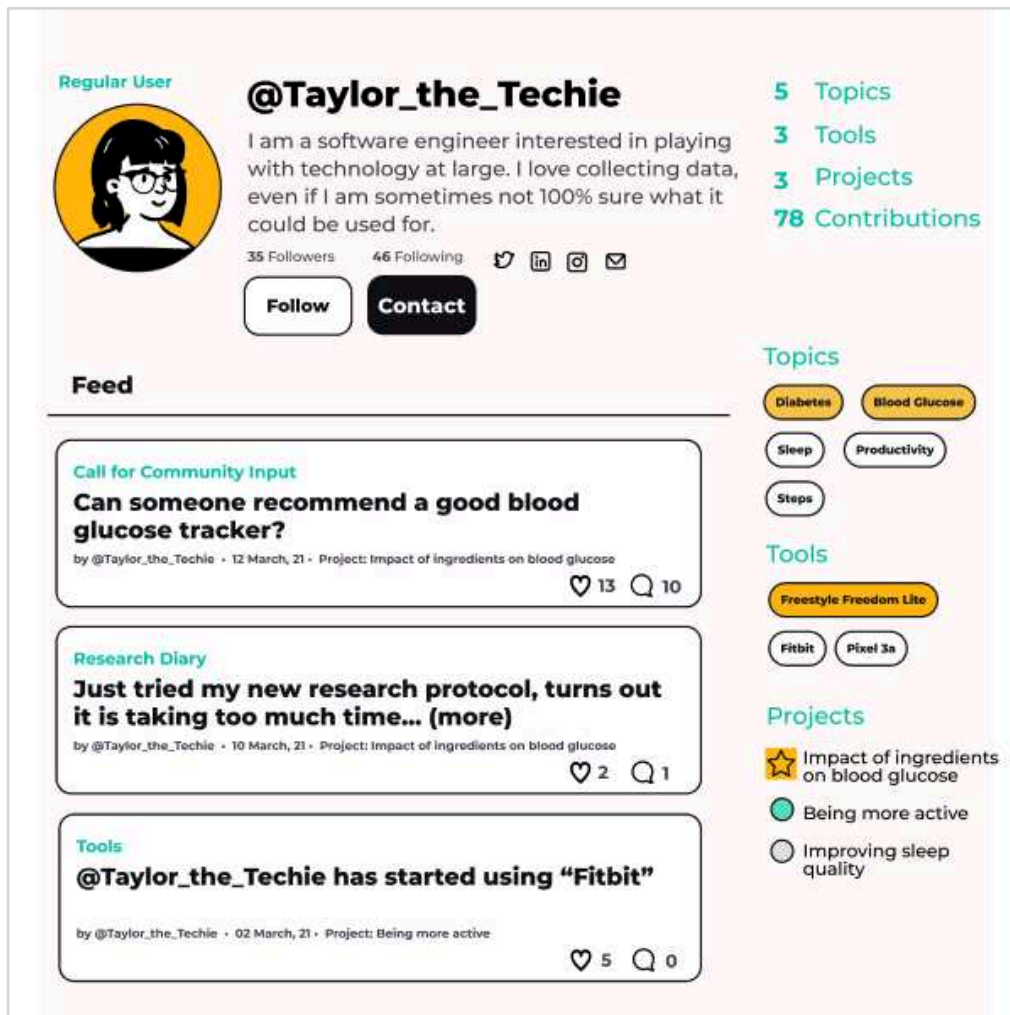


Figure 3.4 Mockup of a profile page for the Personal Science Platform concept. Source of UI components: <https://contrauikit.com/>

Using the mockups, the concept of the Personal Science Platform was thoroughly discussed in a team meeting, and evaluated in terms of its potential to address issues and its feasibility. Possible goals and motivations to use this platform were identified, including “sharing what one has learned”, “being stuck and needing help or ideas and orientation to start a new project”, “finding what others have done” and “connecting and expanding the niche community”.

A principal point of criticism was the lack of feasibility in the context of a PhD: Developing a custom platform of the planned scope would require substantial time and resources, including a lengthy upfront design and development phase, with no guarantee of its success and community adoption. Additionally, the concept heavily relies on a considerable number of users and their active participation to become valuable. Since the platform focuses on users sharing their own projects, motivating a large number of self-researchers to become active users would be essential. The same reasoning applied to the usefulness of question items. As outreach plays a vital role, most users might prefer platforms like Reddit to reach a broader

audience and get quicker responses to their questions. Another concern was that sharing projects on this platform could require more effort compared to formats like the self-research chat, which might discourage users from fully engaging unless there were sufficient incentives. Despite these hesitations, the major categories (user pages, projects, tools, topics) were thought to be suitable, representative of relevant community knowledge, and a potential basis to address the issue of creating a cross-referenced information system.

As a result, the idea was not discarded, but instead adapted in the form of a wiki, to enhance feasibility and set more realistic expectations in terms of initial user engagement. This approach, which represents both the end of the general design thinking process, and the beginning of design iterations for a specific solution, will be elaborated upon in the following section.

3.3.4 Personal Science Wiki

The main idea retained in the previous phase of the design thinking process was to create a cross-referenced information system thought to serve as an infrastructure for a shared knowledge base for the personal science community. In this design iteration, MediaWiki software¹³ was selected as technical infrastructure, aiming to solve some of the issues discussed with regards to the previous prototype, the custom Personal Science Platform.

There are several reasons that motivated us to choose MediaWiki, and a wiki approach in general, for our use case. First, compared to the development of a custom community platform, the costs in terms of time and resources are significantly lower. MediaWiki software is easy to setup and maintain, and has been used extensively, with Wikistats listing more than 430,000 public wikis¹⁴. We wanted to prioritize deploying a running version as fast as possible, over spending much time testing and improving non-functional prototypes, in order to get user feedback from real usage quickly. Additionally, MediaWiki is adaptable to community needs, offering almost 1,500 extensions¹⁵, over 750 configuration settings¹⁶, and useful inbuilt functions, such as a list of “wanted” pages, aggregating non-existent pages that are most often linked by contributors¹⁷. Finally, and importantly, it is a prototypical peer production infrastructure, offering fundamental functionality for this approach out of the box. This base functionality seemed to also offer a solution for a point of criticism of the custom platform

¹³ <https://www.mediawiki.org/wiki/MediaWiki>, last accessed 17.05.2023

¹⁴ <https://wikistats.wmcloud.org/>, last accessed 11.08.2023

¹⁵ https://www.mediawiki.org/wiki/Category:All_extensions, last accessed 11.08.2023

¹⁶ https://www.mediawiki.org/wiki/Category:MediaWiki_configuration_settings_still_in_use, last accessed 11.08.2023

¹⁷ <https://www.mediawiki.org/wiki/Manual:WantedPages>, last accessed 11.08.2023


approach: On a MediaWiki platform, everyone can edit any page. This means that in principle users can create and edit pages for other people and their projects, potentially preventing maintenance bottlenecks and the need for a large number of self-researchers being active contributors on the platform to cover their work.

The resulting concept, referred to as the “Personal Science Wiki”, aimed to provide an infrastructure for developing a community knowledge base. It is available under <https://wiki.openhumans.org/>. The concept retained the main category structure that was suggested earlier: “Tools”, initially defined as information about “self-research tools to record or analyze data”, “Projects” as a space to share and consult self-research projects, “People” pages for practitioners of personal science, for both contributors and non-contributors to the wiki, and “Topics”, for subjects related to personal science practice that do not fall into the other categories.

A fifth category “Notes” was added, to reference and link community meeting notes within the wiki infrastructure. This addition was specifically intended for the weekly Open Humans self-research chats, as these notes were considered a valuable resource for capturing recent topics of interest.

The concept of the wiki, along with the rationale for not pursuing a customized Personal Science Platform, was shared and deliberated with Gary Wolf, a long-term stakeholder within the personal science community and one of the founders of the Quantified Self movement. Following a favorable assessment, we proceeded with the implementation of the wiki approach.

A screenshot of an early version of the homepage, showing the category structure, is shown in Figure 3.4.



Home
Recent changes
Random page

Categories
Tools
Topics
Projects
People

Meetings
Join our meetings!
Self-Research Chat
Notes

MediaWiki Tools
CSS edits
Sidebar edits

What links here
Related changes
Upload file

Special pages
Printable version
Permanent link
Page information
Browse properties

Main page Discussion Read Edit Edit source View history More ▾

Search Personal Science Wiki

Personal Science Wiki

Welcome to the Personal Science wiki! If you are a self-researcher working in a specific personal project, or using self-tracking tools and methodologies for generating empirical knowledge, feel free join this effort to collect and reflect the work of the personal science community. You can learn more about this Wiki.

Don't hesitate to navigate and contribute to the existing wiki pages or create new ones in the following **categories!**

Tools	Topics	Projects	People
<p>Check out self-research tools to record or analyze your data.</p> <p>Some examples:</p> <ul style="list-style-type: none"> • Apple Watch • Fitbit • Diet tracking tools • One Button Tracker • Open Humans ... further results 	<p>Topic pages focusing on a variety of subjects related to personal science practice.</p> <p>Some examples:</p> <ul style="list-style-type: none"> • Dates and Times • Urine analysis • Sleep tracking • HRV (Heart Rate Variability) • Blood glucose tracking ... further results 	<p>Have a look at projects from your fellow self-researchers to get inspired.</p> <p>Some examples:</p> <ul style="list-style-type: none"> • Deciphering My Brain Fog • Memorizing My Daybook • Sleep recordings: Oura vs Fitbit • Smartphone Disengagement • Analyzing My Weight and Sleep ... further results 	<p>Explore our people pages to find out who worked on subject areas you interested in. You might also get in touch :)</p> <p>Some examples:</p> <ul style="list-style-type: none"> • Seth Roberts • Quantified Diabetes • Piotr Wozniak • Gedankenstuecke

Join our community meetings!

- Personal Science Community Meet Ups

New here?

- Getting started guide
- About Personal Science Wiki

Help improving this wiki!

- Wanted Pages
- Expand stub articles
- Open Issues

Figure 3.5 An early version of the Personal Science Wiki homepage, showing the main category structure “Tools”, “Topics”, “Projects”, and “People”

To allow for cross-referencing beyond categories, “Semantic MediaWiki” (Krötzsch et al., 2006) was installed, an extension for MediaWiki that allows to assign properties to pages. This enables semantic querying, such as aggregating all pages that share one or more properties. For the Personal Science Wiki, the use of properties was formalized and encouraged by the creation of templates. For the main categories, “Infobox” and “Linked content on this wiki” templates were created. In the infoboxes, users were thought to add properties manually, while under “Linked content” queries automatically displayed all pages that listed the currently opened page as property. Figure 3.5. shows an early version of a tool page about a wearable tracker called “Oura Ring”. On the top right of the page, in the “Tool Infobox”, users added topic pages relevant to this device, like “Sleep tracking”, or “Activity tracking”. On the bottom of the page, projects and self-researchers using this tool are listed, as well as meetings in which this tool was discussed. For reasons of simplicity, to keep links unidirectional, not all “Infoboxes” and “Linked content” templates contain the same information. Following a rule of linking from the specific to the general, it is, for example, possible to link from a tool to a topic, but not from a topic to a tool. In the case of pages of the “Topic” category, this means that there is no infobox, since it is the most general category. However, since it is possible to link to topics from all other categories, related pages are listed as backlinks under “Linked content”.

Oura Ring

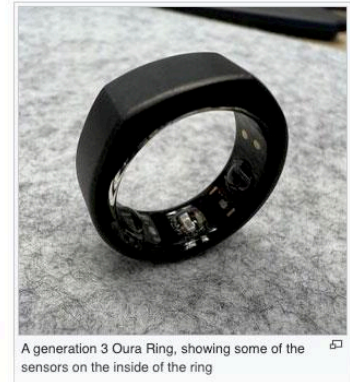
The **Oura Ring** is a wearable that is worn on a finger as a ring which tracks **sleep**, **activity** and **readiness**. Since 2013 there have been three different versions of the ring, with the latest version (v3) being launched in November 2021. At the same time they changed their business model, requiring a monthly subscription for access to all metrics recorded.

Tool Infobox	
Related topics	HRV (Heart Rate Variability), Activity tracking, Sleep tracking, Body temperature tracking

While the sensor set of the rings have changed over the versions, generally they contain an **accelerometer**, a **temperature sensor** as well as an **optical heart rate** sensor. From these sensors the Oura calculates the following metrics:

Contents [\[hide\]](#)

- 1 Differences between models
- 2 Metrics provided
 - 2.1 Body temperature metrics
- 3 Exporting data
- 4 Subscription
- 5 Project using Oura Ring
- 6 References
- 7 Linked content on this wiki



Differences between models [\[edit\]](#) [\[edit source\]](#)

Model	Sleep tracking	Activity tracking	Readiness tracking	Heart rate during sleep	Heart rate during day	Body temperature	Menstrual cycle tracking	Blood oxygen tracking
Generation 1 <small>[label this model] [1]</small>	✓	✓	✓	✓	✗	✓	✗	✗



Linked content on this wiki [\[edit source\]](#)

(The content in the table below is automatically created. See [Template:Tool Queries](#) for details. If newly linked pages do not appear here, click on "More" and "Refresh".)

Projects that use this tool [Collapse]
Impact of work-related stress, Sleep recordings: Oura vs Fitbit, What does clustering tell us
Self researchers who used this tool [Collapse]
Gedankenstuecke Gedankenstuecke, Gedankenstuecke, Gedankenstuecke
We talked about this tool in the following meetings [Collapse]
2021-12-02 Self-Research Chat, 2022-05-19 Self-Research Chat
Category: Tools

Figure 3.6 An early version of the “Oura Ring” page, a page of the category “Tool”, including a “Tool Infobox” template on the top right, and a “Linked content on this wiki” template on the bottom of the page

As the Personal Science Wiki aims to be a peer-produced community platform, integrating and engaging the community is a major focus and challenge.

Once the concept of the wiki was drafted, and its technical feasibility tested by deploying the basic infrastructure, it was presented to the community managers of Quantified Self. They responded positively, especially noting the wiki's potential as a permanent space for curating and preserving content that could be referenced when users asked questions about self-research topics or projects on platforms like Reddit. Following the favorable response from the community managers, the wiki was presented to the broader community during an Open Humans self-research chat meeting. Despite being in a prototypical stage, its usage was encouraged. To collect user feedback, a page named "Open Issues" was created on the wiki,

allowing anyone to add, discuss, or claim tasks. The talk page of this section was designated for open brainstorming of ideas to enhance the wiki further. Additionally, a #wiki channel was established on the Open Humans Slack platform, enabling updates to be shared, and discussions about the wiki were encouraged during the weekly self-research chats.

In this way, the wiki became actively used by a small number of community members right away. In the beginning of April, 2022, almost six months after the internal announcement of the launch of the platform in a self-research chat, the wiki counted 476 content pages, and 13 users with zero to 687 edits, the most active contributor not being a part of the research team. Of the 476 content pages, 373 were project pages imported from the archives of the Quantified Self Show and Tell talk archives, with support from Gary Wolf and Steven Jonas from Quantified Self. We imported these talks in order to provide seed content, as well as with the intention to make this valuable source of knowledge accessible within our semantic system. A more official launch took place during a Keating Memorial Self-Research event on October 27, 2022.

The “Open Issues” page was edited by five wiki users in total, four of which are part of the PhD researcher’s team. 29 issues related to functionality, usability, content structures, and manuals are listed, of which 21 have been resolved, largely by the research team. Apart from that, the wiki became a frequently discussed topic in the Open Humans self-research chats: From September 2021 to May 2023, it was mentioned in 56 of the weekly chats. Topics included general discussions about the wiki and its potential, also in relation to other platforms or technologies, like Wikipedia or ChatGPT, technical and usability issues of the wiki, its organization and governance.

Apart from these discussions, the wiki appeared frequently in the form of links in the self-research chat notes, by community members sharing wiki pages they edited or created.

3.4 Discussion

This chapter represents initial steps to address the research question “What are the barriers to the widespread adoption of personal science practice, and how can they be addressed with a peer production approach?”. The chosen methodology to address this question was a user-centered design thinking process, which has its origins in the fields of industrial design and innovation. The process began with the identification and prioritization of specific problem areas derived from general problem statements, using user research methods. Subsequent phases involved iterations of brainstorming, prototyping, and testing potential solutions, leading to the development and implementation of the Personal Science Wiki.

Regarding the first part of the research question that addressed the **barriers to a wider adoption of personal science practice**, the study contributed to a more profound understanding of the problem statements “the community does not scale up”, and “people tend to start from scratch”. Initially, we learned what “scaling” could mean for personal science, and what types of scaling were aimed for: First, scaling was discussed in the context of data donation. Data donation means that self-trackers donate personal data they collected for their own purposes to a collective dataset that researchers then utilize for scientific studies (Bietz et al., 2019). Given the ubiquity of sensor technology and tracking apps in smartphones, data donation has been considered in recent years for its potential to benefit clinical research and citizen science projects by enabling researchers to tap into large amounts of individually collected data with comparably little effort (Strotbaum et al., 2019). One major goal of the development of the Open Humans platform, next to the empowerment of individuals around their own data, was to create a platform to allow data donations, while leaving the control of the data in the hands of the individual donors (Greshake Tzovaras et al., 2019). Until now, Open Humans has enabled data donation for a wide range of personal data sources, notably allowing the accumulation of diabetes data from the open source artificial pancreas system (OpenAPS) (D. Lewis & Leibrand, 2016), which has led to reuse and publication based on this data (D. M. Lewis et al., 2018). However, based on the team discussions including the directors of Open Humans, scaling by focusing on data donation was deprioritized in this design process. They had observed that many self-trackers showed willingness in giving their data to science, but noticed a lack of broad interest from scientists to use this data on the other hand. They explained this with the theory that reusing this data is not necessarily easier and a guarantee for upscaling, compared to finding study participants who collect data specifically for a study according to the researchers’ protocol. While literature on challenges in data donation often highlights aspects regarding the donors, including ethical dimensions like the protection of privacy, or incentives for participation, potential explanations for the reluctance of researchers can also be found: Since donors “recruit” themselves, and self-tracking might be prevalent more in some demographics than in others, samples risk not to be representative (Bietz et al., 2019). Furthermore, from a technical perspective, potential data quality problems might arise from the use of different devices or software, technical deficiencies or problems with transmissions, which is still underexplored (Strotbaum et al., 2019). Future work is necessary to address reasons for these observations.

Another type of scaling could be reached by automatization of common processes, removing technical barriers by providing ready-to-use tools, e.g. for automatic analysis or combining several data sources. The provision of tools for easy upload or integration of data from different wearables and services is also a part of the Open Humans platform. Available projects include

tools such as several uploaders for genome data, a connector to Fitbit, a Twitter importer, or a Jupyter Notebook integration (Greshake Tzovaras et al., 2019). However, during team discussions, it became apparent that this approach was generally considered to be less feasible on a larger scale and challenging to maintain. One of the primary reasons for this difficulty was the high frequency of changes in application programming interfaces (APIs), data formats, and tools. This observation aligns with the findings of review articles that discuss the challenges of health data integration. These articles also highlight issues such as a lack of system interoperability and the significant human labor required to create and maintain such services due to the rapid pace of technological developments (Dinh-Le et al., 2019; Peng et al., 2020). While this aim was still seen as a long-term goal, considering its potential to remove technical barriers, this way of scaling was also deprioritized for this design process.

Finally, scaling can refer to more people practicing personal science, meaning more people engaging in the whole process of using empirical methods to address personal questions, including formulating their own questions, creating protocols, collecting data, analyzing and acting on it, including finding suitable tools and methods at every stage. In the following, emphasis was placed on this type of scaling, with the goal of enabling more people to engage in the breadth of personal science practice involving all steps from questioning to discovery (Wolf & De Groot, 2020), less focusing on automation or donating data.

Secondly, we gained insights into the connection between the issue of "starting from scratch" and the broader challenge of the community not scaling up in terms of "more people practicing personal science". Engaging in personal science demands a comprehensive set of research skills that span various aspects, including the development of research questions and protocols, the selection of appropriate tools, data collection, analysis, and interpretation (Wolf, 2022). Relevant knowledge is often tacit (Polanyi, 1958), relating to practicing research. Additionally, it involves adapting research methods to one's own unique context, considering that two individuals rarely can use exactly the same methods, which can impose barriers to newcomers. Heyen (2020) observed the lack of accumulation of community knowledge in the form of a shared resource. This deficiency is attributed to the loose connection between the projects undertaken by individual self-researchers. Furthermore, it was noted that even the format of presentations during community events could conceal tacit knowledge, such as failed attempts or iterations of protocol design, by presenting a seemingly cohesive narrative. Nevertheless, there are some common elements found in personal science projects. For instance, Wolf and de Groot (2020) developed a circular process model comprising five research steps based on their experiences with the Quantified Self Show and Tell talks. Additionally, questions of self-researchers often revolve around similar issues, with health and well-being being major themes (ibid.). This sometimes leads to the formation of communities

focused on conducting self-experiments related to specific topics, for example food substitutes (Dolejšová & Kera, 2017). Other researchers identified common aspects related to goal setting (Munson et al., 2020), as well as common pitfalls to self-research (Choe et al., 2014).

Community meetings play a vital role in the personal science community, where self-researchers provide each other with feedback, critique methods, exchange best practices, and share their experiences with tracking and analysis tools. While this verbal, informal exchange has been practiced in numerous community meetings, and such interactions with the community serve as significant motivators for practitioners (Senabre Hidalgo, Ball, et al., 2021), there are some challenges associated with this format: Some individuals might not have time to attend these meetings, and watching recorded sessions can be time-consuming, thus some self-researchers might prefer a more asynchronous, textual format of exchange. Other exchanges occur through personal blogs, forums such as the Quantified Self forum, or social platforms like Reddit. Although many of these have large active user bases, these formats did so far not evolve into a shared community knowledge base that efficiently directs users to resources to reuse and to guide their projects (Heyen, 2020). Thus, the observation that self-researchers tend to “start from scratch”, crafting their methods as they undertake their projects (Wolf & De Groot, 2020), becomes evident.

A primary data source for the user research was the set of interviews conducted by Senabre Hidalgo et al. (2022). Interviewees emphasized the value of being part of a community of practice, which provided them with group support for an inherently individual practice, and allowed them to learn from and be inspired by others’ work. Knowing that one will share one’s work later with others served as an additional motivator. Values that were highlighted were transparency, empowerment, control over one’s own data and life, as well as democratization of data and science, reuse, and sharing.

The issues and motivations are reflected in the personas that were defined and prioritized in early stages of the process. Considering that personal science practice often involves extensive experimentation and trial-and-error, personas representing individuals who exhibit limited interest or reluctance to engage in self-tracking beyond casual or minimal necessary medical monitoring were assigned lower priority. Such were self-trackers primarily interested in donating data to larger studies, as well as scientists seeking to utilize such data, as similar approaches had not experienced significant demand in the past, as outlined earlier in this section.

Conversely, personas assigned high priority represent intrinsically motivated individuals – people enjoying or curious about technology, data, applying research methods to themselves, improving and managing health, well-being, and chronic conditions. It was anticipated that sustained participation would be more likely among these participants, as personal science is

a complex activity that requires a willingness to experiment, iterate, and also embrace failure as part of the learning process.

Regarding the second part of the research question – **how the identified barriers can be addressed with a peer production approach** – the present research and design process also contributed some further understanding.

The results suggest the suitability of a peer production approach in general (cf. Chapter 2): The prioritized personas represent intrinsically motivated user groups with a wide range of motivations and skills, who can likely complement each other's knowledge. The aim is to support individuals in developing their own research projects, in individual and non-streamlined processes, including free exploration and familiarization with a topic, and self-selection and identification of tasks of their interest and expertise. Shared values revolving around community support, sharing, reuse, and transparency further support the argument.

Given the selection of MediaWiki as base technology, which represents a prototypical peer production infrastructure, several elements of peer production are readily available “out-of-the-box”: The common research object is a community knowledge base about personal science practice. Modularity, granularity, and low cost of integration, indirect “stigmergic” coordination, direct communication, and equipotential self-selection of tasks are enabled by visibility of all content and history, the editability of parts of various granularity of all pages by any user, and talk pages. The range of tasks encompasses documentation and consolidation of information about the whole research cycle, including methods, tools, topics, and projects. Regarding learning and communal validation, explicit tutorials or rules have been sparsely implemented so far, primarily to avoid imposing overly restrictive guidelines at the initial stages when there is an unclear need for such structures. This approach is typical for peer production projects, which often commence with fewer rules and gradually strengthen them based on the evolving needs for governance and moderation as the community expands, as observed for example in the case of Wikipedia (Loubser, 2010; Shaw & Hill, 2014). However, learning and communal validation are facilitated by transparency through visibility of all content and edit history by MediaWiki, the possibility to contribute with small edits, reuse of structures from existing pages, and the ability to participate in discussions on talk pages. Moreover, some tutorials and reusable templates for pages of the main categories have been developed to support newcomers and suggest some initial formatting standards.

Wikis have already been utilized in other citizen science or health contexts. For example, MediaWiki has been employed to enrich an historical dictionary with metadata and interpretations provided by students (Opryshko & Nazarovets, 2021), or for creating a knowledge base about cluster headaches (*CK-Wissen:Portal*, n.d.). Furthermore, the bottom-up citizen science platform Public Lab, as discussed in chapter 2.4.2, utilizes a custom website

with wiki functionality and other related artifacts. These artifacts include pages that are not publicly editable but can be replicated and linked to the original page, as well as resources dedicated to introducing issues in order to receive help from more experienced community members (Breen et al., 2019). While there is currently a lack of studies examining the usage and impact of wikis in citizen science, the existing use cases of wikis suggest significant potential for wikis in personal science. In particular, the implementation of wiki functionality in the Public Lab platform is noteworthy, as it serves as a means to help individuals learn how to address their own questions using empirical methods, with a focus on environmental justice.

Another question that arose during the prototyping phases was **how our approach differed from and complements existing approaches**, to determine whether it fills a relevant gap. This involved exploring the alternatives available to potential contributors for sharing their experiences and accessing information about personal science practice. As mentioned earlier, online and offline community meetings are a popular means for community members to share their experiences and receive feedback. However, not everyone has time or desire to participate in meetings, and meeting notes, if available, are not the most accessible form to consume information and may require further curation into another format.

The social media platform Reddit hosts subreddits dedicated to Quantified Self¹⁸ and related topics like data visualization¹⁹. With 12.5 thousand members in the former, and even 19.8 million in the latter case as of July 2023, Reddit provides a fast way to obtain feedback and answers to questions. However, it operates on a publication time and likes-based ordering system, resembling more of a continuous stream of new information rather than an interlinked community knowledge resource. Moreover, users on Reddit often share links in their responses, and the Personal Science Wiki could serve as a valuable website that can be linked in replies on Reddit. Thus, the wiki could complement these subreddits without being in direct competition. Similarly, the Quantified Self forum and Facebook groups attract large numbers of members and contributors, and serve as valuable resources. Similar to reddit, their content presentation follows a feed structure with new posts appearing on top, often containing external links. The Personal Science Wiki might thus play a complementary role for these platforms, too.

Another platform that explicitly focuses on the exchange of experiences of patients is PatientsLikeMe (Wicks et al., 2010). While there are certain similarities with the Personal Science Wiki, such as patients sharing their treatment and symptom experiences with peers, there are also some important differences: PatientsLikeMe adopts a survey-based approach

¹⁸ <https://www.reddit.com/r/QuantifiedSelf/>, last accessed 31.07.2023

¹⁹ <https://www.reddit.com/r/dataisbeautiful/>, last accessed 31.07.2023

to offer users an overview of descriptive statistics with regards to their condition, and connecting individual patients with similar conditions and treatments with one another. On the other hand, the personal science wiki centers on methods for self-observation and experimentation with personal data, enabling individuals to engage in personal science practices and use empirical methods to address their personal questions and challenges.

There have also been prior attempts at creating curated lists of methods and tools for personal science, e.g. "Awesome Quantified Self" on Github²⁰. A challenge with these approaches is that they tend to face maintenance issues, since technologies outdate quickly, and maintenance is usually dependent on the continued involvement of a few individuals. The latter is also true for personal blogs.

In general, sharing detailed projects, especially with comprehensive explanations of methods and iterations, requires significant effort, and people need incentives to undertake this task. Addressing these incentive factors is an essential topic that future work should explore.

To summarize, compared to other existing platforms where personal science practitioners can share their experiences and support one another, the personal science wiki can play the role of a shared knowledge repository with some distinguishing factors. Its key advantages include that it can avoid maintenance bottlenecks due to being editable by anyone. In contrast to platforms relying on time-based posts by individual users, wiki pages can be collaboratively developed over time. It is organized using semantic links and a menu structure aiming at guiding users to relevant information. Wiki pages can be linked on other platforms, with the potential to make them a valuable complement to existing platforms without directly competing with them.

When it comes to **determining whether the selected approach, the Personal Science Wiki, effectively addresses the identified problems**, there is some uncertainty at this stage. This uncertainty arises because we are dealing with what is referred to as a "wicked" design problem (Rittel & Webber, 1973). Such problems lack clear boundaries, definitive tests, or right and wrong solutions. As a result, obtaining a definite answer at this stage is challenging. Obtaining a definite answer would require demonstrating that the use of the wiki led to community expansion, indicated by an increased adoption of personal science practice among a larger number of individuals. This would require a substantial amount of curated information to be added to the wiki, resulting from large-scale community adoption. This startup problem is not unique to the personal science wiki; it is a common challenge in peer production projects. Such projects require buy-in from a sufficient number of contributors to generate content. At

²⁰ <https://github.com/woop/awesome-quantified-self>, last accessed 31.07.2023

the same time, having enough content is crucial to attracting and retaining these contributors (Foote et al., 2023).

The active engagement of a core group of community members, with some making extensive contributions to document projects and curate information about general tracking methods and topics, is an indicator of the general usability of the solution for its intended purpose. Furthermore, frequent sharing of wiki pages and discussions about it during community meetings, along with discussions about its potential to serve as a point of reference to be linked from other platforms, indicates existing use cases and interest within the community that extend beyond the visible edits directly made on the wiki.

From a different perspective, the presence of an infrastructure for a community knowledge base, including feedback and discussions from its active usage, can be seen as another iteration in the design process, because it has opened the door for a more comprehensive and tangible exploration of the problem space. The accumulation of hundreds of project pages from Show and Tell talks about personal science projects, alongside pages addressing tracking topics, methods, and tools, all interconnected through semantic links and integrated within a category structure, constitutes an unparalleled compilation of community knowledge. Consequently, new questions arise regarding the optimal representation of knowledge structures relevant to personal science practice within the wiki's category system, including the expectations and requirements of users regarding these structures. During the usage of the wiki, instances have surfaced where pages do not align well with the category system, lack of naming conventions have posed challenges, and the "Topics" category has evolved into an unstructured catch-all for pages that do not fit in other categories. Formal testing of the functionality of standard user flows for information retrieval has yet to be conducted. Furthermore, feedback has so far only been gathered from core members and active users of the wiki, lacking perspectives from non-users or individuals new to personal science practice. These issues have motivated the planning of a more comprehensive evaluation of the wiki, as well as an empirical study of the underlying structures of personal science knowledge, as detailed in the subsequent chapter.

Take Home Messages

- Design thinking was applied to develop a solution approach for general problem statements in the personal science community ("*the personal science community does not scale up*", "*everybody tends to start from scratch*")
- As a result of the user research process, "scaling" in terms of "more people practicing personal science" was prioritized

- In terms of barriers, difficulties in systematically accessing community knowledge were identified and prioritized.
- Barrier: Accessing community knowledge to build skills and remove entry barriers
- The “Personal Science Wiki” was developed as a work-in-progress peer production infrastructure for community knowledge management.
- The wiki was then published and regularly improved based on user feedback collected in self-research chats and on dedicated wiki pages during a period of about a year, before moving to formal user testing.

4. Usability of the Wiki Approach and Mental Models of Personal Science Knowledge

In the last chapter, we explored and prioritized issues in the personal science community that might impose barriers to the adoption of the practice, and prototyped solutions to address these with a peer production approach. Several iterations of user research, design, and discussions led to the development of the Personal Science Wiki (<https://wiki.openhumans.org>). During the usage of the wiki, it became apparent that not all content aligned well with the proposed category structure, as outlined in chapter 3. Furthermore, there had not been formal tests of the intended user flows, and the feedback received was limited to core community members, while the aim was to make personal science practice also more accessible to a wider audience.

Thus, this chapter will focus on exploring information architectures for personal science knowledge, and formally test the usability of the wiki with a broader target audience. The objective is to gain insights into the effectiveness of the specific implemented solution, as well as to gather knowledge about personal science in a more general context.

4.1 Background: Usability and Mental Models

As the term implies, knowledge management systems are designed to “manage” existing knowledge, typically with the aim of facilitating knowledge transfer between individuals or within organizations. They are often used as a means to enhance collaboration and innovation (An et al., 2014). To ensure the efficiency of these systems, their information architectures should accurately represent the internal mental representations that users have about the given domain (Davidson & Blackman, 2005). These mental representations are often referred to as “mental models.”

“Mental models” is a term originating from psychology (Craik, 1943), which has been defined as “personal, internal representations of external reality that people use to interact with the world around them”. These cognitive structures are created by each individual in function of their experiences, and form a basis for decision-making and reasoning in everyday life (Jones et al., 2011). The concept is also thought of as a sort of “naive theory”: Based on what they already know, individuals form causal explanations of complex systems they encounter through analogical thinking (Collins & Gentner, 1987). Mental models are not necessarily accurate, generally limited, unique to each person, and they are prone to evolve over time with new experiences or learnings (Jones et al., 2011). Since in most cases knowledge

management systems are thought to be used by several people, the knowledge structures need to represent the mental models of all stakeholders for the system to be usable (Davidson & Blackman, 2005). In situations where people regularly exchange knowledge, for example at the workplace, shared mental models are usually already in place. Designers of knowledge management infrastructures must pay attention to recognizing and transferring the mental models in use to the new technical infrastructure, without imposing their own view of the system (ibid.).

For the Personal Science Wiki, categories similar to those in use in the archive of Quantified Self Show and Tell talks were employed to create an initial structure for the knowledge management system. The information gathered in the wiki up to this point forms a novel knowledge base, offering an opportunity to explore alternative ways to organize this information, potentially better representing users' mental models.

A mismatch between system structure and users' mental models of that structure can be a contributing factor for usability issues of a knowledge management system (J. M. Carroll & Reitman Olson, 1988). "Usability" has been defined as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2018). In this context, "effectiveness" refers to the "accuracy and completeness with which users achieve specified goals", i.e. if they successfully complete intended tasks. "Efficiency" relates to resources needed for task-completion, for example, in terms of time or effort. "Satisfaction" is a more loosely defined concept, encompassing emotional, cognitive, or physical responses from users resulting from system use, as well as judgments as to whether the product responds to an actual need and is thus considered useful (Jeng, 2005). The satisfaction dimension transitions into the wider concept of "user experience". This concept relates to the spectrum of users' responses before and after usage, such as emotions, beliefs, or behaviors (ISO, 2018), and includes dimensions such as affect, appeal, flow, motivation, or enchantment (Hedegaard & Simonsen, 2013). Sometimes, other dimensions are included under the concept of usability, like "learnability" – the learning curve for new and more experienced users, or "memorability" – how well information learned through or about the product is retained (Hedegaard & Simonsen, 2013). Usability issues can stem from a wide range of causes, and good usability is a fundamental part of the success of a product. Thus, usability evaluations are fundamental parts of user-centered design processes, to ensure that products align with user needs, are effective and usable, and do not entail negative consequences for the users (ISO, 1999).

In testing the usability of the Personal Science Wiki, we aim to investigate whether both new and existing users can effectively, efficiently, and satisfactorily use the system in the intended

way. This involves not only finding pieces of information that are present on the wiki but also assessing the users' perception of the usefulness and completeness of the information presented in its current format. Therefore, through usability testing of the wiki and exploring mental models, our objective is twofold. Firstly, we aim to gain insights into the specific implemented solution, identifying areas for potential improvement and enhancing its usability. Secondly, we seek to gain deeper insights into the requirements for community knowledge management in the context of Personal Science more broadly.

4.2 Methods

To evaluate the Personal Science Wiki infrastructure and learn about mental models in self-research, a mixed-method online study was planned. It included a usability test, card sorting task, and short interview. The project was examined by the Institutional Review Board of the French National Institute of Health and Medical Research (Inserm, IRB00003888) and was approved on the 10th January 2023 (see supplementary materials for full documentation including submitted materials and approval).

4.2.1 Usability Test

A usability test protocol was established to assess the usability of the developed solution. Usability testing involves evaluating a product, usually a software application, by people representative of typical users groups. The objective is to identify issues that may impact usability. Typically, participants are asked to perform common tasks with the product, while a study lead observes their actions and listens to their comments (usability.gov, n.d.b). Evaluation criteria depend on the task, but usually include metrics like task-completion rates, time to complete task, as well as types and number of errors (Bastien, 2010). For qualitative usability studies, a rule of thumb is to recruit five participants for each iteration of the test to optimize the cost-benefit ratio (Nielsen, 2012).

Since there is not one dominant, straightforward workflow to successfully use the Personal Science Wiki, a list of intended common use-cases was brainstormed and discussed in a team meeting. From this list, four information-seeking tasks were incorporated into the study protocol, including specific pieces of information covering common self-tracking topics, and making use of all main categories, as well as the templates created for the semantic linking of pages. Two more open tasks were added, in which participants were asked to explore the wiki freely with the aim to plan self-research projects, as well as more general feedback questions. The whole list of tasks is shown in Table 4.1.

Task No.	Task / Question	Task Type
1	"Please quickly inspect the home page. What do you expect to find on this wiki? Who do you think might use this wiki, and what for?"	First impression
2	"Please look for a device that records sleep data."	Specific search
3	"Please look for projects other people have done related to sleep tracking."	
4	"Please look for people who have worked on activity tracking."	
5	"Please look for projects that use a Fitbit device."	
6	"Imagine you would like to improve your sleep, and stumbled across this wiki. Please explore the wiki in order to see if and how it could help you to implement your project."	Open search
7	"Based on experience/interests of participant: Imagine you would like to do a project about condition/topic X and you stumbled across this wiki. How would you try to find information that might be useful for you?"	

Table 4.1 Tasks of the usability tests

The usability test was held online, with one participant at a time, and recorded via Google Meet²¹ video conferencing software from an institutional Google Suite²² account. Participants were asked to open the Personal Science Wiki homepage, and share their screen. The PhD researcher was present and moderated the whole process, and the participants were asked to share their thoughts aloud.

The dataset resulting from this study are transcripts obtained from the video recordings. The latter were automatically transcribed using the browser extension tactiq²³, manually corrected, and anonymized. Video recordings were destroyed after transcription.

For each participant, results were summarized by task, including information on task completion, ease of completion, potential difficulties, and additional observations or comments.

From these summaries, a list of issues was derived (see Appendix A.9.1.), and priorities were assigned in a team meeting, and the wiki was adapted accordingly. In the following, the second iteration of usability tests was done using the same study and analysis protocol as before, but with the improved version of the wiki. Again, issues were derived and discussed in a team meeting (see Appendix A.9.2.). Finally, a detailed comparison of the results for each task in both test iterations was created (see Appendix A.9.3.).

²¹ <https://meet.google.com/>, last accessed 03.08.2023

²² <https://workspace.google.com/>, last accessed 03.08.2023

²³ <https://tactiq.io/>, last accessed on 01.06.2023

4.2.2 Card Sorting

The second part of the study involved a card sorting task designed to investigate the mental models that people hold regarding information related to personal science. Card sorting is a user research method commonly used to create or test information architectures that underlie menu structures of websites (Capra, 2005). Different types of card sorting exist, and the variant used here is *open* card sorting (Katsanos et al., 2019). In open card sorting, participants are provided with “cards”, which can be virtual or on paper, that contain concepts, usually titles of websites. They are then asked to group these cards into clusters that make sense to them, and assign a label to each cluster. From these clusters, interaction designers can learn which relationships users see between content, and which organizational structures they use. This can aid in creating navigation structures that enhance the discoverability of content. This technique is a method to directly elicit mental models, and can be applied beyond information architectures to understand how individuals organize and make sense of information (Jones et al., 2011).

As a preliminary step, a subset of page titles from the Personal Science Wiki was chosen to serve as cards for the task. The selection process aimed to include cards representative of the content, covering the main existing categories. Additionally, pages that posed challenges in terms of sorting within the current structure were also included. Different sources provide varying recommendations for the number of cards to be used, ranging from 30 to 40 (usability.gov, n.d.a), 40 to 80 (Sherwin, 2018), and even 30 to 100 cards (Spencer & Garrett, 2009). Balancing the need for a representative sample and avoiding participant fatigue, a preselection of 60 cards was created by the PhD researcher. This selection was further discussed and refined in collaboration with the team. The task was tested in an informal test-run with a volunteer, which led to the removal of cards for reasons of time and complexity. Ultimately, a final list of 45 cards was determined, each card containing the title of a wiki page along with a brief description. Table 4.2. Provides an exemplary selection of cards, while the complete list of cards can be found in Appendix A.8.

Card	Label
A Decade of Tracking Headaches	A Decade Of Tracking Headaches is a Show & Tell talk by Stephen Maher [...].The talk was given on 2018/09/22 and is about Pills intake, Sleep, and Stress.
Activity tracking	Activity tracking typically describes the act of tracking physical activity[1] and is frequently measured through metrics such as steps, calories burned, distance walked/run, heart rate and [...]
Autoethnography using one button	This page provides a step-by-step guide on how one can use a one-

tracker and Jupyter notebook	button tracker such as the Puck.js to do an autoethnography that combines qualitative and quantitative data.
Bangle.js	The Bangle.js[1] is the name of a series of open source smartwatches that are made by Espruino under the leadership by Gordon Williams, who also designed the Puck.js open source hardware that can[...]
Blood glucose tracking	Blood glucose tracking involves methods and tools to measure blood glucose levels, commonly in the context of diabetes but also by non-diabetic users.

Table 4.2 A selection of cards used for the card sorting exercise

Data collection was done using kardSort²⁴, a browser-based card sorting study software. Just like the usability test, the sessions were held and recorded with Google Meet video conferencing software. Participants were asked to share their screen, and vocalize their thoughts during the task. The PhD researcher served as the session moderator, remaining muted during the task itself, but available to address any potential questions that arose. A screenshot of a card sorting session in progress is displayed in Figure 4.1. Participants were informed that they had the freedom to create as many categories as they desired and could allocate as many cards as they liked to each category (with a minimum of one card). It was emphasized that there were no right or wrong solutions. However, participants were encouraged to identify an overarching concept for each cluster and to refrain from using generic labels like "other" or "unclear".

²⁴ <https://kardsort.com/>, last accessed on 01.06.2023

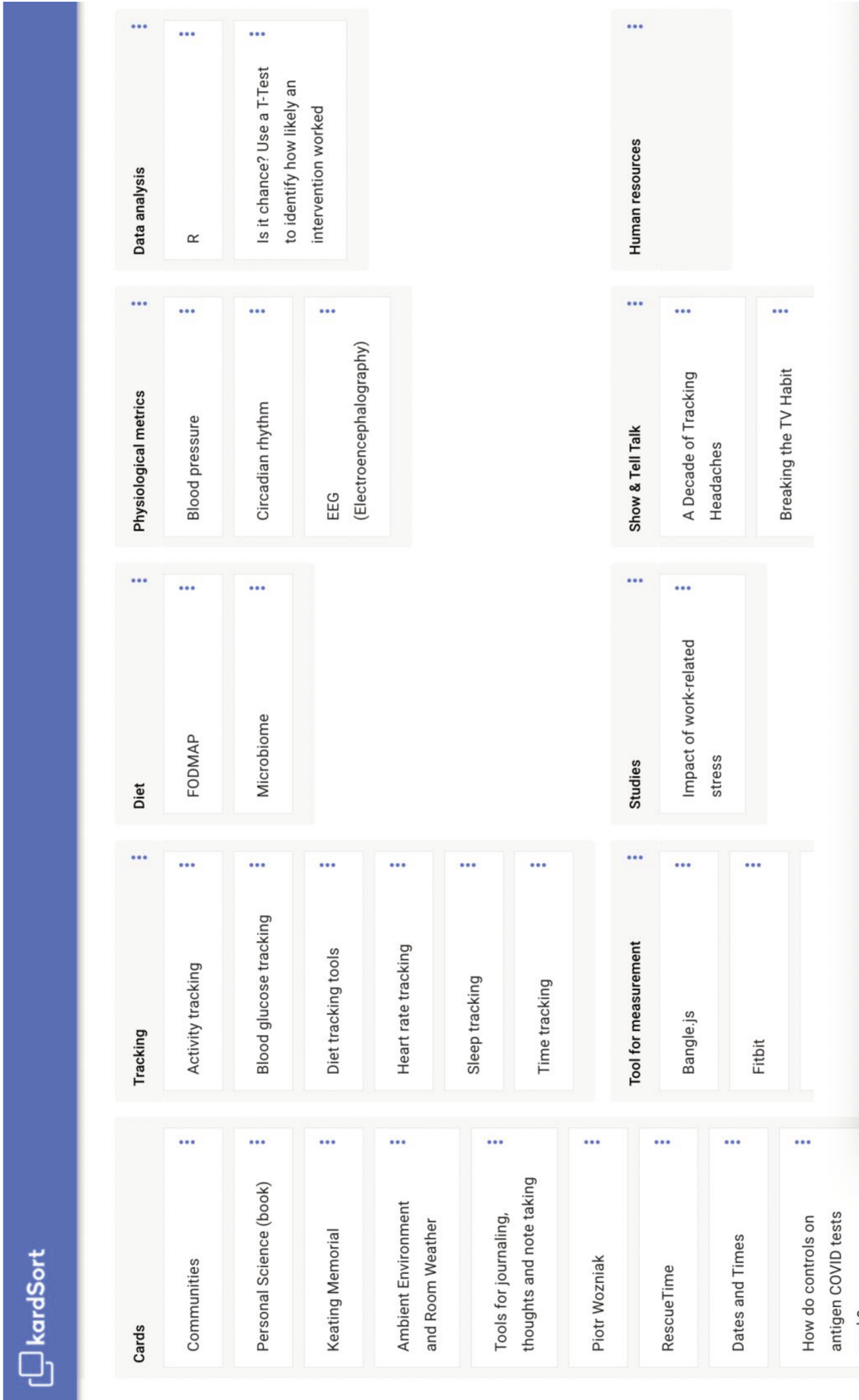


Figure 4.1 Screenshot of an exemplary card sorting session. The left column (“Cards”) contains all cards that have not yet been sorted. All other columns are categories created and filled by the participant

Card sorting data can be analyzed using both quantitative and qualitative approaches, each offering distinct advantages and disadvantages. In quantitative analysis, algorithms such as hierarchical clustering, k-means clustering, factor analysis, or multidimensional scaling are employed to statistically determine a common, or average structure from the results of all participants (Katsanos et al., 2019). These methods offer consistency and enable a rapid and comprehensive overview, even for large datasets with numerous participants (Wood & Wood, 2008). However, a drawback is that they do not provide insights on reasons behind clusterings, and that they do not account for different organizational schemes used and individual variations (Spencer & Garrett, 2009).

On the other hand, exploratory qualitative analysis can be used either independently or to complement quantitative results. This approach involves visually examining (“eyeballing”) user-generated groupings, analyzing user comments, and studying schemes used by individual participants (Spencer & Garrett, 2009). By doing so, qualitative analysis can provide deeper insights into the reasoning and motivations behind participants’ categorization decisions. To harness the benefits of both approaches, the data from this card sorting exercise was analyzed both quantitatively and qualitatively.

For the quantitative analysis, tabular outputs from the kardSort software were downloaded in .csv format (see supplementary materials). Hierarchical cluster analysis with average linkage as the agglomerative clustering routine was selected as the quantitative analysis technique. This approach is commonly used and is believed to yield balanced, easily interpretable clusters (Jarman, 2020; Katsanos et al., 2019). In this analysis the similarity of each card to each other card is calculated in pairwise comparison, gradually building clusters until all cards are connected. The main output is a tree diagram, also called dendrogram (Wood & Wood, 2008). The analysis was done using the programming language Python, making use of existing packages like SciPy (Virtanen et al., 2020) and pandas (The Pandas Development Team, 2023). For the calculation of the distance values and extraction of labels for clusters of cards, custom functions were created. The whole workflow was summarized and published as the open source python package “cardsort”²⁵, which is currently under review at pyOpenSci²⁶. For more information on the cardsort package, see Results section 4.3.6.

For the qualitative analysis, similar to the approach used in the usability tests, transcripts of the sessions were automatically generated with the tactiq browser extension, and

²⁵ <https://github.com/katoss/cardsort>, last accessed on 01.06.2023

²⁶ <https://www.pyopensci.org/>, last accessed on 01.06.2023

subsequently manually corrected and anonymized by the PhD researcher. The cleaned transcripts were then manually tagged using the software taguette²⁷. Tags were created for each card, for categories of feedback, and for user-generated cluster labels, if any comments on them were provided by the respective participant. The complete list of tagged excerpts can be found in the supplementary materials.

4.3 Results

4.3.1 Description of Study and Sample

The whole study took place from 23rd January to 24th March 2023, including the first iteration of usability tests from 23rd January to 9th February, and the second iteration from 2nd March to 24th March. For the recruitment, the aim was to find participants interested in personal science or self-tracking in the larger sense. Lack of prior involvement with the community and extensive tracking experience were no exclusion criteria, since the aim of the study was to also test and explore usability, mental models, barriers and needs of potential new users and future community members. Calls for participation were distributed via the Quantified Self forum, the Learning Planet Institute, direct invitation via the slack of Open Humans, email, and snowball sampling.

21 participants were recruited in total, of which 12 identified as male and nine as female. The average age was 34.90 years (SD = 11.36). As the highest completed level of education, six participants reported holding a PhD, eight a Master degree, and 6 had finished High School. Regarding the professional background, participants were almost exclusively from engineering or research (19 of 21 participants), predominantly from the fields of computer science (nine participants) and biology (four participants). Four participants mentioned professional experience in the health domain. 95% of participants resided in the global north: 14 reported living in Europe, five in Northern America, one in Eastern Asia, and one in Southern Asia.

Two individuals reported having none or almost no self-tracking experience, 11 participants tracked casually, either occasionally or daily one or more variables with commercially available tools. Eight participants reported being intensive trackers, i.e. having done self-research projects over a span of several years. Seven of the latter reported active involvement with the personal science community (Quantified Self and/or Open Humans), three considered themselves passively involved, having attended a few meetings or consulted the Quantified

²⁷ <https://www.taguette.org/>, last accessed on 01.06.2023

Self forum without active participation. 11 participants had never been involved in personal science community activities. However, three individuals from this group were or are in contact with other communities, one on a weight monitoring forum, one in Facebook groups regarding mental health, and one was working in academic research in the health monitoring domain. The most frequently mentioned area of interest in self-tracking was general fitness (nine participants), including physical activity, heart rate and blood oxygen tracking. Six people tracked variables related to mental health, five were interested in sleep, three each in diet and productivity, two each in chronic conditions and meta research on personal science, and one each in menstrual health, location, and microbiome tracking. Multiple answers were possible, and 13 participants reported tracking multiple variables.

Motivations and goals for tracking included monitoring, identifying patterns, pursuing specific goals such as weight loss, meta-interests in self-tracking or personal science, interest in trying interventions and exploring possibilities of technology to impact one's own health.

Participants were also asked about their familiarity with the Personal Science Wiki, and their experience with wikis in general. 14 reported having never used the Personal Science Wiki, four had browsed it, and three had edited some or even many pages. All participants had experience with wikis in general, primarily Wikipedia. The majority (16) had already edited wiki pages or were involved in setting up wiki infrastructures.

To gain insights into participants' experiences and challenges with existing information sources, they were prompted to share their recent experiences and levels of satisfaction with information searches and resources related to personal science. Participants reported seeking information for various purposes, such as deciding on which tracking devices or software to purchase or download, learning how to use them, and gaining a general understanding of tracking topics and how to track specific variables. As information sources, participants mentioned relying on general online searches, scientific articles, blog articles, podcasts, Open Humans or Quantified Self forums, social news aggregation platforms like Reddit, seeking advice from friends, and, more recently, turning to artificial intelligence chatbots like ChatGPT²⁸ or Bing Chat²⁹ for information on personal science-related topics.

Seven individuals reported being overall quite or very satisfied with the resources. Points of criticism included lack of trustworthy resources, either because of advertisement (three mentions), lack of unbiased information or systematic analyses backed up by research (two mentions), and conflicting opinions and reviews (two mentions). Three people mentioned not

²⁸ <https://chat.openai.com/>, last accessed 03.08.2023

²⁹ <https://www.microsoft.com/en-us/edge/features/bing-chat>, last accessed 03.08.2023

always finding practical use info about all topics. Finally, four participants identified a lack of information about personal science or self-research projects beyond simple monitoring, including missing information about how to formulate research questions, which interventions can address these questions, a missing link between reports of personal experiences and the methods and protocols these people used, or lack of information about the existence of this practice at large.

4.3.2 First Usability Test Iteration

Five individuals from the sample described above participated in the first usability test iteration, all of them directly after having completed the card sorting task. The mean age of this subsample was 34.6 years (SD=9.2, range = 27 – 50 years), and 40% of the participants were female. One person had experience both with the personal science community and with the Personal Science Wiki. Four participants had experience consulting and editing wikis in general, while one participant (P3) had experience in consulting wikis but not in editing them.

The usability test comprised one introductory question inquiring about participants' expectations regarding the wiki, followed by four tasks aimed at locating specific pieces of information. Two additional open exploratory tasks were included, and participants were given an opportunity to provide feedback and ask questions. The specific tasks are listed in the Methods section in Table 4.1.

Upon their **initial impression** of the homepage, participants who had never used the wiki before anticipated finding an introduction to personal science, its origins, and its potential applications. They expected information about self-tracking organized around the main categories. One participant noticed a link to community meetings (P12), while another expressed a desire to find manuals for tools:

“I guess I would expect to find information about the tools that people use [...]. At least general information. I don't know if I would expect to find manuals, I don't think so. But it would be nice if there were some.” (P7)

Regarding the presumed target audience, participants listed people interested in personal science or in their own health. One participant mentioned the openness to user-contributions (P8), as known from Wikipedia.

Not all of the **specific search tasks** (tasks 2 – 5, see Table 4.1.) were successfully completed by all participants: While all participants were able to find devices that track sleep data, only two out of five located projects related to sleep. Three out of five found people related to activity tracking, and four out of five found projects using Fitbit devices, without hints given by the study lead. In cases where participants successfully completed the tasks, some took additional time due to exploring various paths or experiencing moments of hesitation.

Most of the time, participants used the search bar to access pages relevant to the keywords mentioned in the tasks; in some cases they also utilized the category structure. Reasons for incomplete or delayed task completion included a lack of keywords related to the task, such as “sleep”, on the homepage, leading to confusion of where to start looking for the information. Furthermore, participants obtained unspecific search results for complex search terms, such as “projects sleep tracking” (P7). Another issue that caused difficulties for most participants in at least one task was that they did not scroll down to find the section “Linked content on this wiki” at the bottom of the page. Two participants expressed surprise about finding content below the “Reference” section, as they were accustomed to conventions learned from Wikipedia:

“I’m a bit used to that after references on the normal Wikipedia there is nothing, I don’t look further down.” (P1)

The **open search tasks** concerning a sleep tracking project and an optional other project on another topic of interest (tasks 6 – 7, see Table 4.1.) do not have a clearly defined goal, since information needs and expectations vary for each individual. Therefore, they cannot simply be assessed based on task completion like the prior tasks. Instead, these tasks aim to explore the paths users take to look for information, identify the information they expect or desire to find, and discover potential missing content.

For the sleep project (task 6), all participants consulted the “Sleep tracking” topic page. Two of them attempted to find more specific information by searching for the term “improving” either on the sleep tracking page or in the search bar. All participants expressed a wish to find information about tools for sleep tracking and how to use these tools. Additionally, two participants showed interest in exploring existing project pages related to sleep on the wiki (P3, P8). Wishes for more information about factors that impact sleep, an overview or bigger picture about sleep tracking, and manuals on how to use tools were each expressed once (P7). With regards to the latter point, the participant elaborated that they would appreciate information about the methods used in projects extracted from video recordings of the respective talks, suggesting a format similar to “wiki-how”. Furthermore, they expressed a desire for support on data analysis.

The task was repeated with a topic of personal interest by four out of five participants (task 7). These subjects chosen by the participants comprised the Apple Watch, blood glucose or diabetes, note-taking and diaries, and diet tracking. Reasons for participants to choose these topics included that they were already tracking, having a research interest in, using a tool, or having a condition related to the topic.

Regarding the Apple Watch (P1), the participant found a page on the topic, and expressed positive surprise to find an overview of sensors in different models and information about data export that was new to them. Missing information about a new model motivated that participant to edit the page accordingly after the study.

The participant interested in blood glucose tracking (P3) discovered a page about the device they were using (FreeStyle Libre). They noticed information about a new version of the device that they had not been aware of previously. The participant also made a remark about practical information that was missing, regarding how to properly apply and remove the sensor, as well as details on obtaining a replacement sensor for free in different countries. All of this information had been challenging for the participant to find on their own in the past.

The participant who was interested in note taking and diaries (P8) did not find the tool they use to digitize handwritten notes (ReMarkable). However, this served as motivation for them to consider creating that page later on. Additionally, they expressed a desire to find more information about how to quantify written text.

Lastly, the participant with an interest in diet tracking (P12) found the overview of tools on the diet tracking page to be helpful, particularly the information about the app they were using. Moreover, they noticed a project page with a title related to salt consumption, a topic they had recently developed an interest in, and expressed the intention to watch the video associated with this project.

From the usability tests, identified issues were compiled into a comprehensive list, categorized, and prioritized through a team discussion. The priority assigned to each issue was based on its perceived impact on usability and the feasibility of potential solutions. The list of issues can be found in Appendix A.9.1. A detailed summary of task completion and user journeys for each task can be found in Appendix A.9.3.

4.3.3 Changes based on Results

After the first usability test iteration, we addressed high-priority issues that were identified as impacting the usability of basic functionality and were feasible to change (see Appendix

A.9.1.). These issues primarily related to the wiki's homepage and the discoverability of linked content. The following are the most significant changes we implemented:

Regarding the **homepage**, the study revealed that users were not consistently directed to the category overview pages, leading them to miss a crucial opportunity to discover pages based on their category tags. Consequently, we rearranged the interface to prominently display the links to the main categories (Topics, Tools, Projects, People). Additionally, we removed the lists showing example pages, since some participants mistakenly believed they represented all content available. Moreover, we added content that suggested active community life, i.e. an automatically updating calendar of upcoming community events, encouraging users to participate, as well as a featured article. Figure 4.2. shows a screenshot of the updated homepage. For comparison, a screenshot of the former user interface can be found in Figure 3.4. in section 3.3.4.

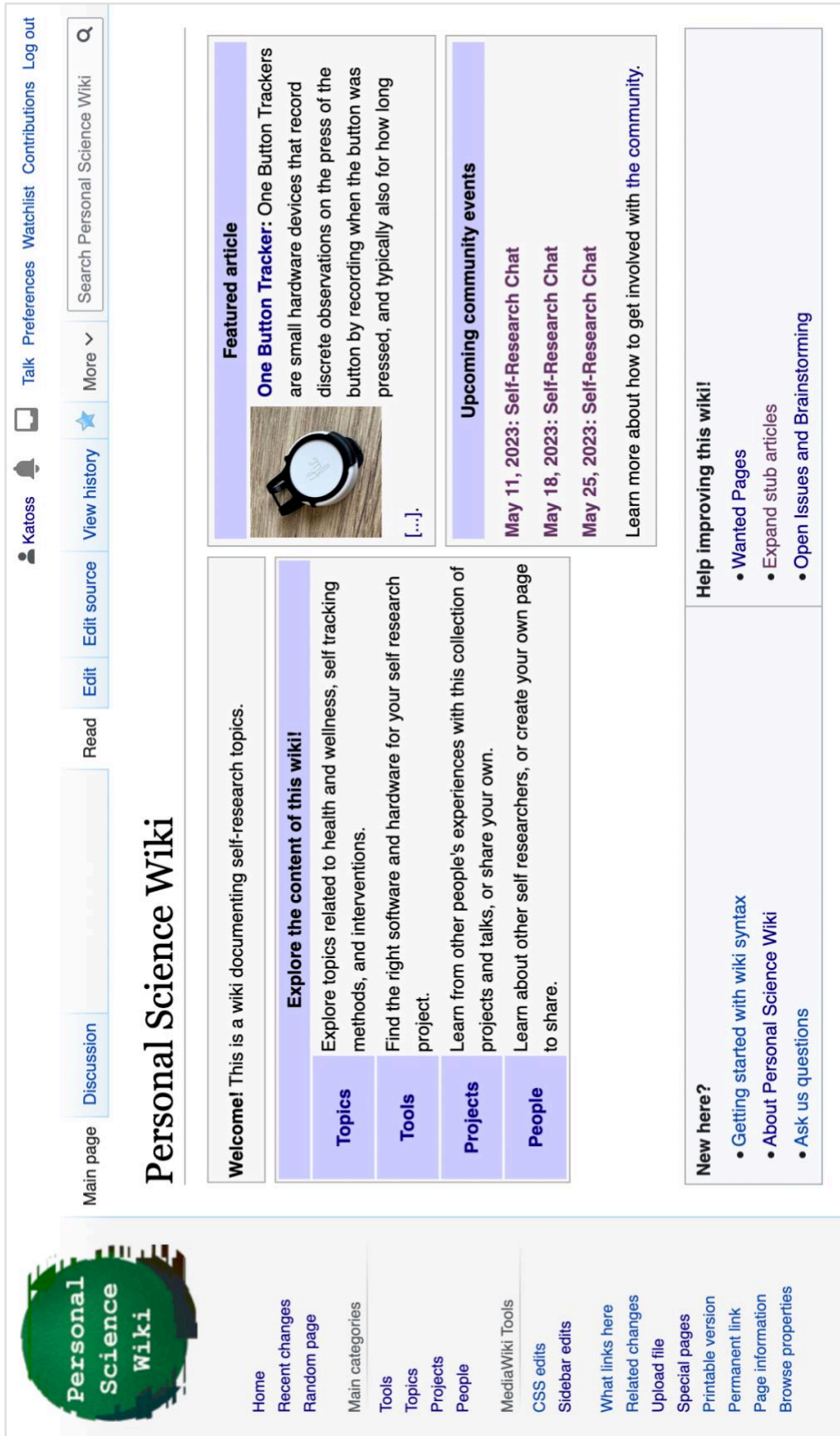


Figure 4.2 Screenshot of the updated user interface of the Personal Science Wiki homepage after the first iteration of usability tests

Regarding the **discoverability of content**, the usability test revealed that most participants were unsure how the content was aggregated and how to access these aggregations. To address this issue, several changes were implemented: First, since users tended to not scroll to the bottom of the page where the “linked content” section was placed, this section was removed and the content placed on top of the page, within the “infobox” template. Additionally, because several participants reported difficulties reading the lists of linked projects, especially in the case of several dozen linked pages, the display was adapted to only show the count of the pages instead of the page titles themselves. Figure 4.3. shows an example of an updated page of the category “Tools”. The section “Linked pages on this wiki” has been moved into the “Tool Infobox” (top right), and shows a link with the count of linked pages for each linked category instead of a list of these pages. For comparison, a former version can be consulted in Figure 3.5. in chapter 3.3.4.

Page [Discussion](#)
Read [Edit](#) [Edit source](#) [View history](#)
More [Search Personal Science Wiki](#)

Oura Ring

The **Oura Ring** is a wearable that is worn on a finger as a ring which tracks sleep, activity and **readiness**. Since 2013 there have been three different versions of the ring, with the latest version (v3) being launched in November 2021. At the same time they changed their business model, requiring a monthly subscription for access to all metrics recorded.

While the sensor set of the rings have changed over the versions, generally they contain an accelerometer, a temperature sensor as well as an optical heart rate sensor. From these sensors the Oura calculates the following metrics:

Contents [hide]

- 1 Differences between models
- 2 Metrics provided
 - 2.1 Body temperature metrics
 - 2.1.1 Use for menstrual cycle tracking
- 3 Exporting data
- 4 Subscription
- 5 Project using Oura Ring
- 6 References

Differences between models [edit | edit source]


Model	Sleep tracking	Activity tracking	Readiness tracking	Heart rate during sleep	Heart rate during day	Body temperature	Menstrual cycle tracking	Blood oxygen tracking

Tool Infobox [?]

HRV (Heart Rate Variability), Activity tracking, rate tracking, Body temperature tracking, Heart rate tracking

Related topics [Sleep tracking](#), [Body temperature tracking](#), [Heart rate tracking](#)

Linked pages on this wiki [Projects \(4\)](#), [People \(2\)](#)



A generation 3 Oura Ring, showing some of the sensors on the inside of the ring

Figure 4.3 Screenshot of the updated “Oura Ring” page, used as an example for a Tool page

Secondly, an important workflow the wiki aims to enable is finding content, like projects or tools, related to a topic of interest, such as sleep or activity. The main entry point for this in the first version of the wiki was to consult the respective topic page. This page contained these aggregations of linked content in the “Linked content on this wiki” section and in the infobox. However, not all participants found this user flow to be obvious from the start. Apart from that, most participants resorted to the search function to find the topic pages. While this approach generally led to successful discovery if the right keywords were used, alternative paths via the category system, which were intended to support content discovery, were less utilized. Additionally, when the search did not yield relevant results, participants expressed frustration and uncertainty about where to look next. In response, efforts were made to improve the information scent provided by the category system. Alongside highlighting the top-level categories on the homepage, subcategories were introduced to offer an alternative discovery path alongside the search results. This change aimed to enhance content discovery and user experience on the wiki.

The creation of subcategories was primarily based on the semantic properties of the existing pages, aiming to establish balanced subcategories that effectively represented and structured the existing content. This involved counting the occurrence of page properties for each category and grouping similar properties together. The new subcategories were then programmatically assigned to the pages using the MediaWiki API. Additionally, subcategories were influenced by feedback from the usability tests and early qualitative analysis of the results from card sorting tests that had been conducted. This approach resulted in the creation of subcategories such as "Data analysis" or "Interventions," which represented categorizations that had not existed as properties before. Table 4.3 provides a list of all subcategories for each category.

Top-level category	Subcategories
Topics	Blood testing and tracking tools; Body temperature tracking tools; Data analysis tools; Diet tracking tools; Fitness and heart rate tracking tools; Hardware; Mental health, journaling and self-report tools; Open source tools; Productivity, learning, and cognitive abilities tools; Sleep tracking tools; Software
Tools	Data analysis; Disease, pain and chronic condition; Discussions; Experiment design; Interventions; Personal Science Community; Things to track
Projects	Body measurement projects; Cognition and learning projects; Diet, digestion and weight loss projects; Disease, pain and chronic condition projects; Environment projects; Fitness and physical activity projects; Habits projects; Heart rate and cardiovascular health projects; How to's; Menstrual health, fertility and pregnancy projects; Mental health projects; Productivity projects; Sleep projects; Show and Tell (<i>note: category existed before the usability test</i>); Social life and social media projects
People	-

Table 4.3 Subcategories created on the wiki after the first iteration of usability tests

4.3.4 Second Usability Test Iteration

After implementing the changes described above, a second iteration of usability tests was conducted. The study protocol was similar to that of the first test iteration (see Table 4.2.), and the participants represented a subset of five individuals of the sample described in section 4.3.1. All of these participants also took part in a card sorting exercise during the same session, just before the usability test.

In this second iteration, the mean age of the participants was 39 years, with a standard deviation of 11.2, and an age range of 27 to 55 years. All participants identified as male. Three participants had prior experience with the personal science community, two of whom had been and still were in contact with the community for several years (P21, P17), and one had been involved in the past (P19). Two participants had already edited the Personal Science Wiki (P17, P21), and one of them was a frequent contributor. Additionally, all participants had experience both in consulting and editing Wikipedia or other wikis.

Regarding the **first impression**, expectations revolved around finding information about tracking activities and research projects, and information with regards to the main categories listed on the homepage. A participant who consulted the wiki the first time expressed:

“As a general thing it feels like tools, or let's say articles, tools, information, tutorials about how to generate data and analyze this data for tracking your own personal [...] health habits. [...] And who will read this? I think individuals who want to have a better understanding

of how their habits or their surroundings or their actions impact their personal health, mental or physiological health.” (P20)

In the **specific search tasks**, the specific search tasks showed a significantly higher rate of task completion and overall efficiency compared to the first iteration. This time, each task was successfully completed by 100% of the participants. For all tasks except one, either the search function or the subcategories were used to find the desired information. However, in task four ("Please find people who have worked on activity tracking"), four out of five participants hesitated when they encountered the fact that the "People" category, unlike the other categories, had no subcategories to guide them to the relevant pages. Eventually, they accessed the aggregation through the "activity tracking" topic page, which all participants successfully located.

In the **open search task** regarding the sleep project, four participants began by consulting the "sleep tracking" "Topic" page, then inspected curated content and linked pages from there, including the list of linked projects. One person, instead, went to the "Project" category, to the subcategory "sleep projects", and explored the list of projects from there. Those who consulted the "sleep tracking" page mentioned that they wanted to get an initial overview of the topic, including information about interventions and devices. However, they criticized the lack of curated information at this stage of exploration.

Regarding the list of linked projects, four participants expressed the opinion that there were too many projects listed under the topic "sleep," making it difficult to determine which ones were truly relevant to their interests. Many of the projects tagged with the keyword "Sleep" were found to track sleep as just one of several variables, lacking a hierarchical arrangement based on relevance. Additionally, some project titles were deemed unhelpful as they were not considered informative enough about the project's focus or methods. Participant 19 commented on this matter:

“So, I'd start with [...] topics, and sleep tracking again. And I'd probably start here trying to get an understanding of why and when I start sleep tracking. Yeah, I guess this doesn't tell me too much because it's got a list of devices and apps and sleep phases. I thought it would be giving me much more, so I'll probably go to projects from here [Project link in infobox]. So I get a sense of what kind of projects people are doing for sleep tracking. But then there's a long list of 78 sleep tracking projects and I'm guessing not all are relevant to me, because some seem to talk about other things that I'm probably not interested in, like, ECG and activity monitoring. [...] Sleep might be a secondary or tertiary aspect. [...] some of the other projects have slightly unclear names. [...] ‘Social studies’ [Title of a project page] doesn't tell me too

much about why it's linked to sleep. Or 'sleep as a galaxy' [Another project title]. [...] So, I'll probably have to do some trial and error, see a few and read through it, to get an idea, whether it helps. But it still doesn't really give me a much clearer idea about sleep tracking itself. I think if this page had a little more detail..."

Finally, all five participants repeated the task with a topic of interest, covering topics such as chronic pain (P19), fitness including weight loss or gain as goals (P18, P20), microbiome (P21), and cognitive testing (P17). Participants reported being interested in these topics due to reasons such as already tracking the topic, living with a chronic condition, wanting to explore methods to improve health or performance, and attempting or having tried in the past to achieve specific goals.

Regarding chronic pain and microbiome, the respective participants were pleasantly surprised to find these topics covered on the wiki in the form of "Project" or "Topic" pages. However, they expressed a desire for more content to be available, similar to the participant researching cognitive testing.

Regarding weight loss or weight gain, a topic that was represented by more content on the wiki compared to the other topics participants had chosen, participants appeared to be more satisfied with the existing information. One participant, who consulted a topic page about weight tracking, expressed finding the content interesting and relevant. They referred to information on tracking devices, projects, and details about nutrients. Another participant, while exploring the list of linked projects related to weight, mentioned the need for a faster method to extract relevant information from project pages. They specifically highlighted the desire for quicker access to details such as methods, variables, goals, and results:

"So I have the tool, I have the topic, but it would be nice to have something in the project info box as metadata about, okay, what was the goal? If there's some statistics [...] like improved performance by 50% or key value [...] something with that I can really easily see, okay, there is some merit to this work. There is not only the topic but they have used some tools behind to verify what they're saying. And yeah, I would add maybe some more metadata to the project infobox for faster reading of the page to see if I really want to take eight minutes to watch the video, or more time to read the text." (P18)

When asked for general feedback, one participant who has been a long-term community member (P21) commented on the potential and role of the wiki approach in the context of recent technological developments in information retrieval. They mentioned AI chatbots utilizing large language models, integrations, and alternative usage of other technologies like GitHub or notebooks over MediaWiki. They formulated the potential of the wiki as potentially

filling the gap of a missing “centralized resource”, and what the focus of this resource should be:

“I think there's a need for a centralized resource where people interested in doing experiments can find other experiments or experiments that are along that same line that they can modify appropriately for their own purposes. So like the immediate thing that you should be able to tell when you look at the personal science wiki is, you should be immediately able to find the experiments that kind of relate to the problem you're trying to solve.” (P21)

Detailed results for each task in comparison with the results of the first iteration of usability tests are listed in Appendix A.9.3. As before, issues were collected in a list, categorized, and assigned a priority in a team discussion (see Appendix A.9.2). The complete list of anonymized transcripts of all participants can be found in the supplementary materials.

4.3.5 Card Sorting

The card sorting task was conducted throughout the entire duration of the study, either as a standalone activity or before the usability test for those who participated in both. The entire sample, as described in section 4.3.1, took part in this task.

The resulting data from the study comprises 21 transcripts of the task recordings, which cover participants' comments during the task and their feedback afterward (see supplementary material). Regarding the outputs from the kardSort software of the card sorting task itself, one dataset had to be removed due to the presence of a miscellaneous category, which could potentially skew the results of the quantitative analysis (Spencer & Garrett, 2009). Nevertheless, the comments from that particular participant were still considered for the qualitative analysis. Consequently, 20 kardSort outputs were utilized for further quantitative analysis, represented as tabular data in CSV format. The data included columns for card ID and label, category ID and label, and user ID. The complete output table, as well as a table mapping the participant ID to the respective user ID in the kardSort output is provided in the supplementary materials.

In total, the 20 remaining participants created 147 categories, which translates to 8.4 categories on average per participant (Range 5 – 12, SD = 1.8). The data was analyzed using hierarchical cluster analysis, which calculates pairwise distance between all cards, and merges them into clusters from the bottom-up until all cards form one cluster. In the case of card sorting, if all participants sorted two cards together, they are assigned the lowest distance, and inversely, if all sorted two given cards in separate categories, they are assigned

the highest distance. As the linkage method, average linkage was employed, which uses the average distance of the points in pairs of clusters and has been found to produce balanced results. The results were visualized as a dendrogram (see Figure 4.4.). For the analysis and visualization, methods from the “cardsort” Python package was used (see section 4.3.6.). The code of the whole quantitative analysis can be found in the supplementary materials.

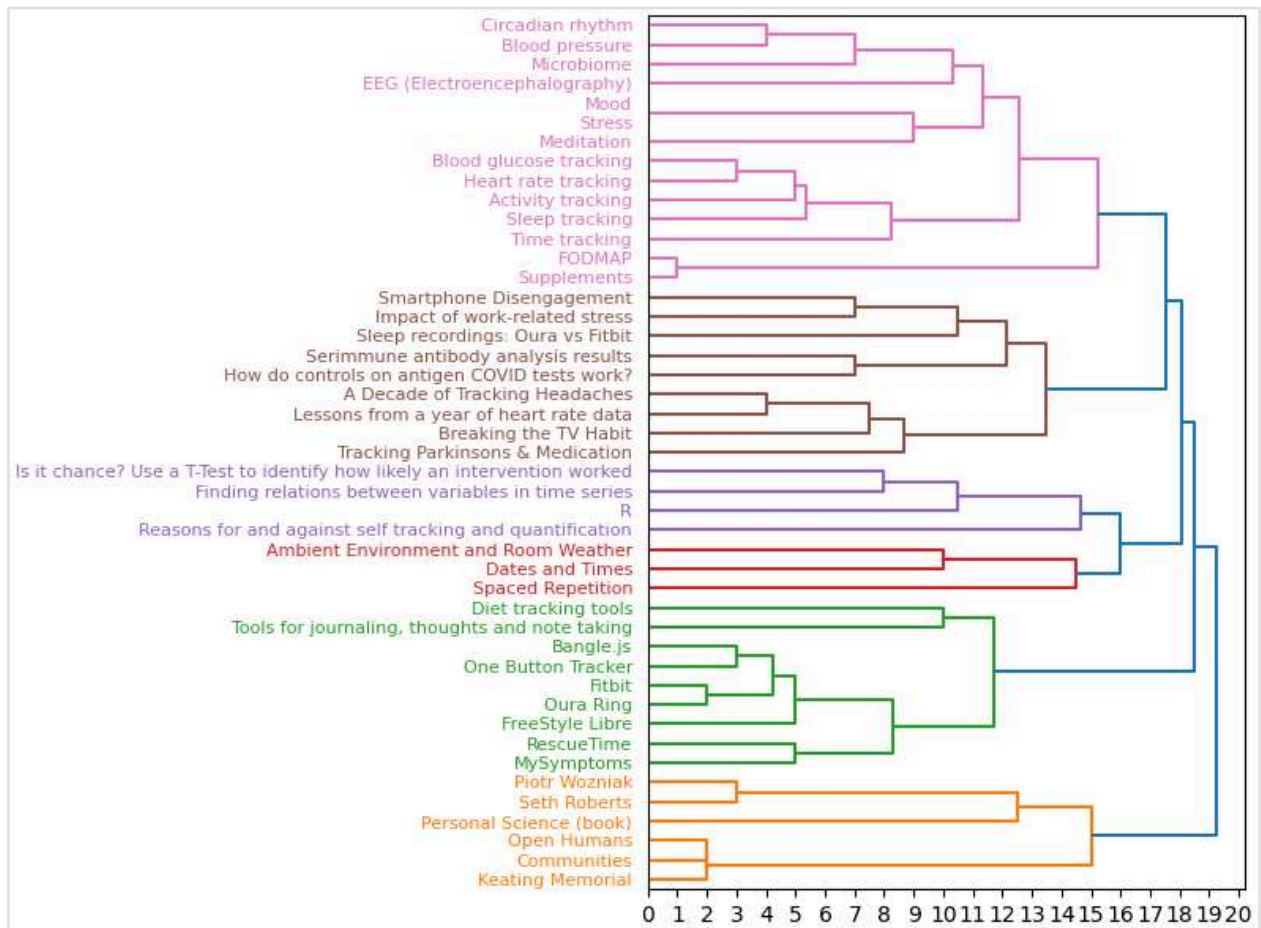


Figure 4.4 Dendrogram visualizing the results of hierarchical cluster analysis of the card sorting outputs of all 20 participants

The color cutoff as shown in Figure 4.4. was set at 80% or a distance of 16 participants. This cutoff was chosen in a team discussion, and informed by what cutoff resulted in clusters containing cards that were similar enough to represent a single content category, and separate enough from the other categories. The chosen threshold results in six categories containing three to 14 cards, and eight cards on average.

To understand which concepts are covered in these clusters, participant-generated labels were analyzed in the next step. Since the hierarchical cluster analysis represents an “average” mental model (Paul, 2014), it is possible that no participant grouped all cards in a cluster together exactly as seen in the dendrogram. To still get an impression of participant-generated

labels for the clusters, the following method was used: For each cluster, we first tried to output labels created for the whole set of cards. Then, the same was tried for subsets of cards in a cluster, removing one or more cards or subclusters. This allowed us to identify both concepts that roughly cover complete clusters, as well as concepts for subclusters in some cases. To identify overarching concepts independent of exact wording, the labels were ordered by perceived similarity by the PhD researcher, which was discussed and adapted in a team discussion. User-generated labels that only differed in terms of capitalization or use of singular or plural were listed as a single label. A summarized and ordered list of labels and sub-clusters identified with this method is shown in Appendix A.10. The full list with all tested combinations can be found in the supplementary materials. Based on the results, we describe the clusters as follows (for cards belonging to each color refer to Figure 4.4.):

- **Pink cluster:** Labels are largely related to tracking methods, or variables to track (often formulated as variables related to the body). Subclusters exist for interventions or personal improvement, health topics, mental health, as well as diet and nutrition.
- **Brown cluster:** Labeled predominantly as projects or experiments, but also as discussions or lessons learned, resources/media/Show and Tell talk, or community blog. Subclusters present regarding mental health and specific health problems.
- **Violet cluster:** Labels largely refer to methods, with a focus on data analysis, but also research questions or tools. Other concepts covered regard frequently asked questions, general skills and self-tracking in general, studies, community, advice or blog, resources and references.
- **Red cluster:** Labels refer to parameters, variables or entities, but also to methods. For the card “Spaced repetition”, labels regarding cognitive abilities, or interventions have also been assigned.
- **Green cluster:** Combinations of cards in this cluster have predominantly been labeled as tools, including devices and apps, sometimes with the keywords regarding measurement or tracking. Another concept covered is tracking methods, and subclusters are assigned labels with regards to topics like general health and fitness or mental health.
- **Orange cluster:** Combinations in this cluster are labeled predominantly regarding community, people or self-researchers, and resources or references or meta-information.

To gain further insights, the 21 transcripts of the card sorting session were analyzed qualitatively in addition to the quantitative analysis. While the quantitative analysis shows an average over all participants, the motivation for the qualitative analysis was to obtain a better

understanding of the organizational schemes used by individual participants, including ambiguities and problems.

Using taguette, tags were created for each card, for user-generated categories if they were commented on by the respective participants, as well as for categories of feedback that emerged frequently. The latter categories were created by the PhD researcher and discussed with the research team. The full list of tagged excerpts can be found in the supplementary materials.

The **individual cards** that were most frequently commented on were “R”, “Meditation”, “Spaced Repetition”, “Activity tracking”, and “FODMAP”. Most comments addressed that these cards were perceived as hard to place for different reasons. “R”, as the only programming language in the list, was perceived as lying between tools, methods, and data analysis. Several participants not familiar with the topic did not directly understand what the term referred to. The latter is also true for “FODMAP” and “Spaced Repetition”, which were terms both new to many participants, and also perceived as being hard to place in a cluster. Participants thus added them to different clusters, e.g. by topic (for example, diet and nutrition in case of FODMAP), or to methods or topics more generally. Seven participants created a category with labels referring to “Interventions” or “Buttons You Can Push”, to which “FODMAP”, “Spaced Repetition”, and also “Meditation” were frequently added to. In the case of “Meditation”, while the concept was known to all participants, there were questions regarding the content of the page, which was perceived to influence categorization. Participant 20 said:

“Then there are things that I will not know where to put, like meditation [...]. Depends on what it is about. You will have things like explaining, what's meditation and things like explaining how to develop, like, a meditation habit. So I want to know where to put some of these things.”

Also the card “Activity tracking” was perceived as ambiguous in some cases, potentially referring to physical or fitness activities, or to activities in the larger sense, i.e. with which activities someone spends their time.

With respect to **categories**, participants frequently left comments on their reasoning behind these. The following section lists some comments on categories representing clusters from the hierarchical cluster analysis (see Figure 4.4.):

Clusters labeled “Tools”, “Devices” or similar (green cluster), were frequently one of the first categories made by participants. Participant 10 expressed:

“I mean, it’s natural, I guess, that I started with some very simple categories and soon it started to get more and more [...] complex. And I have created first categories, which were more related to tools and apps. Because there’s [...] the ones which you hear about a lot. Even if you’re not knowing [...] self-research, you know that there is Fitbit, you know, that there is this and that.”

Participant 18 interpreted their “Devices” category as *“it is all devices which are used to collect information on the user, on the study participant, or on yourself”*.

With respect to the pink cluster, participant 11 comments on their category “Things to track”:

“The kind of third category that I’ve noticed is like things you would track. So like blood glucose, blood pressure, sleep, etc. So, I’m just going to call it things to track. And say, Sleep, blood pressure, blood glucose. And I definitely know people track their meditation. And their stress.”

Several times this cluster is explained in relation to the “Tools” cluster. Participant 15 explained the difference between their “Tools” and “Method” category like this:

“For now I’m not sure why I separated method and tools, but tools are like a little bit more specific. This [“Supplements” and “Activity tracking” in “Method” category] are like more general, and a very high level way of doing well, of tracking your personal information.”

Participant 9 expressed:

“So I also see value in creating a new category, which I would like to call methods. Because I see that there are tools, which do diet tracking, for example, [...] but there are also instances of methods like time tracking. It’s a method which you use to achieve getting or collecting data.”

Combinations in the brown cluster, frequently labeled with terms similar to “Projects” or “Experiments”, are described as *“descriptions of actual projects”* (P9, category “Projects”), *“information related to specific empirical research that you’re doing”* (P21, “Experiments”), or *“all the books and testimonies of people who did projects on doing personal science and then [...] explain their experience from that.”* (P7, “return on experience / testimony”).

For the violet cluster, participant 9 who created a category “data analysis” explained their reasoning, opposing the category from data collection:

“So I'm finding it a little bit hard to fit the first card and the third card like “using a t-test” and “finding relations between variables in time series”, because of the reason that these are specific data analysis techniques, which don't really fit into any of the other categories. Because most of the methods here are a little bit more generic. So [...] I can see the value of having this in its own criteria. [...] In theory, this would be a resource on how to use the data, this essentially a statistical method. But the other methods that I have here are in a league in itself, like it's heart rate tracking, activity tracking. it seems like a bit more generic whereas this specifics into, not really tracking, but into analyzing the tracking data. So I can see that this could be a different category [...]”

Cards in the red cluster were put together by three users (Categories “Analytical approaches and measurements”, “Parameters”, “Equipment”), in each case with several other cards of varying topics. None of these categories were commented on, but comments on the individual cards illustrate thoughts with regards to these, for example *“Ambient Environment and Room Weather? Now, that's something we can measure, which is not related to biology. I don't have anything for this one, I need a new category, for now, let it aside.”* (P5, “tracking of time usage and events”).

With regards to “Dates and times, participant 2 said: *“So it's [...] almost like [...] your primer. You should know what each of these things mean because they're gonna come up a lot in everything that you're doing. Because like “dates and times” it's not a thing to track.”* (P2, “Primer/Glossary”), and participant 9 put it into “data collection”, arguing *“I will move ‘dates and times’ into data collection because I see all these talks about setting the scene for actually collecting and [...] like collecting good self-reported data.”*

“Spaced Repetition”, one of the cards most commented on (see comments on individual cards above), is frequently described as “technique” (P3, P4, P7, P9) or “intervention” (P11, P14), “things you can do” (P1) or “buttons you can push (P2).

Finally, the last, orange cluster, relating to communities, was described by participant 7 as *“making connections between people and building communities to help people find resources for their project”* (“Community building”). Pronounced subcategories, which are visible in the dendrogram, were commented on by participant 8: *“And then the final one. It's important knowledge where things probably could get more specific because we have five items that are not necessarily similar at all. We're talking about a book, a community or two communities,*

and a specific activity of that community [Keating Memorial], then communities in general” (“communities / what’s going on / shared”).

Regarding **other feedback**, the comments were clustered in feedback about entry points, newcomers, hierarchies, cards fitting in several categories, page titles, as well as general feedback, with many quotes overlapping several of these categories.

“Entry points” and “newcomers” refers to feedback regarding the possibility or desirability of the use of different organizational schemes for different user groups, such as newcomers or experts.

Participant 2 expressed: *“For now, [...] I would think that you'd want a spot that's like “Hey, is this your first time on the site?” [...] And then based on what what they say you can be like “Hey, we recommend you go through the primer”, which would be like a section that would break down the basics for them and then [...], if it's somebody who's already doing a tracking then [...] they could probably skip the primer stuff and [...] you could just direct them to [...] the further learning stuff.”*

Participant 17, a frequent contributor to the Personal Science Wiki, directly referred to different organizational schemes at the beginning of the task, wondering: *“Should I categorize by tool or subject matter?”,* justifying their choice of categorizing by subject saying: *“Well, I know all the types of resources and it's a very straightforward kind of problem. It is just: Is this an intervention or a tool, or a concept or a topic? And I think I was thinking of the readers of the Wiki who are going there for the first time. So “general skills” are the kind of things that everybody can use and should probably know about. Then we get into the general fitness and then the specific health problems”.*

Participants frequently expressed the wish to create **hierarchies** within their category system, which was not possible with the kardSort tool. There were suggestions such as breaking down “experiments” by “body part” (P21), or having “tracking” as a parent category for “tracking device”, and for each device the variables that it can track as subcategory (P1). Some participants already created separate categories for software and hardware, or data collection and data analysis tools, indicating the possibility of an overarching tools category.

Topic areas were also suggested to be broken down, for example by participant 19: *“And for something like health/well-being/medical, I'd probably have a few subcategories. One could be just wellness and well-being, One could be medical issues like Parkinson's.”* or participant 3: *“I think that in my personal case that I'm diabetic, I found very easy to sort the Freestyle Libre and the other card, glucose self-tracking [...] together on a category that was very specific to them. But they would also make sense in a category that is health and is more wide and could include other things.”*

Related to the possible **coexistence of different organizational schemes**, participants often expressed that some cards could be part of several categories, depending on the scheme of interest. For example, people could go into a “people” category, or be sorted with the topics they contributed to, like “sleep” in the case of “Piotr Wozniak” (P16). Participant 15 expressed *“I think ‘Entity’ and ‘Bio/Health’ might overlap and the ‘heart rate tracking’, ‘blood glucose tracking’, and ‘sleep tracking’ might go equally to ‘bio and health’”*.

Overlaps were also particularly expressed for cards that explicitly relate several topics, like the card “Sleep recordings: Oura vs. Fitbit”, which could be interpreted as belonging to tools or health topics (P19, P15), or on top of that to discussion or meta categories (P15).

There were also few comments with respect to card **titles** (equaling wiki page titles), all referring to the perception that by the title of a card, one could not necessarily infer the content of the page, which could, in turn influence the categorization. In the words of participant 7, *“When you have stress and you say, ‘Okay, stress is a feeling of emotional strain.’ [...] So it’s a nice definition, but it doesn’t tell me what the group aims to do.”*

Finally, feedback in the category “general” concerned comments about the content and purpose of the knowledge resource more generally by participant 21, a long-term community member. They found that some of the contents represented in the card sorting activity were “misfiled”, i.e. might not be suitable content in this type of resource. On the example of the cards “FODMAP” and “Supplements”, they elaborate: *“[...] to me, the purpose of specialized wiki is to do things that you wouldn’t get out of general Wikipedia. Because if I’m looking for just general information, like for example, about supplements or about FODMAP. I think that should just be in Wikipedia.”*

On the other hand, they saw potential in everything related to experiments, including “practical guidelines”, “step by step examples”, and information about “specific technologies” in a detail that Wikipedia does not provide.

In summary, the quantitative and qualitative analysis of the card sorting activity gave insights about different potential organizational schemes, hierarchies, and different entry points for different users. Participants’ categorization decisions were informative, as they revealed the reasoning behind certain groupings and provided ideas for new categories that could contain outlier cards. Moreover, the card sorting exercise offered valuable insights into the potential content orientation and focus of the wiki.

4.3.6 Development of the “cardsort” Python Package

This part of the PhD thesis also led to the development of the open-source “cardsort” Python package (Kloppenborg & Greshake Tzovaras, 2023). This package provides functionalities for analyzing and visualizing data from open card sorting tasks. Figure 4.5. shows a part of the package’s documentation.

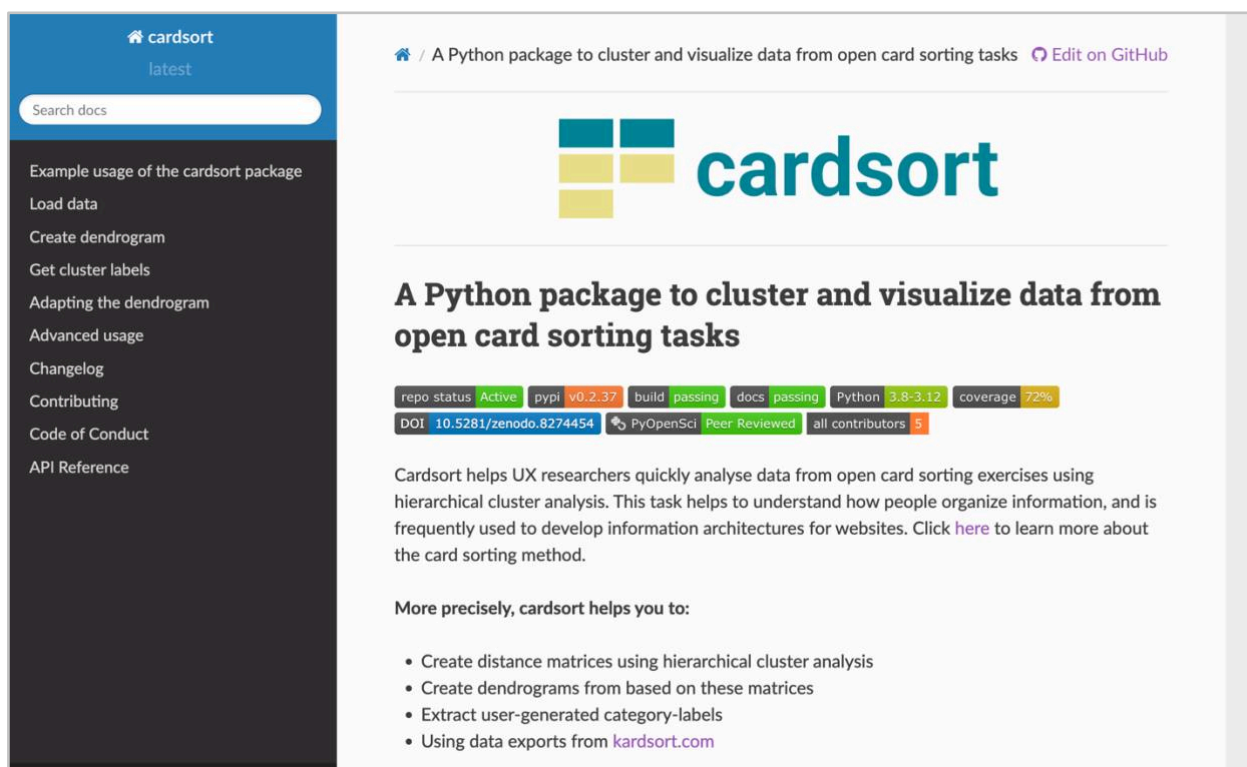


Figure 4.5 A screenshot of the documentation of the “cardsort” Python package (<https://cardsort.readthedocs.io/>)

During the research for data collection and analysis tools for the card sorting study (see sections 4.2.2 and 4.3.5.), it became evident that there were no FOSS tools available for data analysis. A brief market research indicated that several providers, such as Optimal Workshop or UXtweak, offer proprietary, browser-based tools that offer data collection and analysis capabilities. While these tools are convenient and user-friendly, they are closed-source and require substantial monthly subscription fees, which can impose barriers for small studies, casual users, or academic researchers without dedicated budgets.

A browser-based tool that allows free data collection for up to 20 cards is kardSort³⁰ (see Figure 4.1. for a screenshot of the user interface). The results from kardSort can be exported in various formats compatible with analysis tools like Casolysis (Endmann et al., 2015) and

³⁰ <https://kardsort.com/>, last accessed 04.08.2023

SynCaps³¹. These tools are also free of charge and offer a range of analysis methods for card sorting tasks, including hierarchical cluster analysis, similarity matrices, dendrograms with cluster labels, and heatmaps. However, it is worth noting that both Casolysis and SynCaps are closed-source, no longer actively maintained, and only run on Windows.

Functions for hierarchical cluster analysis already exist in Python packages, such as SciPy (Virtanen et al., 2020). However, using SciPy for this purpose still presents some challenges. For instance, none of the standard distance functions can be directly used to calculate the distance matrix from card sorting exercises. Additionally, extracting user-generated cluster labels requires a custom function. To remove these barriers and accelerate the analysis process for other researchers, I decided to package the functions I had created for my analysis during this thesis into an open-source Python package. By providing open-source code, other researchers can fully understand the analysis methods, and potentially adapt them to their needs.

The target audience for this package includes individuals who perform card sorting tasks, for example for user research purposes. Basic Python skills are necessary, such as installing and importing packages, and creating a dataframe from a CSV file. The package accepts CSV files that adhere to the "Casolysis Data (.csv)" format, such as the output generated by the kardSort tool.

So far, cardsort offers the following functionalities:

- Calculation of a distance matrix based on hierarchical cluster analysis,
- visualization in form of a dendrogram, including customization options (see Figure 4.4. for an example),
- extraction of user-generated cluster labels for combinations of cards.

Cardsort has been peer reviewed by pyOpenSci³². The code is available on GitHub (see <https://github.com/katoss/cardsort>), alongside a detailed documentation with usage examples (<https://cardsort.readthedocs.io/>). Contributions and feedback are highly welcome.

4.4 Discussion

Here, we explored if and to which extent the Personal Science Wiki – as presented in Chapter 3 – can serve as a knowledge management tool for the personal science community. In particular, we investigated whether the wiki implementation fits with practitioners' mental models around personal science. Based on card sorting and usability tests, we improved on

³¹ <https://syntagm.co.uk/design/cardsortdl.shtml>, last accessed 04.08.2023

³² <https://www.pyopensci.org/>, last accessed 04.08.2023

the category system and page structures to better align the knowledge management with the mental models of participants, leading to a better task performance.

The approach has some **limitations**. To begin with, the large majority of study participants were people residing in the global north, with high levels of education, most of them working in technical professions or research, in particular from STEM fields. Similar demographics have been found to predominate in the Quantified Self movement (Choe et al., 2014; Nafus & Sherman, 2014), suggesting that this sample represents typical profiles engaging in self-research. However, the sample cannot provide insights about the requirements and accessibility of the wiki to other potential user groups, e.g. of less technology-savvy people or those from other socioeconomic and cultural backgrounds. To enable broader participation in personal science, it is essential to consider the requirements of these other user groups, making them a crucial point for future research.

Secondly, the selection of cards might have had an influence on the clustering outcome. To prevent participant fatigue due to an overwhelming number of cards for clustering, we chose a sample of 40 wiki page titles for the cards. Despite our efforts to select cards representative of the content, it remains uncertain whether different samples would have yielded similar clusters.

Finally, the study methods themselves present certain limitations: In the usability test, I tested information searches we believed were common, relying on the research team's experience with the personal science community. I also asked participants to explore information on the wiki with regards to a hypothetical self-research project. With these tasks we intended to avoid merely asking the users about their needs (Nielsen, 2001; Nielsen & Levy, 1994), but to observe usage of the wiki. This allowed us to explore the usability of intended workflows, as well as expectations of information needs of potential users. However, future work should focus on observing user flows in real usage situations. Related to this, while we have gained insights about the functional usability with regards to intended workflows, expectations of information needs and attitudes toward the designed solution, at this step it remains to be explored whether the wiki presents a step towards sustainably solving long-term goals. These outcomes, such as supporting community scaling, or the wiki's establishment as a community knowledge resource, rely on consistent usage and contributions from users over an extended time period. To work towards these goals, future work could investigate the information needs of various user groups during the planning of actual projects and determine the role the wiki can play in fulfilling these needs.

However, the wiki as an infrastructure, along with its real-world usage and the knowledge represented on it until now, serves as a valuable research object that can serve as a step towards the long-term goals.

To begin with, conducting formal user tests with a mix of potential and already active users allowed us to understand the **factors that impede or enhance the usability of this specific platform**. A surprising and insightful finding from the first usability test iteration was that a majority of the participants encountered difficulties with basic information search tasks. These problems arose when using various sections, including the homepage, the category overview pages, the content pages, and the search function.

Participants were intended to consult pages related to the task, such as “sleep”, or “Fitbit”, and find connected information from there. These were accessible either by visiting the “Topics” or “Tools” category overview page and locating the respective page of interest in the alphabetically ordered list of pages, or by using the search function. However, it became evident that there was a lack of information scent, meaning there were insufficient perceptual clues gradually guiding users to the desired information (Chi et al., 2001). Indeed, participants often found themselves unable to locate the links to the category pages on the homepage, or mistakenly assumed that the list of random example pages was representative of larger content categories. Additionally, the absence of subcategories on the category overview pages made it challenging for participants to quickly identify the subset of pages relevant to their interests, especially when they were not searching for a specific term present as a page. Similarly, the search function frequently led to relevant results when participants looked for a specific search term for which a page existed, but not for aggregations like all “projects about sleep”.

To improve the information scent, as well as to offer an obvious alternative path to the search function in case it did not yield relevant results, thus aiding error recovery and flexibility (Nielsen, 2005).

On the content pages, participants often struggled to locate the aggregations of related pages, which is one of the key functions of the wiki. An explanation for this, which some participants explicitly mentioned, was that these aggregations were placed below the “References” section, where they did not expect any crucial information, as they had learned from their experience with Wikipedia. The problem here can be explained by the breaking of conventions from familiar systems that users are accustomed to, which goes against the usability heuristic of “consistency and standards” (Nielsen, 2005), which advises following platform standards whenever possible.

To avoid this, the box with linked content was removed from the bottom of the page and added to the “Infobox” on the top right. For easier readability in case of a large amount of links, we

decided to display a link showing the page category with a number representing the count of links, instead of a list of links. .

The changes were successful: In the second usability test iteration, one hundred percent of the participants completed all specific search tasks successfully, frequently making use of alternative pathways via the new subcategory system.

Beyond that, the open exploration tasks during the usability tests helped us gain insights into **what users expect from a knowledge resource about personal science**, what subjects they are interested in, what information they think they need to realize their projects, and in which format.

To begin with, the topics of interest that the participants shared were well representative of topics usually addressed in personal science (Wolf & De Groot, 2020), covering health and well-being topics, from general fitness to chronic conditions, as well as a few more technical topics related to tracking tools and methods. Motivations were also representative, including improving health or performance, deepening self-understanding, or interest in technology (Senabre Hidalgo, Ball, et al., 2021). In turn, the fact that no participant selected a topic that was out-of-scope, or absent on the wiki suggests that all participants had a similar, realistic understanding of what type of knowledge and processes are covered in personal science. However, it is essential to consider that all participants in the usability test had prior exposure to personal science information during the card sorting task, which could have influenced their expectations.

Regarding information requirements, participants repeatedly expressed their expectation for an overview page for each topic, serving as an entry point and orientation to learn about common variables and tracking tools, intervention techniques, and curated lists of exemplary self-research projects. Additionally, they emphasized a desire for practical information of immediate use-value, such as step-by-step guides for data collection or analysis.

Projects, which were the most common content type due to the import from the Quantified Self Show and Tell talk archive, were often perceived as a potentially rich source of information, despite certain limitations in terms of discoverability and information presentation. Specifically, participants found that page titles, which corresponded to the titles of the respective Show and Tell talk in the case of imported project pages, lacked sufficient information scent to indicate the content of the project. Moreover, tags were deemed insufficient for filtering projects, particularly when there were numerous projects associated with a single tag, as observed in the case of projects related to the topic “sleep”. Participants expressed a desire for a hierarchy that could identify projects primarily focused on sleep, to distinguish these from projects only remotely related to sleep (e.g. tracking sleep as one of many variables). In the current implementation, all projects that use a tag appear on the same level, regardless of how

significant that topic is to each project. . Another point of criticism was the format of imported project pages, with some participants expressing preference for a table containing relevant information, such as methods, goals, variables, and outcomes, or links to reusable information like notebooks, rather than talk videos and transcripts. These critiques point to the significance of the direct use-value of information in personal science: Projects of other people, at least in the context of planning one's own project, seem to be most interesting in terms of how their methods and learnings can be reused.

Finally, we made an observation related to factors motivating users to edit a page: In three participants, a perceived lack of a specific piece of information or page that the participants knew about and had found useful in the past, and which they thought would be useful for other people, triggered the desire to add that information. Two of these participants mentioning such a lack took action and edited the wiki accordingly after the study. One of these participants had not been a user of the wiki before, and added the information without creating an account. This observation aligns with existing literature, which suggests that low entry barriers, such as not requiring an account, can increase casual contributions, potentially triggered by a desire to improve low quality contributions (Hill & Shaw, 2021).

The second part of the study, the card sorting task, provided a better understanding of **how people order self-research information based on their mental models**, as well as how they think the information would be easiest to access, including different paths for different audiences. On a high level, a large majority of people made use of a mix of two specific organizational schemes. Combinations of different organizational schemes is a common observation in card sorting studies (Spencer & Garrett, 2009), and many participants expressed the perception that many cards could belong to several categories depending on what scheme one applies. These two organizational schemes were, first, ordering by topic – “subject matter” or “health topic” in the words of two participants explaining their choices, and second by “type of resource”. The first referred to taking topic areas, such as diabetes or diet tracking, and sorting all related content, for example wearables and project reports in these categories. In some cases, participants said they would like to add hierarchies, like “specific health problems” or “general fitness” as parent categories.

Ordering by type of resource translated to creating categories like “tools” or “techniques” or “methods”, “interventions”, “variables” or “things to track”, “projects”, “people” or “community”, and “resources”, “discussions” or “meta”. Hierarchies mentioned for parts of this organizational scheme included distinctions like hardware or software, or analysis or tracking tools for “tools” and similar labels, or a distinction between physical and psychological variables for “things to track”. Dividing by “health topic” or “body part” on the second level was also considered.

The results of the hierarchical cluster analysis mostly support the organization by type of resource, with some emerging subcategories for topics relating to mental health or diet tracking.

Many participants explicitly expressed the thought that there were several possible ways to order the cards, depending on the interest and prior knowledge of the respective user. Specifically, users distinguished between first-time users of the wiki or those new to self-research, and experienced practitioners, considering their different informational needs. Participants believed that newcomers would likely require orientation help, leading them to propose entry points with hierarchies starting with general skills, general health or specific health issues, and then gradually guiding the user to relevant information.

In conclusion, these findings show that the category system initially in place (“Tools”, “Topics”, “Projects”, and “People”) roughly represents mental models of the study participants, but that adding further categories and carefully creating hierarchies and different entry points have potential to contribute to a better usability and user experience.

The card sorting study provided valuable insights into usability, and vice versa, as participants' feedback often extended beyond the specific task. Since all participants were aware that the card sorting task was related to the information architecture for a wiki for personal science, many of them offered more general feedback with usability in mind. For instance, several participants considered ways to support newcomers in finding information, such as providing different entry points for different user groups or implementing various organizational schemes. Additionally, some participants noted that certain titles were not indicative of the content, which affected their ability to navigate the site effectively. One participant even mentioned their understanding of the wiki concept and pointed out cards they believed should not be part of the wiki.

Conversely, usability tests, particularly in the first round, highlighted the importance of not only having a category and semantic structure but also ensuring their discoverability.

Findings from the card sorting exercise suggest that mental models not only differ among individuals, but also that a single person can conceptualize multiple variations of useful information architectures for personal science-related information, depending on the goals of the information search or users' prior knowledge. This indicates that offering multiple pathways to access the same information holds potential to support different mental models and thus aiding users in reliably discovering the information they seek in different contexts. Recommendations from the W3C consortium also support the idea of providing multiple pathways (W3C Web Accessibility Initiative, 2019). This concept challenges the idea of conflicting mental models and instead proposes that these models can be complementary, acknowledging that a single best solution might not exist.

From the results, a list of remaining open issues to fix within the wiki was deduced (see Appendix A.9.2.). Beyond the Personal Science Wiki, the learnings from this study, as well as from the real usage of the wiki, contribute to the wider understanding of user requirements in the management of knowledge relevant for self-research practice. The broader implications of the lessons learned are explained and placed in a larger context in the general discussion in the following chapter.

Take Home Messages

- A user study with 21 participants was led to uncover issues with the current wiki implementation and to obtain insights into information architecture requirements.
- Changes in interface and navigation structure informed by the usability test improved the findability of specific content to 100% in the second test iteration.
- The card sorting study suggested the co-existence of several mental models organizing self-research-related information, which might be useful for different user groups and different search contexts.
- Additionally, the study revealed participants' content expectations and topics of interest with regards to a personal science knowledge resource, as well as potential issues when using content in talk-format in a knowledge management system.

5. Discussion

This thesis explored the application of peer production as a collaborative approach in citizen science. First, it examined key elements of peer production platforms and how they can be implemented in citizen science contexts. By operationalizing the theory into a working model of peer production, seven essential elements were identified. These elements were then illustrated through case studies and discussed in terms of motivations and trade-offs of whether or not choosing peer production over other collaborative approaches, particularly crowdsourcing (see Chapter 2). The findings suggest that a peer production approach is well-suited for situations that value the reuse and adaptation of resources, exploration, self-identification of tasks, and input from individuals with diverse motivations and skills. These aspects are particularly present during the developmental stages of research projects. Furthermore, the chapter provides design considerations to guide the conceptual design of peer production platforms in citizen science.

Secondly, this thesis explored the development of a peer production approach in a specific use case, aimed at supporting the personal science community in overcoming barriers to wider adoption and scaling of self-research practice. To accomplish this, a participatory design thinking approach was employed, allowing for the identification and prioritization of issues, as well as the development of solution approaches in close collaboration with community members (see Chapter 3). User research findings highlight the importance of scaling in terms of enabling more individuals to practice personal science, rather than concentrating on scaling through data donation or automation approaches. We found that a key barrier to engaging in personal science, which requires a range of research skills, is a lack of accumulation and access to community knowledge. This insight shifted the focus to community knowledge management as the objective of the envisaged peer production approach.

As a consequence, the Personal Science Wiki was developed as an infrastructure for knowledge management. Early deployment was prioritized to gather feedback from the community from real usage, allowing for continuous discussions and refinements of the system. This process also uncovered broader issues related to information architecture and open questions in terms of usability of intended user flows, which motivated a formal usability and card sorting study (see Chapter 4). This study helped to identify and address usability issues, revealed user expectations regarding covered topics and processes, and provided insights into information architectures aligning with user mental models. It further highlighted challenges regarding the deduction of practical information from the rich resource of self-research talks from the Quantified Self archives.

The subsequent general discussion section connects the findings elaborated in the respective chapters to additional topics and learnings that emerged during the dissertation process, aiming to provide insights and guidance for those considering the adoption of a peer production approach or the creation of knowledge management systems within communities of practice in citizen science and beyond.

The Personal Science Wiki stands as an example of a community knowledge management system. This system faces common challenges, shared across domains like personal science and others, related to the documentation and transmission of tacit knowledge (An et al., 2014; Hafeez & Alghatas, 2007; Nonaka & Takeuchi, 1995), effective community engagement (Kraut et al., 2011), as well as the development of infrastructures and information architectures (Davidson & Blackman, 2005). Section 5.2. addresses the lessons learned from working with the personal science community and how these insights can translate to the broader development of knowledge management systems within communities of practice.

In striving to effectively reply to community needs, the design of the peer production approach prioritized user-centeredness and participation from the outset. This process unveiled challenges related to community-building (Kraut et al., 2011), meaningful yet unburdening participatory design methods, and project leadership in participatory design within academic contexts (Ahmed et al., 2021). When integrated, participatory design and peer production hold potential to be mutually beneficial, enhancing user-friendliness of peer production platforms, and extending participatory design opportunities beyond explicit design phases (Wubishet et al., 2013). Section 5.3. explores this symbiotic relationship between participatory design and peer production approaches, alongside offering lessons and recommendations regarding encountered challenges. A process overview of the whole PhD project can be found in Figure 5.1.

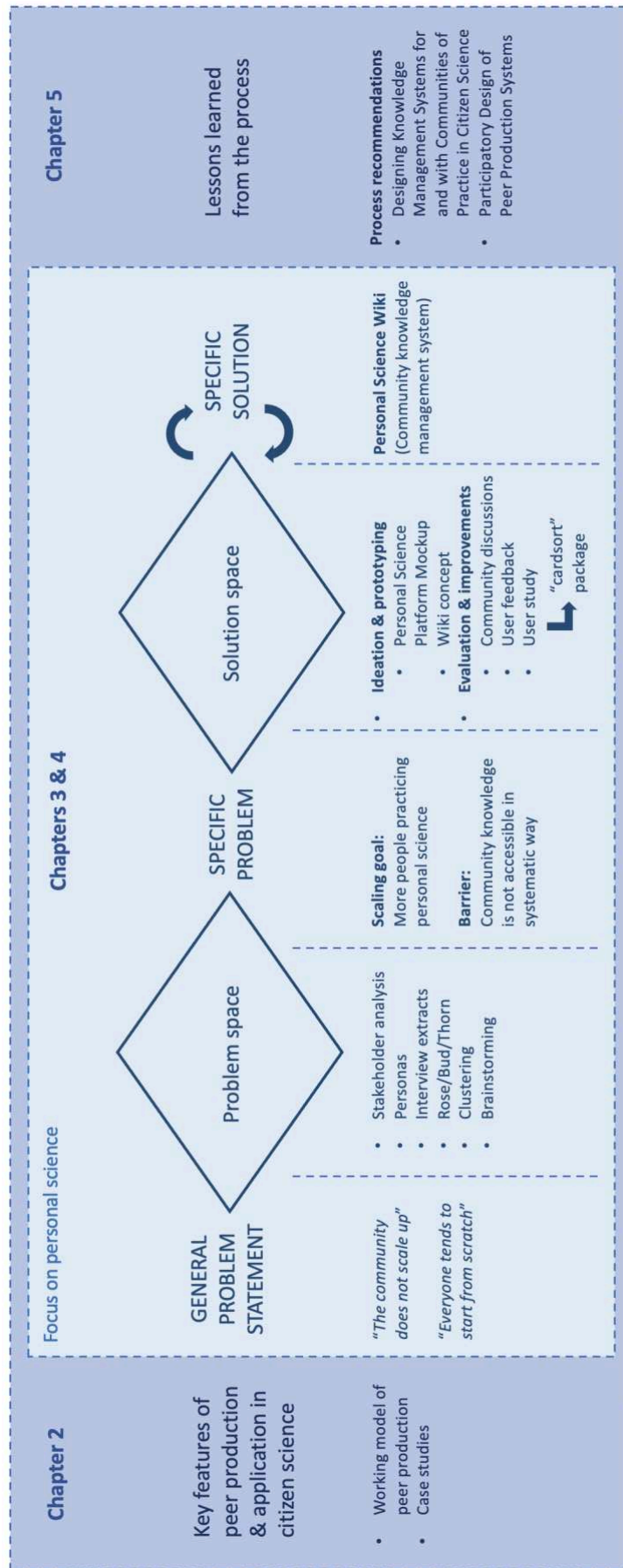


Figure 5.1 PhD project process overview

5.1 Community Knowledge Management in a Citizen Science Community of Practice

This dissertation was partly motivated by identifying barriers to personal science and to develop an approach that could assist the community in overcoming these obstacles and ultimately scaling up. During the design thinking process, the focus of this open task quickly shifted to knowledge management. The following section explores the lessons learned from working with the personal science community regarding community knowledge management, and discusses them in relation to existing literature. Although the findings are specific to the personal science community and its knowledge management context, they are thought to hold relevance for researchers and practitioners aiming to develop knowledge management systems with communities of practice. These insights may be applicable to other contexts where individuals utilize and adapt research methods or other complex processes for their own objectives, as similar challenges are likely to arise.

5.1.1 Reflections on Challenges

The development of a shared knowledge repository for the personal science community encompassed several challenges regarding the types and formats of information that individuals require to effectively engage in self-research, the establishment of an appropriate infrastructure for project documentation and collaborative knowledge building, as well as attracting contributors and contributions. Understanding and fostering effective knowledge management has been a frequent subject of inquiry in business and organizations (Metaxiotis et al., 2005), but also in distributed online communities, such as open source (Awazu & Desouza, 2004), and online health communities (Ghalavand et al., 2020).

One of the initial hurdles of the design process involved establishing an **information architecture** for the wiki. Although not obligatory for a wiki setup, we took the decision to implement an information architecture and establish semantic connections between pages. This approach aimed to facilitate the discovery of relevant content, a priority identified during the user research phase. Technically, this involved creating categories to categorize pages and assigning other pages as properties to enable aggregation and querying, utilizing the capabilities offered by the Semantic MediaWiki extension.

Given the absence of a predefined and limited user base for the system, coupled with uncertainty regarding the types of knowledge users would contribute and their specific information needs, we opted to propose and evaluate a structure inspired by the existing

framework employed in the archives of Quantified Self for Show and Tell talks, and to adapt it as needed. This structure consisted of four primary categories: "Tools," "Topics," "Projects," and "People." Additionally, we included a category specifically dedicated to community meeting notes, and a subcategory of "Projects" for Show and Tell talks. We seeded the wiki with imported Show and Tell talks, added and linked meeting notes to pages in the categories, and observed user contributions and feedback for about a year. The live-testing process yielded valuable insights regarding both usability and information architecture, highlighting certain shortcomings. It became apparent that the category "Topics" was too broad and encompassed various content that did not fit within the other categories. For instance, the "Topics" category ranged from specific topics like "Headaches" and "Heart rate tracking" to more complex subjects such as "Finding relations between variables in time series" and even event-related content like the "Keating Memorial" event. Some pages did not seem to fit into any specific category, such as the "Personal Science book." Additionally, there were instances where it was unclear whether certain content, such as a summary page on "Diet tracking tools," should be categorized as a topic or a tool.

To represent user needs when addressing the aforementioned challenges, I conducted an empirical user study to gain deeper insights into their mental models and information expectations, as outlined in Chapter 4. Mental models are internal representations of reality that people use and need to interact with the world around them (Craik, 1943). Apart from the card sorting task, which is a dedicated tool to elicit mental models (Jones et al., 2011), the open exploration of the wiki with the aim to plan an imaginary personal science project added valuable insights into expected information needs and information search sequences. Intentionally, I ran the study with a mixed sample of experienced community members, including contributors to the Personal Science Wiki, and people new to personal science. Surprisingly, our findings suggest that mental models and information expectations were largely consistent among participants, regardless of their level of experience or their specific areas of interest within self-research. We gained insights into how to divide the "Topics" category, notably by separating pages about health topics or "Things to track", like "Diet tracking" or "Chronic pain", which are thought to serve as entry points, from pages regarding topics like data analysis or community resources. For the entry points, participants frequently wished to find an introduction to the tracking topic, including best practices and a curated list of exemplary projects. Almost all participants expressed that there were several ways to classify pages, notably by subject matter or type of resource. With regards to this, they would prefer being able to access pages via both classification schemes, thinking about different pathways for new or more experienced users.

Our findings regarding a partial mismatch between the information architecture in place in the beginning and the expectations of users reflect findings from Davidson and Blackman (2005).

The authors argue that in order to ensure the effectiveness and adoption of knowledge management systems, designers must refrain from imposing their own mental models of the subject area's structure. Instead, the authors propose a thorough analysis of the usage context and a process of socialization between developers and users, which is thought to facilitate an understanding of the collective mental models held by the stakeholders. Besides, they emphasize the importance of embracing uncertainty throughout the process rather than imposing rigid structures from the outset. An approach with potential for engaging communities in managing initially unstructured data is that of folksonomies. Folksonomies, a blend of “folk” and “taxonomy”, are user-generated classification schemes (I. Peters & Weller, 2008). They are gradually developed and improved over time depending on the classification needs that arise through practice. They are also in use in citizen science contexts, where users develop new classification schemes for data through tagging. For example, in the Zooniverse project “Gravity Spy”, volunteers develop new labels for previously undefined classes of glitches to improve gravitational wave sensors (C. Jackson et al., 2018). Given that the semantic tags and categories of the Personal Science Wiki can be edited by users, the possibility of new user-generated classification systems emerging over time is present. Maintenance efforts to support processes like this should be undertaken, e.g. by facilitating tag gardening, creating spaces for discussions about folksonomies, and clearly communicating decisions (C. Jackson et al., 2018).

Another challenge during the development of a knowledge management system for personal science was to gain an understanding of the characteristics of relevant knowledge. In personal science, individuals design, run, and analyze their own research projects, which requires a wide range of research skills and know-how. Projects are adapted to the needs and context of the individual, and technology changes frequently, rendering it challenging or even impossible to reuse the exact same research protocol twice. In addition, there is no direct epistemic need to collaborate and agree on common procedures in this practice whose sample is characterized by being “self-directed n-of-1 studies” (De Groot et al., 2017).

A substantial part of the knowledge described above can be understood as **tacit knowledge**. Introduced by Polanyi (1958), tacit knowledge refers to knowledge that can be paraphrased as know-how or capabilities of an individual. It is usually procedural, context-specific, and acquired through practice, and can be only imperfectly articulated (Ambrosini & Bowman, 2001). The transfer of tacit knowledge is a key challenge in organizations (An et al., 2014), workplaces (Nonaka & Takeuchi, 1995), and communities of practice (Hafeez & Alghatas, 2007).

To date, a large part of accumulated knowledge in personal science is present in the form of talks in which self-researchers present their own projects. Hence, challenges in knowledge

management within the context of personal science involve making individual experiences accessible to others by capturing the implicit procedural knowledge shared in these talks and, ultimately, extracting commonalities from the accumulation of individual projects. Prior works have taken steps towards this by conceptualizing personal science practice as a circular process model (Wolf & De Groot, 2020), and by introducing skills and concepts relevant for each step (Wolf, 2022). In this thesis, an alternative approach was adopted: the design and deployment of an infrastructure to allow the accumulation and curation of self-research knowledge by the community. To this end, I employed a peer production approach for several reasons: First, for the possibility to allow anyone to contribute openly to eventually attract contributions from a range of individuals and to alleviate maintenance bottlenecks (see Chapter 3). Second, this mode of collaboration seemed to reply to the information needs of the task, which would profit from leveraging the creativity of different individuals with a wide range of motivations and skills (see Chapter 2). Finally, the approach aligned values of openness, sharing, and mutual support in the community already acting as peers. As peer production infrastructure, I chose a wiki format. Wikis are easy to deploy, provide peer production functionality out of the box and are largely adaptable to community needs. In addition, wiki systems are frequently used for knowledge management, with instances in subject areas similar to personal science, such as bottom-up citizen science (Breen et al., 2019), or chronic pain management (*CK-Wissen:Portal*, n.d.).

During the user research study (see Chapter 4), project pages were frequently identified as the unique selling point and exclusive content of the wiki. Until now, most project pages are imported Show and Tell talks, all following the same structure consisting of a short description, a video and a transcript of the talk, and linked to relevant “Topic”, “Tool”, “Project” or “People” pages in the “Project Info Box”. The talks follow a specific format that has been practiced within the Quantified Self movement for around 15 years, making use of a specific format structured by the questions “What did you do?”, “How did you do it?”, and “What did you learn?” (Wolf & De Groot, 2020). This format is thought to encourage a focus on and reflection of the process, motivations, and insights.

This format of the Show and Tell talks can be seen as an instance of storytelling. The spiral model proposed by the knowledge management researchers Nonaka and Takeuchi (1995), which conceptualizes the conversion of tacit to explicit knowledge and vice versa, highlights storytelling as a mechanism for facilitating the transformation of explicit knowledge into tacit knowledge. By adding documentation and contextual information to explicit knowledge sources, such as data, tacit knowledge is thought to be more easily internalized. As a result, storytelling has been recognized as a valuable component of holistic knowledge management (Schilcher, 2009).

However, our user study indicates that the existing format of talks presents several barriers when used within the knowledge management system. While participants expressed a willingness to watch talks if they were certain the content was relevant to their own projects, they were discouraged by the sheer volume of projects on the platform. Participants faced difficulties in quickly determining the relevance of projects, even though they were tagged with topics. The classification of projects by topics was found to be insufficient, particularly when numerous projects were listed under a specific topic, such as "sleep." Additionally, the lack of a discernible hierarchy meant that remotely related projects could also be tagged with the same topic. As a result, several participants expressed the desire for manual curation of exemplary sleep projects on the "Sleep tracking" topic page. Another issue identified was the use of figurative and catchy titles for the talks, which did not necessarily provide informative content descriptions. This compelled participants to hover over or click on numerous projects to ascertain their potential relevance. Some participants suggested improvements, such as providing tables summarizing project goals, methods, results, and potentially offering reusable notebooks. Additionally, prioritizing projects using the capabilities of large language models was suggested as a potential solution.

A potential explanation for this might be that in the context of the Personal Science Wiki, users perceive the talks based on their personal utility in supporting their own project creation rather than considering them within the framework of a Show & Tell talk event. This hints towards different expectations and preferences when consuming talks outside of the event setting, and informs requirements with regards to the documentation of projects within the knowledge resource. Since this is a task of information retrieval, users are confronted with information overload when faced with too much information to process. Information overload is a common issue in the information society (Quintas et al., 1997), and the aim to guide users efficiently towards relevant resources has motivated various research directions, for example regarding recommender systems (Khusro et al., 2016), including recent developments around large language models (Fan et al., 2023), or semantic technologies to structure and link related resources (Simperl et al., 2010). While storytelling has been framed as a way to alleviate information overload (Sax, 2006), our study points to potential pitfalls when the stories themselves represent an overwhelming amount of information. While the pages containing these stories are already filterable via semantic tags and categories of the wiki's information architecture, further efforts need to be made to extract relevant information from talks and guide users to talks of their interest. An advantage of the peer production approach for this issue is that the pages can be edited afterwards, so it is possible for users to add sections with summaries of key knowledge or add new semantic tags to Show and Tell talks, the latter of which has already been practiced by users of the Personal Science Wiki.

The aforementioned findings were derived through the active involvement of users or study participants in **engaging with the wiki** itself. This approach proved instrumental as it provided a tangible object for testing and critique. Likewise, the use of the "Personal Science Platform" mock-up, as outlined in Chapter 3.3.3., enabled us to identify the strengths and weaknesses of that approach, ultimately leading to the development of the wiki in subsequent iterations. Real usage and user-generated contributions to the wiki shed light on various aspects such as information architecture, semantic links, templates, and community utilization. It is important to emphasize that some of these insights were only attainable through the practical implementation of the wiki infrastructure: Non-functional prototypes, for instance, would not have captured issues related to spam, maintenance, and the peer production of content.

One drawback of working with a deployed system at an early stage is the potential challenge of implementing radical changes, which may concern or confuse users. In our case, concerns were raised regarding the potential loss of user-generated content, an outcome that would significantly discourage contribution. We took these concerns seriously and prioritized preventing such loss throughout design iterations.

Despite these disadvantages, we believe that the advantages of utilizing a working prototype early on outweigh the challenges. As outlined above, the feedback obtained through real usage gave us valuable feedback regarding technical feasibility, community adoption, and use cases that would have not been possible to derive with prototypes only. The evaluation study proved to be a valuable complement to the free usage of the platform. It provided an opportunity to capture the experiences of non-users, and created a dedicated space for discussing ideas and concerns. Furthermore, it served to uncover usability issues in intended user flows that had gone unnoticed before.

These lessons align with reflections of Resnick and Silverman (2005) based on their experience in technology design, who underscore the importance of iteration and functioning prototypes as conversation starters that lead to insightful discoveries, rather than abstract idea discussions.

In personal science, despite being a largely individual practice, the **community** plays an important role for many individuals. One such significance lies in its motivational role: the social aspect of connecting with like-minded people for discussions has emerged as a frequent motivator for self-research, encouraging sustained engagement in their practice (Senabre Hidalgo et al., 2022). This significance is further underscored by the presence of a community with varying degrees of connection that has persisted for approximately 15 years (Wolf & De Groot, 2020). Community members engage in knowledge exchange through both online and offline channels, including meetings and discussion platforms. However, the absence of a shared collection of knowledge has been noted (Heyen, 2020).

Throughout the design process and evaluation study detailed in Chapters 3 and 4, I actively engaged with a diverse range of community stakeholders. This approach enabled us to explore requirements and perspectives of both experienced practitioners, as well as casual trackers. Importantly, collaborating with individuals in community management positions proved invaluable in gaining insights into previous unsuccessful endeavors, common motivations, challenges, and misconceptions. We also crafted personas to delineate and prioritize different user types based on their motivations and skills.

Similarly, as knowledge management systems are envisioned to be populated and utilized by an existing community, complete with preexisting social connections and established modes of knowledge exchange, an understanding of these dynamics is crucial for a successful adoption of the system (Davidson & Blackman, 2005). Communities of practice have been defined as “groups of people learning from each other while working towards a common interest or goal” (Cheng & Hill, 2022). Initially employed to describe apprenticeship processes in communities, such as tailors, midwives, and non-drinking alcoholics, at the core of this concept lies the acquisition and development of skills and knowledge through learning within a community setting. It is frequently mentioned in the context of legitimate peripheral participation (LPP) (Lave & Wenger, 1991), which explains how newcomers learn a practice and integrate into a community by starting with simple tasks and observing the actions of others. In online contexts, communities of practice can be defined as “affinity spaces where members with similar interests and identities contribute to a shared collection of knowledge in a distributed manner” (Cheng & Hill, 2022). They are often loosely defined, sometimes even through the mere usage of a common hashtag (Shrestha et al., 2021).

The personal science community of practice can also be interpreted as a “**community of volatile practice**”, a term introduced by Kou and Gray (2019) to describe the communities of practice of User Experience (UX) practitioners, which is characterized by being emerging, thus constantly taking up new knowledge from other disciplines and occupations, including academic and non-academic literature as well as personal experiences. The authors suggest the importance of identifying specific roles within the community, such as learners, facilitators, or experienced practitioners, and emphasizing the ways in which these roles can be supported. To achieve this, they propose the assignment of technology stewards responsible for addressing the community’s technological requirements and ensuring their needs are met. While I engaged with community stakeholders throughout the process and focused on roles more explicitly when developing personas, I have only begun to scratch the surface in terms of their roles within the community’s knowledge sharing practice. In this context, the role of the technology steward was assumed by the PhD researcher and the research team, the implications of which will be further discussed in section 5.2.2. Nonetheless, these observations underscore the significance of comprehending the community within peer-

produced knowledge management systems, along with recognizing the ever-evolving, volatile nature of knowledge that technological infrastructures and governance rules must accommodate.

Finally, a pivotal question is how we can determine whether the knowledge management system is successful or moving in a positive direction. In our case, a clear **indicator of success** would be a high adoption rate of the Personal Science Wiki, accompanied by a substantial amount of user-generated content covering a wide range of topics. This would benefit both experienced practitioners, who would have a platform to document their projects and access resources for new projects, as well as newcomers to personal science practice, who could acquire the necessary skills and successfully execute their own projects with the guidance provided on the wiki. Such achievement would signify the resolution of the overarching problem statement that initially motivated this thesis. Success on this scale is influenced by many external factors and can hardly be controlled or predicted. Thus, intermediate measures need to be identified. This is complicated by the fact that there is no “right” way to do a personal science project, projects can span any area of personal data and have a lot of variation, so information needs can vary greatly. Furthermore, by principle, wikis are thought to continuously evolve and are rarely “done”, especially regarding practices like personal science, which keeps evolving with the emergence of new technologies.

Defining measures of success can pose challenges, particularly when dealing with complex problem contexts (Buchanan, 1992). Foote et al. (2023) propose longevity and productivity as success measures for peer production systems. For knowledge management systems, Davidson and Blackman (2005) identify two broad criteria – the system should be both useful and actually used.

Concerning actual usage, we know that the wiki is used by a small number of community contributors, who continue to draft and discuss pages on topics of their interest, documenting their own projects. Similarly, we can determine longevity and productivity: The wiki has remained actively used since its launch, spanning nearly two years. Maintenance tasks such as spam removal and design adjustments based on feedback have been handled by the research team until now; ensuring ongoing maintenance post the conclusion of the PhD project will be imperative for sustained longevity. In terms of productivity, over a hundred content pages have been generated, not including the imports for Show and Tell sessions or Self-Research Chat notes.

Measuring usefulness is less straightforward. To explore usefulness we can explore the functionalities the wiki provides that were not available before, understand their significance and potential, and analyze how individuals are utilizing, contributing to, or referencing the resource. In terms of usefulness, there are a few first indicators of the role the wiki plays:

community members had expressed a wish to have a central, community-owned, open place to document projects and processes, and to link to from other platforms. The use of this has already shown in some cases: wiki links are frequently added to community meeting notes, and it users have been referred to it in Quantified Self subreddits³³. At the same time, the content of the wiki represents a growing accumulation of self-research knowledge, a database that can become an object of research itself to gain new insights about personal science practice. The wiki's value for this purpose will amplify as it grows.

5.1.2 Limitations and Future Work

The development of an effective knowledge management system for the personal science community of practice is a complex and expansive task. This section aims to discuss the limitations of the research and provide connections to future research directions. Through this dissertation project, valuable insights were gained regarding the shortcomings of existing approaches, user requirements, and the potential benefits of utilizing a peer-produced wiki approach. These added understandings also serve as valuable indicators for potential future research directions.

In terms of information needs, study participants frequently expected overview pages for health or wellbeing topics of interest, including best practices and directions to start their practice. Future work could address these information needs in more detail, for example by doing field studies with individuals who develop new projects, in which they reflect on their information needs at each stage.

Similarly, we learned that the narrative format of Show and Tell talks might not be ideal to quickly scan a large amount of projects for relevance. Future research is necessary to determine how to extract and present relevant keywords or procedural information to this end. In terms of the information architecture, the user study has yielded insightful findings that offer new directions for future work. These directions include exploring various entry points tailored to different users, implementing hierarchical structures, and enhancing content linking. It is imperative to implement and test these proposed improvements in practical settings to assess their effectiveness.

This work has made diligent efforts to comprehend and involve a diverse range of stakeholders throughout the design process. Building upon the research conducted by Kou and Gray (2019) on volatile communities of practice, future work should also focus on examining roles within community knowledge management, in order to effectively support them.

³³ <https://www.reddit.com/r/QuantifiedSelf/comments/14c8wq4/wiki/>, accessed 04.07.2023

Additionally, since communities of practice are tightly coupled with situated learning, future work should further examine LPP processes that are already present in the community, meaning how newcomers get in touch with self-research, develop skills, and gradually take more central roles. To this end, parallels could be investigated between personal science and the numerous literature on other communities of practice, in domains like Wikipedia editing (Bryant et al., 2005), development of open source software (Von Krogh et al., 2003), or fanfiction writing (Fiesler et al., 2017).

Similarly, while this work primarily focuses on the connection between personal science and citizen science or peer production perspectives, it could be intriguing to explore the intersections between personal science and other online health communities. There exist numerous interest groups that engage in knowledge exchange on social media or other online platforms, addressing similar subject areas as personal science. For instance, research has been conducted on support, information search behavior and needs within various subject areas of interest in personal science, such as diabetes (Zhang, 2017), mental health (Pretorius et al., 2019), or smoking cessation (Ploderer et al., 2013). Further work can be found on other relevant topics like patient empowerment (Johnston et al., 2013), community support as compared to individualistic approaches (Eagle, 2022), or user engagement and retention (Wan et al., 2020). Examining the parallels and potential synergies between personal science and these online health communities could provide valuable insights and contribute to a broader understanding of collaborative knowledge sharing in the healthcare domain.

A different challenge relates to preventing misinformation and ensuring data privacy regarding sensitive health topics. The quality of online health information has been a frequent focus of research, for example on sources like Wikipedia (Smith, 2020) or social media like TikTok (Milton et al., 2023), since misinformation can induce health risks (Swire-Thompson & Lazer, 2020). In personal science, individuals autonomously choose their own research methods and evaluate the usefulness of their findings. This autonomy is a value, empowering individuals to take control of their own health. The personal science community largely adheres to scientific research principles and fosters critical thinking by actively providing feedback on research designs and potential explanations for observations (Heyen, 2020). Most personal science projects focus on understanding or experimenting with patterns in everyday life, such as changes in diet or bedtime, activities that many people undertake without engaging with communities or healthcare professionals. However, considering that personal science operates in the health domain and aims to scale up, it is essential to address the necessity and implementation of systematic quality control mechanisms for the wiki.

Finally, scaling up is also connected to who the personal science community wants to attract and to what extent current structures represent are suitable and encouraging for people of diverse backgrounds and identities. The sample of stakeholders involved in this design process indicates a predominance of community members primarily from Europe and Northern America, with a majority being male and possessing higher levels of education, particularly in technology and sciences. Connecting personal science with recent work in computer-supported collaborative work could be useful for critically reflecting on questions of epistemic justice and the design of inclusive knowledge spaces (Ajmani et al., 2023; Haimson et al., 2021). Incorporating insights from such research might facilitate the creation of more inclusive knowledge-sharing environments, and can ultimately support the empowerment of a broader segment of society through self-research practices.

5.2 From Participatory Design to Peer Production

Another motivation for this dissertation was to explore peer production as an approach for collaborative knowledge production in citizen science. To achieve this, theory was operationalized into a working model and applied to three case studies. This study aimed to understand and illustrate key platform features of peer production in citizen science platforms. This included understanding motivations for and reasons against adopting peer production features, as well as the identification of potential levers of change for platforms that do not implement this approach (c.f. Chapter 2).

Subsequently, the research focused on developing a peer production approach in a specific use case, namely for knowledge management in the personal science community of practice, as discussed in Chapters 3 and 4. This involved exploring whether peer production aligned with needs and values of the community, prototyping, implementing a solution, and an evaluation study.

While section 5.1. focused on the personal science knowledge management resource and infrastructure, thus the common knowledge object produced by peer production, this chapter reflects on the peer production project itself and the participatory design process leading to it. Even though the findings are specific to the personal science context, they might serve as a valuable reference for anyone considering collaboratively designing and implementing a peer production approach in a community of practice in citizen science contexts and beyond.

5.2.1 Reflections on Challenges

The second chapter of this thesis focused on contextualizing peer production within the field of citizen science in general. citizen science encompasses various practices and is therefore

challenging to generalize. However, the working model provided insights into key characteristics of peer production approaches in citizen science, illustrated through the case studies. By examining three platforms with diverse goals and collaboration approaches, an understanding was obtained regarding the contexts in which the choice of a peer production approach may be appropriate and the **motivations and trade-offs** associated with it. The findings suggest that peer production might be particularly suitable during the design and planning phases of research projects, allowing for bottom-up research, fostering creativity, problem-solving, reuse and adaptation of existing resources. Additionally, there are other potential use cases where harnessing the collective creativity of a diverse community can be beneficial, such as in the discovery or interpretation of patterns in data, or the identification of bugs. However, it is important to consider potential challenges when considering a peer production approach. These challenges may include effectively scaling up projects while maintaining control and ensuring uniformity, as well as addressing biases in data collection and processing.

The subsequent design process with the personal science community of practice, which falls under the larger definition of citizen science (Heyen, 2020), shed light on a different aspect of peer production: the design and maintenance of a peer production infrastructure, the creation of and relationship with the contributor and user community, as well as their engagement within the design process. Instead of providing a finished peer production platform to be filled by the community, I aimed to **involve potential future users during the whole design process**, similar to citizen science projects labeled with terms like “extreme” (Haklay, Muki, 2016), “co-created”, or “collegial” (Shirk et al., 2012), in which citizen scientists work either independently or together with scientists acting in professional capacity during all research phases.

Participatory design has its roots in the 1970s and 80s in Scandinavia, motivated by the empowerment of workers and improving democracy in the workplace. This included learning about and respecting work reality and work processes, and to prioritize and generate prototypes together with future users of technologies (Spinuzzi, 2005).

Citizen science frequently makes use of online or offline methods from participatory design to facilitate participation in research steps for tasks such as idea generation, decision making, or prototyping. These practices are often labeled with terms like “participatory action research” or “community-based participatory research” (Senabre Hidalgo, Perelló, et al., 2021). While the development of or decision for data recording or analysis tools of varying technical complexity is frequently a part of these endeavors (Breen et al., 2019; Lukyanenko et al., 2016; Macintyre, 2016), it is usually one step within a distinct, time bound project for a specific data collection study.

In our case, however, the focus on the development of the technical infrastructure for knowledge accumulation was more explicitly on building a sustainable technical infrastructure for community knowledge accumulation. Similar focal points have been addressed in other projects within the context of Open Science or citizen science. For example, in the development of the data sharing platform DataOne, a participatory design process was conducted, including stakeholder identification, workflow modeling, persona creation, and usability testing (Michener et al., 2012).

It should not be neglected to draw parallels to the development of other peer production platforms. In fact, engagement of users with diverse motivations and skills is a central value of commons-based peer production (CBPP) (Benkler, 2016). Nevertheless, in the reality of free and open source (FOSS) platforms, a lack of meaningful end-user participation has been observed (Nichols & Twidale, 2006). This has consequences such as usability issues or the perception that this software is developed "by experts for experts," which can negatively impact widespread adoption of these platforms (Wubishet et al., 2013). Even in Wikipedia, where theoretically there are fewer technical barriers to contribution, complex rules and norms make it difficult to involve newcomers or contributors who do not fit the dominant demographic (Collier & Bear, 2012; Halfaker et al., 2013). Wubishet et al. (2013) argue that adopting principles from participatory design could enable more meaningful end-user engagement and help to equalize power imbalances in FOSS projects. The following paragraphs will reflect on our experiences with the creation of a peer production infrastructure and community, as well as our attempt to enable a participatory design process with meaningful user engagement.

One important lesson consisted in the realization that the phrase "build it and they will come" does not hold true, and that there is much more to creating a sustainable peer production platform than just the provision of an infrastructure. This realization is in line with observations in many other online platforms and communities. In fact, it has been observed that most online communities, including peer production approaches such as wikis, fail to take off (Kraut et al., 2011). A definitive explanation of success factors is pending, and factors such as communication structures or the integration of participatory design methods have not provided satisfactory explanations thus far (Clement et al., 2008; Foote et al., 2023).

According to Kraut et al. (2011), **building a successful online community** involves three major challenges: carving out a useful niche, defending the niche, and getting to critical mass. The first challenge refers to a niche in terms of the topics that are covered, the people to address, and the supported activities. In our case, existing problems within the personal science community that had not been successfully addressed in the past were the main starting point, which indicates the existence of a promising niche. The topics are centered around personal science projects, and the user base consists of people practicing or interested

in practicing these activities. In doing user research and collaborating with community stakeholders, we refined the niche by deriving specific problems from general problem statements, and developing corresponding solution approaches.

Competing for a niche includes both competing communities or platforms, as well as other ways to spend one's time. To this end authors recommend emphasizing a unique selling proposition, as well as content and user ID sharing with competitor platforms, if applicable. These were the measures I took to this end: Ensuring a unique value proposition compared to other platforms or previous attempts was a primary consideration during the design phase, as discussed in Chapter 3. This involved characteristics such as the open and community-owned nature of the wiki, allowing for collaborative consensus-building on best practices and the ability to report and adapt both completed and ongoing projects. Another important aspect was the value of having a centralized resource that could be easily linked to from other websites. Content-sharing on the wiki is possible and welcome, by sharing links to other resources. Additionally, we shared content from Quantified Self archives by importing talks as seed content. ID sharing does not apply because we decided to not require accounts in line with Hill and Shaw (2021).

Finally, getting to critical mass for a sustainable contributor base is an ongoing challenge. We are confronted with the "hen-and-egg" problem of platforms relying on user-generated content: we need content to attract users, and users to create content. This assumption was backed up by feedback during the usability study, in which participants frequently expressed that a lack of content on topics of their interest made the platform less attractive at this stage, as compared to other online resources. Kraut et al. (2011) recommend seeding content, which we did with project imports, as well as getting early members to contribute content, to subsequently attract more users. Regarding the latter point, most peer production projects never grow bigger than a small number of core contributors (Schweik & English, 2012b). The Personal Science Wiki already has a small contributor base, who use it to document their projects, or share experiences and best practices on self-research topics of their interest. The fact that personal science projects are typically independently run by individuals can be advantageous in this early stage. Individuals seeking an open, accessible place to document and share their projects may not necessarily require the content contributions of others to fulfill this objective. Apart from that, initially, we intentionally kept the contributor base small by limiting the announcement of the wiki's publication to a small community circle. This approach allowed us to share an early minimum viable product version and anticipated that a larger user base could potentially complicate the implementation of changes. Although the feedback from wiki contributors during the early stages proved, and continues to prove valuable in addressing basic technical issues and identifying challenges with the information architecture, it is important to highlight the significance of conducting a usability study that includes participants

who are currently non-users: By involving individuals who have not yet engaged with the platform, valuable insights can be gained regarding the user experience, usability, and potential barriers for new users, including reasons why somebody might not want to use the platform.

Finally, one point in the case of the Personal Science Wiki is that could have a positive influence on maintenance of the platform and potential upscaling is that there already exists a core community, and it does not need to be built from scratch. Moreover, the fundamental values within this community, such as peer behavior, mutual support, and open sharing, align with the principles of peer production. This alignment can contribute to the success of a peer production approach, as the presence of social embeddedness and shared values has been observed as a success factor (Khatri et al., 2022).

Further reflections regard the participatory aspects and **meaningful engagement of community members** throughout the process. This perspective is particularly intriguing as meaningful engagement is a fundamental aim and value across various fields relevant to this dissertation, including citizen science, personal science, peer production, and user-centered design. As elaborated above, the use of participatory design methods has been proposed as a solution to address user-engagement challenges in FOSS (Wubishet et al., 2013), and to co-create citizen science projects (Senabre Hidalgo et al., 2018). However, the adoption of participatory design in research and design also requires critical scrutiny. While genuine participation, mutual learning, and the equalization of power relations serve as motivating factors for participatory design (Luck, 2018), it is important to recognize that these practices are still embedded within existing institutional power dynamics, and might even reinforce them. This issue becomes particularly apparent when academic researchers collaborate with marginalized communities (Harrington et al., 2019; Pierre et al., 2021). Furthermore, the implementation of authentic participatory methods that go beyond tokenism can entail various practical, professional, and personal costs for all parties involved, thereby necessitating careful reflection on their feasibility and relevance in different contexts (Williams et al., 2020).

Inspired by Ahmed et al. (2021) in which the first author uses an autoethnographic approach to reflect on the community-based design process for open-source voice training technology in the context of her PhD, I will reflect on community engagement within my dissertation project in the following. To begin with, the participatory design process was initiated as part of my PhD research, which provided funding and enabled me to dedicate myself full-time to this project. This context fostered a sense of ownership, responsibility, and priority in certain decision-making processes. For instance, considerations regarding technical complexity and study methods were influenced by their compatibility within the three-year timeframe.

Additionally, I agree with the perspectives of Ahmed (2021) and Klocker (2012), who argue that the reliance on a thesis solely authored by the PhD student to demonstrate “individual research competence” reinforces the sense of project ownership and thus a divide between the researcher as a project lead and the community. Similarly, two members of my research team (Bastian Greshake Tzovaras and Mad Ball) became part of the core team leading the project. They have extensive experience leading community meetings and platforms related to personal science, established relationships with many community members, and are themselves some of the most active community members. Thus, their involvement can be viewed as an integral part of the community, rather than as an external design role, providing valuable insights derived from years of engagement. Nonetheless, this arrangement also resulted in some decisions, meeting notes, or documentation remaining within our immediate circle on our institutional cloud server, without direct accessibility for other community members.

Simultaneously, it can be argued that the project was made possible solely within the **context of the PhD**, as it provided the necessary resources and motivation to address this task. Likewise, I faced the challenge of engaging community members in a sustainable and meaningful way, without overburdening them. Since, unlike the core team, most community members engage in personal science in their free time, I aimed to avoid placing excessive demands on them throughout this initially only loosely defined design project which would span several years. In the initial research and ideation phases, I gathered opinions indirectly by extracting motivations, frustrations, and ideas from interviews conducted by my team with self-researchers (Senabre Hidalgo et al., 2022). Problem statements, personas, initial ideas, and non-functional prototypes were developed and discussed within the core team, with some collaboration from other research team members who had experience interacting with personal science practitioners through conducting interviews. Once the concept of the wiki emerged, I engaged an external stakeholder with extensive experience in personal science community management to evaluate the potential and feasibility of the approach. Upon receiving a positive response, we expanded the circle to include participants in self-research chat meetings to introduce the idea, gather their opinions, and obtain suggestions. We encouraged the use of the wiki and actively sought feedback, dedicating time during self-research chats to discuss wiki-related issues. I also created dedicated pages on the wiki for leaving feedback and brainstorming ideas, which were publicly accessible, along with the chat notes. We as the core team collected feedback and implemented it, and dealt with minor or technical issues. We also ensured the maintenance of the wiki, such as removing spam. While we did not ask community members to do these tasks to not overburden them, we regularly reported the changes made to the wiki during self-research chats and asked for feedback. Subsequently, the usability and card sorting study provided dedicated time and space to

discuss wiki issues, ideas, and potential in more detail with wiki contributors, other community members, and potential new users. The combination of structured and open tasks proved to be an effective approach, leading to valuable insights and stimulating discussions. In addition, I would like to emphasize the potential of combining methods of design iterations, such as persona workshops, or testing prototypes, with features offered by peer production: The latter can complement the former with open, always available pathways for users to give feedback or even address tasks by themselves. This can remove bottlenecks and can help integrate feedback of users beyond the participants in time-bound design and evaluation activities.

In hindsight, despite our efforts to create spaces for community members and integrate them into brainstorming and decision-making processes, there was still clear leadership from the core team throughout this project. We did not explicitly assign roles to community members to not overburden individuals who were not acting in professional capacity, and motivated by peer production values of self-assignment of tasks. This, in addition to a lack of extensive open contributing guidelines, and the context of the project being run as part of a PhD, might have reinforced the divide between the core team and other community stakeholders in the design process, similar to the observations described in “the tyranny of structurelessness” (Freeman, 1972).

The primary **motivation for using a participatory design approach** might serve as an additional explanation: While empowerment, engagement and autonomy are values in personal science and peer production, the initial motivation behind the participatory design process in this case was not primarily centered on equalizing power relations between the research team and the personal science community. The motivation was predominantly a practical one: engaging the community to build a solution that effectively addresses a real issue, is useful for the community, and will be actually used. Moreover, the social justice dimension was less prominent in this project, as it did not involve researchers working with a marginalized community, as discussed in Harrington et al. (2019). On the contrary, most stakeholders I collaborated with had affiliations with academic institutions, some of them held professor titles, or had extensive experience in the technology or medical industry. Therefore, the power imbalance of working with a PhD student was less pronounced, despite the leadership role within the project. Additionally, the fundamental problem statements that drove the work had emerged from within the community, the motivation was thus community-based. My supervisor and other members of the laboratory had established relationships with many community members, resembling a peer-to-peer dynamic. Considering these factors, the prioritization of minimizing the workload on other community members and conducting primary development within the core team seems less problematic from a social justice perspective in this specific case. However, a more explicit opening of pathways for other community

members to engage in the work of the core team could have fostered a greater sense of ownership for other community members, potentially enhancing the project and making it more inclusive. Moreover, since the ambition of the personal science community is to expand participation to a broader range of society (Wolf & De Groot, 2020), social justice considerations will undoubtedly become more significant in the future, which underscores the importance of carefully designed participatory processes moving forward.

Finally, the growing conversations surrounding participatory approaches in domains like computer-supported collaborative work and citizen science unfold in the context of diminishing presence of expansive projects rooted in community-based production (Hill & Shaw, 2019). Recently, there has been a notable exodus and protests on the major social platforms Twitter and Reddit due to recent acquisitions and policy changes (Pierce, 2023). These developments underscore the significance of community-based resources, commons, and more inclusive power dynamics as counter responses: Ultimately, this issue revolves around the fundamental question of who shapes the future landscape of the internet.

5.2.2 Limitations and Future Work

The co-creation of a peer production solution with the personal science community of practice is a multifaceted task that presents challenges not only in terms of infrastructure and the common knowledge object itself (as discussed in section 5.2.), but also in terms of meaningful community engagement through participatory design methods, community-building, maintenance, and establishing pathways for ongoing resource improvements. This section aims to address the limitations of the research and establish connections to future research directions.

To begin with, although the intention was to engage the community and actively integrate them into the development process of the peer production approach, the initial focus of the work did not prioritize the participatory design process. The significance of participatory design was only fully recognized in later phases and with hindsight. Moreover, as process analysis was not initially planned, incomplete notes prevented a comprehensive autoethnographic reflection on the design process. Meaningful engagement and equitable participatory design methods have been subject of recent discussions (Harrington et al., 2019; Pierre et al., 2021), and this work reinforces the importance of early focus and co-development of methods in future community-centered design processes. Future work should integrate explicit designation of roles, and explicit open contributing guidelines. Additionally, autoethnographic methods, as demonstrated by Ahmed et al. (2021), can aid reflection on experiences, for example aided by keeping a research diary. While during the PhD meeting notes, as well as notes on the

design process were frequently taken, they were not taken with the aim to do an autoethnographic study, and were thus not consistent or complete throughout the whole process.

Exploring the synergies between peer production, LPP, and participatory design to offer pathways for continuous user engagement in design is an interesting avenue for future research (Wubishet et al., 2013), considering that they all value and offer features for user engagement in their own way.

Another emerging requirement during the process was the challenge of community-building and achieving critical mass within the wiki. Future work should address this issue, potentially testing the appropriateness of design claims used in Kraut et al. (2011) for peer production and citizen science contexts. Since governance is a crucial aspect of peer production, it is also necessary to focus on effective mechanisms for integrating community governance, for example by referring to Fuster Morell et al. (2021).

Furthermore, it is crucial to test peer production approaches in further citizen science contexts, as generalization from the findings of the personal science wiki case study is limited, considering the vastness of the field. This thesis can serve as a reference point by providing insights into motivations, peer production features applicable to citizen science contexts more broadly, and lessons from the practical implementation in a specific use case, extending beyond theoretical concepts and elaborations.

5.3 Conclusion

The aim of this thesis was to enhance the comprehension of peer production within the context of citizen science, with a specific emphasis on personal science as a case study. To achieve this goal, the initial phase of this research delved into key aspects of peer production platforms and their implementation in citizen science environments. Subsequently, I employed the acquired knowledge to a citizen science community of practice, designing a peer production approach in collaboration with the personal science community.

Operationalizing peer production theory, in the first part of the research I identified seven elements of peer production platforms adapted to the general citizen science context. These elements include a common research object, a wide range of tasks, granularity, modularity, and low cost of integration, equipotential self-selection, quality control mechanisms, learning trajectories, and direct and indirect coordination features. Through the examination of three case studies on citizen science platforms, this research did not only provide examples of the implementation of peer production features in citizen science but also enhanced the understanding of motivations and tradeoffs associated with peer production as compared to

other collaborative approaches like crowdsourcing. The study suggests that reasons for not adopting peer production can include the fast scaling of research studies, the need for exclusive data rights, and the control exerted by research teams to ensure randomization and minimize bias. On the other hand, motivations for implementing peer production can include creativity, problem-solving, discovery, mutual support for research design development, and allowing self-identification of tasks by experts.

By adopting a community-centered, participatory design thinking approach, in the second part of the research I identified issues related to the accumulation of a shared knowledge resource in personal science. Such a resource could allow newcomers or experienced users to access existing community knowledge efficiently, reducing the need to start projects from scratch or rely on the collection of best practices from a variety of potentially outdated or biased online resources. To address this, a wiki approach was prototyped, which proved in line with community values, suitable for the task and feasible in practice. The wiki was seeded with content through automatic imports and usage by a core contributor base. Iteratively, through real-life usage and a usability and card sorting study, the wiki demonstrated its value as a research object by itself, in revealing open knowledge management issues and for discussing solutions. The key issues identified included usability challenges, information architecture improvements, and accessibility of the Show and Tell format for efficient determination of relevance, method extraction, and reuse. Additionally, the study provided reflections on challenges and best practices associated with participatory design. It highlighted the importance of consciously creating pathways for meaningful engagement, and emphasized the need to strike a balance between time-bound academic research projects and the capacities of community members and long-term community objectives. Furthermore, the potential of using peer production infrastructures in supporting ongoing participatory design processes was discussed.

The main contributions of this thesis include the development and deployment of the Personal Science Wiki, which serves as an infrastructure for peer-producing a shared knowledge resource for the personal science community that is already in active use. Beyond the wiki, the study shed light on the mental models individuals hold regarding self-research knowledge, expectations of information needs, and issues with information formats. These insights inform the design of information architectures and content requirements for personal science knowledge resources more broadly. By taking steps to remove barriers to knowledge sharing, this research ultimately contributes to the goal of fostering wider participation in personal science and exploring its potential for individual well-being, clinical discoveries, and public health advancements.

Moreover, the participatory design process has yielded valuable lessons and best practices that can serve as guidance for adapting peer production infrastructures to other communities that share characteristics with personal science, in order to support them in leveraging collective intelligence to extract common knowledge from individual practices. When I attempted this process in the context of personal science, I encountered a complex challenge. The relevant knowledge involves a nuanced interplay between explicit and tacit knowledge, as it revolves around learning a continuously evolving practice. Recorded talks and their transcription can convey tacit knowledge, but this format lacks efficiency in a knowledge management system for swiftly discovering relevant content and extracting methods for reuse. Likewise, the design of metadata and information architectures must accurately reflect mental models of different target user groups while adhering to platform standards and ensuring usability. Community knowledge management is inherently a social practice, involving various stakeholders who contribute, consume, and progressively enhance content, structure, and governance mechanisms based on user feedback. Despite encountering challenges related to community building and meaningful yet unburdening participatory mechanisms, we show how blending peer production with participatory design methods can offer an infrastructure for integrating feedback loops and principles of openness and participation from the early design phases through later stages of system implementation and maintenance.

Finally, this research contributes to the broader field of citizen science by enhancing the comprehension of peer production as a form of online collaboration within citizen science. By offering a comprehensive operationalization of peer production theory and presenting tangible instances of peer production characteristics extracted from case studies of different citizen science platforms and a design process involving the personal science community, this study elucidates both the theoretical underpinnings and practical implications of adopting a peer production approach in diverse citizen science contexts. Through the identification of key characteristics, motivations, trade-offs, challenges, and strategies concerning the design, implementation, and sustainability of peer production within these contexts, this research equips stakeholders with tools for informed decision-making and the implementation of online collaboration approaches tailored to the objectives of citizen science projects. In doing so, this work aims to contribute to the advancement of citizen science initiatives, facilitating the realization of their full potential and fostering deeper engagement of participants.

Bibliography

- Adair, M. (2011, March 21). Music review: YouTube Symphony Orchestra's final concert. *Los Angeles Times*. <https://www.latimes.com/archives/blogs/culture-monster-blog/story/2011-03-21/music-review-youtube-symphony-orchestras-final-concert>
- Ahmed, A. A., Kok, B., Howard, C., & Still, K. (2021). Online Community-based Design of Free and Open Source Software for Transgender Voice Training. *Proceedings of the ACM on Human-Computer Interaction*, 4(CSCW3), 1–27. <https://doi.org/10.1145/3434167>
- Ajmani, L., Houtti, M., Foriest, J., Vincent, N., Devito, M. A., & Johnson, I. (2023). *Epistemic injustice in online communities: Unpacking the values of knowledge creation and curation within CSCW applications*.
- Ambrosini, V., & Bowman, C. (2001). Tacit Knowledge: Some Suggestions for Operationalization. *Journal of Management Studies*, 38(6), 811–829. <https://doi.org/10.1111/1467-6486.00260>
- An, X., Deng, H., Chao, L., & Bai, W. (2014). Knowledge management in supporting collaborative innovation community capacity building. *Journal of Knowledge Management*, 18(3), 574–590. <https://doi.org/10.1108/JKM-10-2013-0413>
- Antin, J., & Cheshire, C. (2010). Readers are not free-riders: Reading as a form of participation on wikipedia. *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work*, 127–130. <https://doi.org/10.1145/1718918.1718942>
- Anton, V., Germishuys, J., Bergström, P., Lindegarth, M., & Obst, M. (2021). An open-source, citizen science and machine learning approach to analyse subsea movies. *Biodiversity Data Journal*, 9, e60548. <https://doi.org/10.3897/BDJ.9.e60548>
- Arnstein, S. R. (1969). A Ladder Of Citizen Participation. *Journal of the American Institute of Planners*, 35(4), 216–224. <https://doi.org/10.1080/01944366908977225>

- Awazu, Y., & Desouza, K. C. (2004). Open knowledge management: Lessons from the open source revolution. *Journal of the American Society for Information Science and Technology*, 55(11), 1016–1019. <https://doi.org/10.1002/asi.20050>
- Ball, M. P., Bobe, J. R., Chou, M. F., Clegg, T., Estep, P. W., Lunshof, J. E., Vandewege, W., Zaranek, A., & Church, G. M. (2014). Harvard Personal Genome Project: Lessons from participatory public research. *Genome Medicine*, 6(2), 10. <https://doi.org/10.1186/gm527>
- Bastien, J. M. C. (2010). Usability testing: A review of some methodological and technical aspects of the method. *International Journal of Medical Informatics*, 79(4), e18–e23. <https://doi.org/10.1016/j.ijmedinf.2008.12.004>
- Battisti, E., Alfiero, S., & Leonidou, E. (2022). Remote working and digital transformation during the COVID-19 pandemic: Economic–financial impacts and psychological drivers for employees. *Journal of Business Research*, 150, 38–50. <https://doi.org/10.1016/j.jbusres.2022.06.010>
- Bautista-Puig, N., De Filippo, D., Mauleón, E., & Sanz-Casado, E. (2019). Scientific Landscape of Citizen Science Publications: Dynamics, Content and Presence in Social Media. *Publications*, 7(1), 12. <https://doi.org/10.3390/publications7010012>
- Bechhofer, S., De Roure, D., Gamble, M., Goble, C., & Buchan, I. (2010). Research Objects: Towards Exchange and Reuse of Digital Knowledge. *Nature Precedings*. <https://doi.org/10.1038/npre.2010.4626.1>
- Benkler, Y. (2002). Coase's Penguin, or, Linux and "The Nature of the Firm." *The Yale Law Journal*, 112(3), 369. <https://doi.org/10.2307/1562247>
- Benkler, Y. (2006). *The wealth of networks: How social production transforms markets and freedom*. Yale University Press.
- Benkler, Y. (2016). Peer production and cooperation. In J. Bauer & M. Latzer (Eds.), *Handbook on the Economics of the Internet* (pp. 91–119). Edward Elgar Publishing. <https://doi.org/10.4337/9780857939852>

- Benkler, Y., Shaw, A., & Hill, B. M. (2015). Peer Production: A Form of Collective Intelligence. In T. Malone & M. Bernstein (Eds.), *Handbook of Collective Intelligence* (p. 33). MIT Press.
- Bietz, M., Patrick, K., & Bloss, C. (2019). Data Donation as a Model for Citizen Science Health Research. *Citizen Science: Theory and Practice*, 4(1), 6.
<https://doi.org/10.5334/cstp.178>
- Bonney, R. (1996). Citizen Science: A Lab Tradition. *Living Bird: For the Study and Conservation of Birds*, 15(4), 7–15.
- Boone, M. E., & Basille, M. (2019). Using iNaturalist to Contribute Your Nature Observations to Science. *EDIS*, 2019(4), 5. <https://doi.org/10.32473/edis-uw458-2019>
- Botero, A., & Saad-Sulonen, J. (2013). Peer-Production in Public Services: Emerging Themes for Design Research and Action. In E. Manzini & E. Staszowski (Eds.), *Public and collaborative: Exploring the intersection of design, social innovation and public policy* (First printing, September 2013).
- Breen, J., Dosemagen, S., Blair, D., & Barry, L. (2019). Public laboratory: Play and civic engagement. In *The Playful Citizen: Civic Engagement in a Mediatized Culture* (pp. 162–174).
- Bretthauer, D. (2001). Open Source Software: A History. *Published Works*, 7.
https://opencommons.uconn.edu/libr_pubs/7
- Brown, T. (2008). Design Thinking. *Harvard Business Review*.
- Bruns, A. (2008). *Blogs, Wikipedia, Second life, and Beyond: From production to produsage*. Peter Lang.
- Bryant, S. L., Forte, A., & Bruckman, A. (2005). Becoming Wikipedian: Transformation of participation in a collaborative online encyclopedia. *Proceedings of the 2005 International ACM SIGGROUP Conference on Supporting Group Work - GROUP '05*, 1. <https://doi.org/10.1145/1099203.1099205>
- Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, 8(2), 5.
<https://doi.org/10.2307/1511637>

- Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. *Journal of Research in Nursing*, 25(8), 652–661.
<https://doi.org/10.1177/1744987120927206>
- Capra, M. G. (2005). Factor Analysis of Card Sort Data: An Alternative to Hierarchical Cluster Analysis. *PROCEEDINGS of the HUMAN FACTORS AND ERGONOMICS SOCIETY 49th ANNUAL MEETING*.
- Carroll, J. M., & Reitman Olson, J. (Eds.). (1988). Mental Models in Human-Computer Interaction: Research Issues About What the User of Software Knows. In *Handbook of Human-Computer-Interaction* (pp. 45–65).
- Carroll, N., & Richardson, I. (2016). Aligning healthcare innovation and software requirements through design thinking. *Proceedings of the International Workshop on Software Engineering in Healthcare Systems*, 1–7.
<https://doi.org/10.1145/2897683.2897687>
- Chang, J., & Yang, J. (2009). What Drives People to Contribute in Peer Production Projects? - A Review of the Participating Motivaton of Peer Producers. *2009 Third International Symposium on Intelligent Information Technology Application Workshops*, 50–53.
<https://doi.org/10.1109/IITAW.2009.53>
- Chen, S.-L. (2019). How Empowering Is Citizen Science? Access, Credits, and Governance for the Crowd. *East Asian Science, Technology and Society*, 13(2), 215–234.
<https://doi.org/10.1215/18752160-7497711>
- Cheng, R., & Hill, B. M. (2022). Many Destinations, Many Pathways: A Quantitative Analysis of Legitimate Peripheral Participation in Scratch. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2), 1–26. <https://doi.org/10.1145/3555106>
- Chi, E. H., Pirolli, P., Chen, K., & Pitkow, J. (2001). Using Information Scent to Model User Information Needs and Actions on the Web. *CHI '01: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*.

- Chiaravalloti, R. M., Skarlatidou, A., Hoyte, S., Badia, M. M., Haklay, M., & Lewis, J. (2022). Extreme citizen science: Lessons learned from initiatives around the globe. *Conservation Science and Practice*, 4(2). <https://doi.org/10.1111/csp2.577>
- Choe, E. K., Lee, N. B., Lee, B., Pratt, W., & Kientz, J. A. (2014). Understanding quantified-selfers' practices in collecting and exploring personal data. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1143–1152. <https://doi.org/10.1145/2556288.2557372>
- Chu, K. (n.d.). *Double Diamond DESIGN PROCESS*. Retrieved July 28, 2023, from <https://servicedesignvancouver.ca/wp-content/uploads/2014/11/SDV-DoubleDiamond.pdf>
- CK-Wissen:Portal. (n.d.). CK-Wissen:Portal. Retrieved July 3, 2023, from <https://ck-wissen.de/ckwiki/index.php?title=CK-Wissen:Portal>
- Clement, A., Costantino, T., Kurtz, D., & Tissenbaum, M. (2008). Participatory design and web 2.0: The case of PIPWatch, the collaborative privacy toolbar. *Proceedings Participatory Design Conference*.
- Collier, B., & Bear, J. (2012). *Conflict, Confidence, or Criticism: An Empirical Examination of the Gender Gap in Wikipedia*. CSCW'12, Seattle, Washington, USA.
- Collins, A., & Gentner, D. (1987). How people construct mental models. In D. Holland & N. Quinn (Eds.), *Cultural Models in Language and Thought* (1st ed., pp. 243–266). Cambridge University Press. <https://doi.org/10.1017/CBO9780511607660.011>
- Craik, K. J. W. (1943). *The nature of explanation*. University Press, Macmillan.
- Crawford, K. (2018). Design Thinking Toolkit, Activity 9 – Rose, Bud, Thorn. *Atomic Spin*. <https://www.colorado.edu/researchinnovation/rose-bud-thorn>
- Crumley, C. L. (2015). Heterarchy. In R. A. Scott & S. M. Kosslyn (Eds.), *Emerging Trends in the Social and Behavioral Sciences* (1st ed., pp. 1–14). Wiley. <https://doi.org/10.1002/9781118900772.etrds0158>

- Davidson, G., & Blackman, D. (2005). The Role of Mental Models in the Development of Knowledge Management Systems. *International Journal of Organisational Behaviour*, 10(6), 757–769.
- De Groot, M., Drangsholt, M., Martin-Sanchez, F., & Wolf, G. (2017). Single Subject (N-of-1) Research Design, Data Processing, and Personal Science. *Methods of Information in Medicine*, 56(06), 416–418. <https://doi.org/10.3414/ME17-03-0001>
- Design Council. (2007). *Eleven lessons: Managing design in eleven global brands. A study of the design process*. <https://www.designcouncil.org.uk/our-work/skills-learning/resources/11-lessons-managing-design-global-brands>
- Di Cecco, G. J., Barve, V., Belitz, M. W., Stucky, B. J., Guralnick, R. P., & Hurlbert, A. H. (2021). Observing the Observers: How Participants Contribute Data to iNaturalist and Implications for Biodiversity Science. *BioScience*, 71(11), 1179–1188. <https://doi.org/10.1093/biosci/biab093>
- Dinh-Le, C., Chuang, R., Chokshi, S., & Mann, D. (2019). Wearable Health Technology and Electronic Health Record Integration: Scoping Review and Future Directions. *JMIR mHealth and uHealth*, 7(9), e12861. <https://doi.org/10.2196/12861>
- Dipple, A., Raymond, K., & Docherty, M. (2012). Stigmergy in web 2.0: A model for site dynamics. *Proceedings of the 3rd Annual ACM Web Science Conference on - WebSci '12*, 86–94. <https://doi.org/10.1145/2380718.2380731>
- Dixon, S. (2023). *Number of social media users worldwide from 2017 to 2027*. Statista. <https://www.statista.com/statistics/278414/number-of-worldwide-social-network-users/>
- Dolejšová, M., & Kera, D. (2017). Soylent Diet Self-Experimentation: Design Challenges in Extreme Citizen Science Projects. *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 2112–2123. <https://doi.org/10.1145/2998181.2998365>
- Dulong de Rosnay, M. (2013). *Peer-production online communities infrastructures*. 65–68. <https://doi.org/hal-00833476>

- Dulong de Rosnay, M. (2021). Open Licensing Peer Production. In M. O'Neil, C. Pentzold, & S. Toupin (Eds.), *The Handbook of Peer Production* (1st ed., pp. 109–122). Wiley.
- Eagle, T. (2022). Exploring Collective Medical Knowledge and Tensions in Online ADHD Communities. *Companion Computer Supported Cooperative Work and Social Computing*, 245–250. <https://doi.org/10.1145/3500868.3561402>
- ECSA (European Citizen Science Association). (2015). *Ten Principles of Citizen Science*. <https://doi.org/10.17605/OSF.IO/XPR2N>
- Eknoyan, G. (1999). Santorio Sanctorius (1561–1636) – Founding Father of Metabolic Balance Studies. *American Journal of Nephrology*, 19(2), 226–233. <https://doi.org/10.1159/000013455>
- Elliott, M. (2006). Stigmergic Collaboration: The Evolution of Group Work. *M/C Journal*, 9(2). <https://doi.org/10.5204/mcj.2599>
- Endmann, A., Fischer, H., & Krökel, M. (Eds.). (2015). Casolysis 2.0: Flexible Auswertung von Card Sorting Experimenten. In *Mensch und Computer 2015 – Usability Professionals* (pp. 445–456). De Gruyter. <https://doi.org/10.1515/9783110443882-056>
- Epstein, D. A., Caldeira, C., Figueiredo, M. C., Lu, X., Silva, L. M., Williams, L., Lee, J. H., Li, Q., Ahuja, S., Chen, Q., Dowlatyari, P., Hilby, C., Sultana, S., Eikey, E. V., & Chen, Y. (2020). Mapping and Taking Stock of the Personal Informatics Literature. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 4(4), 126:1-126:38. <https://doi.org/10.1145/3432231>
- Evans, S., Davis, K., Evans, A., Campbell, J. A., Randall, D. P., Yin, K., & Aragon, C. (2017). More Than Peer Production: Fanfiction Communities as Sites of Distributed Mentoring. *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 259–272. <https://doi.org/10.1145/2998181.2998342>

- Fan, W., Zhao, Z., Li, J., Liu, Y., Mei, X., Wang, Y., Wen, Z., Wang, F., Zhao, X., Tang, J., & Li, Q. (2023). *Recommender Systems in the Era of Large Language Models (LLMs)* (arXiv:2307.02046). arXiv. <http://arxiv.org/abs/2307.02046>
- Feng, S., Mäntymäki, M., Dhir, A., & Salmela, H. (2021). How Self-tracking and the Quantified Self Promote Health and Well-being: Systematic Review. *Journal of Medical Internet Research*, 23(9), e25171. <https://doi.org/10.2196/25171>
- Ferretti, F. (2019). Mapping do-it-yourself science. *Life Sciences, Society and Policy*, 15(1), 1. <https://doi.org/10.1186/s40504-018-0090-1>
- Fiesler, C., Morrison, S., Shapiro, R. B., & Bruckman, A. S. (2017). Growing Their Own: Legitimate Peripheral Participation for Computational Learning in an Online Fandom Community. *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 1375–1386. <https://doi.org/10.1145/2998181.2998210>
- Foote, J., Shaw, A., & Hill, B. M. (2023). Communication networks do not predict success in attempts at peer production. *Journal of Computer-Mediated Communication*, 28(3), zmad002. <https://doi.org/10.1093/jcmc/zmad002>
- Foucault, M. (1977). *Discipline and punish: The birth of the prison*. Pantheon Books.
- Freeman, J. (1972). The Tyranny of Structurelessness. *Berkeley Journal of Sociology*, 17(1972–1973), 151–164.
- Fuster Morell, M., Senabre Hidalgo, E., & Cigarini, A. (2021). *A framework for assessing the commons qualities of citizen science: Comparative analysis of five digital platforms*.
- Gasson, S., & Purcell, M. (2018). Legitimate peripheral participation in hybrid FOSS community innovation. *Proceedings of the 51st Hawaii International Conference on System Sciences 2018*, 4554–4563.
- GBIF: The Global Biodiversity Information Facility. (2022). *What is GBIF?* <https://www.gbif.org/what-is-gbif>

- Ghalavand, H., Panahi, S., & Sedghi, S. (2020). Opportunities and challenges of social media for health knowledge management: A narrative review. *Journal of Education and Health Promotion, 9*(1), 144. https://doi.org/10.4103/jehp.jehp_754_19
- Gilmour, J., Machin, T., Brownlow, C., & Jeffries, C. (2020). Facebook-based social support and health: A systematic review. *Psychology of Popular Media, 9*(3), 328–346. <https://doi.org/10.1037/ppm0000246>
- Goi, H. C., & Tan, W.-L. (2021). Design Thinking as a Means of Citizen Science for Social Innovation. *Frontiers in Sociology, 6*, 629808. <https://doi.org/10.3389/fsoc.2021.629808>
- Granados, C., & Pareja-Eastaway, M. (2019). How do collaborative practices contribute to innovation in large organisations? The case of hackathons. *Innovation, 21*(4), 487–505. <https://doi.org/10.1080/14479338.2019.1585190>
- Greshake Tzovaras, B., Angrist, M., Arvai, K., Dulaney, M., Estrada-Galiñanes, V., Gunderson, B., Head, T., Lewis, D., Nov, O., Shaer, O., Tzovara, A., Bobe, J., & Ball, M. P. (2018). *Open Humans: A platform for participant-centered research and personal data exploration* [Preprint]. Bioinformatics. <https://doi.org/10.1101/469189>
- Greshake Tzovaras, B., Angrist, M., Arvai, K., Dulaney, M., Estrada-Galiñanes, V., Gunderson, B., Head, T., Lewis, D., Nov, O., Shaer, O., Tzovara, A., Bobe, J., & Price Ball, M. (2019). Open Humans: A platform for participant-centered research and personal data exploration. *GigaScience, 8*(6). <https://doi.org/10.1093/gigascience/giz076>
- Greshake Tzovaras, B., Senabre, E., Alexiou, K., Baldy, L., Morane, B., Bussod, I., Fribourg, M., Wac, K., Wolf, G., & Ball, M. (2021). *Quantified Flu: An individual-centered approach to gaining sickness-related insights from wearable data* [Preprint]. Health Informatics. <https://doi.org/10.1101/2021.03.10.21252242>
- Grossman, L. (2006, December 25). You—Yes, You—Are TIME’s Person of the Year. *Time Magazine U.S.* <https://time.com/time/magazine/article/0,9171,1569514,00.html>

- Gumienny, R., Gericke, L., Wenzel, M., & Meinel, C. (2013). Supporting creative collaboration in globally distributed companies. *Proceedings of the 2013 Conference on Computer Supported Cooperative Work*, 995–1007.
<https://doi.org/10.1145/2441776.2441890>
- Hafeez, K., & Alghatas, F. (2007). *Knowledge Management in a Virtual Community of Practice using Discourse Analysis*. 5(1).
- Haimson, O. L., Dame-Griff, A., Capello, E., & Richter, Z. (2021). Tumblr was a trans technology: The meaning, importance, history, and future of trans technologies. *Feminist Media Studies*, 21(3), 345–361.
<https://doi.org/10.1080/14680777.2019.1678505>
- Haklay, M., Fraisl, D., Greshake Tzovaras, B., Hecker, S., Gold, M., Hager, G., Ceccaroni, L., Kieslinger, B., Wehn, U., Woods, S., Nold, C., Balazs, B., Mazzonetto, M., Rüfenacht, S., Shanley, L., Wagenknecht, K., Motion, A., Sforzi, A., Riemenschneider, D., ... Vohland, K. (2021). Contours of citizen science: A vignette study. *Royal Society Open Science*, 8(8). <https://doi.org/10.1098/rsos.202108>
- Haklay, Muki. (2016, April 29). Introducing “Doing It Together Science” – an EU citizen science project. *Extreme Citizen Science Blog*.
<https://uclexcites.blog/2016/04/29/introducing-doing-it-together-science-an-eu-citizen-science-project/>
- Halavais, A. (2013). Home made big data? Challenges and opportunities for participatory social research. *First Monday*, 18(10). <https://doi.org/10.5210/fm.v18i10.4876>
- Halfaker, A., Geiger, R. S., Morgan, J. T., & Riedl, J. (2013). The Rise and Decline of an Open Collaboration System: How Wikipedia’s Reaction to Popularity Is Causing Its Decline. *American Behavioral Scientist*, 57(5), 664–688.
<https://doi.org/10.1177/0002764212469365>
- Halfaker, A., & Taraborelli, D. (2013). *Making Peripheral Participation Legitimate: Reader Engagement Experiments in Wikipedia*.

- Harrington, C., Erete, S., & Piper, A. M. (2019). Deconstructing Community-Based Collaborative Design: Towards More Equitable Participatory Design Engagements. *Proceedings of the ACM on Human-Computer Interaction*, 3(CSCW), 1–25. <https://doi.org/10.1145/3359318>
- Hawthornthwaite, C. (2009). Crowds and Communities: Light and Heavyweight Models of Peer Production. *Crowds and Communities: Light and Heavyweight Models of Peer Production*, 1–10. <https://doi.org/10.1109/HICSS.2009.137>
- Hecker, S., Garbe, Lisa, & Bonn, Aletta. (2018). The European citizen science landscape—A snapshot. In S. Hecker, Haklay, Muki, Bowser, Anne, Makuch, Zen, Vogel, Johannes, & Bonn, Aletta (Eds.), *Citizen Science: Innovation in Open Science, Society and Policy* (pp. 190–200). UCL Press.
- Hedegaard, S., & Simonsen, J. G. (2013). Extracting usability and user experience information from online user reviews. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2089–2098. <https://doi.org/10.1145/2470654.2481286>
- Hepp, A., Alpen, S., & Simon, P. (2021). Beyond empowerment, experimentation and reasoning: The public discourse around the Quantified Self movement. *Communications*, 46(1), 27–51. <https://doi.org/10.1515/commun-2019-0189>
- Heyen, N. B. (2016). Self-Tracking as Knowledge Production: Quantified Self between Prosumption and Citizen Science. In S. Selke (Ed.), *Lifelogging: Digital self-tracking and Lifelogging—Between disruptive technology and cultural transformation* (pp. 283–301). Springer Fachmedien. https://doi.org/10.1007/978-3-658-13137-1_16
- Heyen, N. B. (2020). From self-tracking to self-expertise: The production of self-related knowledge by doing personal science. *Public Understanding of Science*, 29(2), 124–138. <https://doi.org/10.1177/0963662519888757>
- Heyen, N. B., & Dickel, S. (2019). Was ist Personal Health Science? In N. B. Heyen, S. Dickel, & A. Brüninghaus (Eds.), *Personal Health Science: Persönliches*

- Gesundheitswissen zwischen Selbstsorge und Bürgerforschung* (pp. 1–19). Springer Fachmedien. https://doi.org/10.1007/978-3-658-16428-7_1
- Hill, B. M., & Shaw, A. (2019). Wikipedia and the End of Open Collaboration? *Wikipedia@20*.
- Hill, B. M., & Shaw, A. (2021). The Hidden Costs of Requiring Accounts: Quasi-Experimental Evidence From Peer Production. *Communication Research*, *48*(6), 771–795. <https://doi.org/10.1177/0093650220910345>
- History of Wikipedia. (n.d.). In *Wikipedia*. Wikimedia Foundation. Retrieved July 21, 2023, from https://en.wikipedia.org/wiki/History_of_Wikipedia
- Hochmair, H. H., Scheffrahn, R. H., Basille, M., & Boone, M. (2020). Evaluating the data quality of iNaturalist termite records. *PLOS ONE*, *15*(5), e0226534. <https://doi.org/10.1371/journal.pone.0226534>
- Hossain, M., & Kauranen, I. (2015). Crowdsourcing: A comprehensive literature review. *Strategic Outsourcing: An International Journal*, *8*(1), 2–22. <https://doi.org/10.1108/SO-12-2014-0029>
- Howe, J. (2006). The Rise of Crowdsourcing. *Wired*. <https://www.wired.com/2006/06/crowds/>
- Irwin, A. (1995). *Citizen science: A study of people, expertise, and sustainable development*. Routledge.
- ISO. (1999). *ISO 13407:1999(en): Human-centred design processes for interactive systems*. International Organization for Standardization. <https://www.iso.org/obp/ui/#iso:std:iso:13407:ed-1:v1:en>
- ISO. (2018). *ISO 9241-11: Ergonomics of human-system interaction—Part 11: Usability: Definitions and concepts*. International Organization for Standardization. <https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en>
- Jackson, C., Crowston, K., Østerlund, C., & Harandi, M. (2018). Folksonomies to Support Coordination and Coordination of Folksonomies. *Computer Supported Cooperative Work (CSCW)*, *27*(3–6), 647–678. <https://doi.org/10.1007/s10606-018-9327-z>

- Jackson, S. J., Bailey, M., & Welles, B. F. (2020). *#HashtagActivism: Networks of race and gender justice*. MIT press.
- Jain, L., Jamieson, K., Mankoff, R., Nowak, R., & Sievert, S. (2020). *The New Yorker Cartoon Caption Contest Dataset* [dataset]. <https://nextml.github.io/caption-contest-data/>
- Jarman, A. M. (2020). *Hierarchical Cluster Analysis: Comparison of Single linkage, Complete linkage, Average linkage and Centroid Linkage Method*.
- Jeng, J. (2005). Usability Assessment of Academic Digital Libraries: Effectiveness, Efficiency, Satisfaction, and Learnability. *Libri*, 55(2–3).
<https://doi.org/10.1515/LIBR.2005.96>
- Jin, H., Peng, Y., Chen, J., & Park, S. T. (2022). Research on the Connotation and Dimension of Consumers' Quantified-Self Consciousness. *Sustainability*, 14(3), Article 3. <https://doi.org/10.3390/su14031504>
- Johnston, A. C., Worrell, J. L., Di Gangi, P. M., & Wasko, M. (2013). Online health communities: An assessment of the influence of participation on patient empowerment outcomes. *Information Technology & People*, 26(2), 213–235.
<https://doi.org/10.1108/ITP-02-2013-0040>
- Jones, N. A., Ross, H., Lynam, T., Perez, P., & Leitch, A. (2011). Mental Models: An Interdisciplinary Synthesis of Theory and Methods. *Ecology and Society*, 16(1).
- Kasperowski, D., & Kullenberg, C. (2018). The many Modes of Citizen Science. *Science & Technology Studies*, 2–7. <https://doi.org/10.23987/sts.74404>
- Katsanos, C., Tselios, N., Avouris, N., Demetriadis, S., Stamelos, I., & Angelis, L. (2019). Cross-study Reliability of the Open Card Sorting Method. *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–6.
<https://doi.org/10.1145/3290607.3312999>
- Kempner, J., & Bailey, J. (2019). Collective self-experimentation in patient-led research: How online health communities foster innovation. *Social Science & Medicine*, 238, 112366. <https://doi.org/10.1016/j.socscimed.2019.112366>

- Khatri, S., Shaw, A., Dasgupta, S., & Hill, B. M. (2022). The social embeddedness of peer production: A comparative qualitative analysis of three Indian language Wikipedia editions. *CHI Conference on Human Factors in Computing Systems*, 1–18.
<https://doi.org/10.1145/3491102.3501832>
- Khusro, S., Ali, Z., & Ullah, I. (2016). Recommender Systems: Issues, Challenges, and Research Opportunities. In K. J. Kim & N. Joukov (Eds.), *Information Science and Applications (ICISA) 2016* (Vol. 376, pp. 1179–1189). Springer Singapore.
https://doi.org/10.1007/978-981-10-0557-2_112
- Klocker, N. (2012). Doing Participatory Action Research and Doing a PhD: Words of Encouragement for Prospective Students. *Journal of Geography in Higher Education*, 36(1), 149–163. <https://doi.org/10.1080/03098265.2011.589828>
- Kloppenborg, K., & Greshake Tzovaras, B. (2023). *Cardsort: A Python package to cluster and visualize data from open card sorting tasks* (v0.2.27) [Computer software]. Zenodo. <https://doi.org/10.5281/ZENODO.8206282>
- Kniffin, K. M., Narayanan, J., Anseel, F., Antonakis, J., Ashford, S. P., Bakker, A. B., Bamberger, P., Bapuji, H., Bhave, D. P., Choi, V. K., Creary, S. J., Demerouti, E., Flynn, F. J., Gelfand, M. J., Greer, L. L., Johns, G., Kesebir, S., Klein, P. G., Lee, S. Y., ... Vugt, M. V. (2021). COVID-19 and the workplace: Implications, issues, and insights for future research and action. *American Psychologist*, 76(1), 63–77.
<https://doi.org/10.1037/amp0000716>
- Kollock, P. (1999). The Economies of Online Cooperation: Gifts and Public Goods in Cyberspace. In *Communities in Cyberspace*. Routledge.
- Kosmala, M., Wiggins, A., Swanson, A., & Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment*, 14(10), 551–560.
<https://doi.org/10.1002/fee.1436>
- Kostakis, V., & Bauwens, M. (2020). Grammar of Peer Production. In M. O’Neil, C. Pentzold, & S. Toupin (Eds.), *The Handbook of Peer Production* (1st ed., pp. 21–32). Wiley.

- Kostakis, V., Vragoteris, V., & Acharja, I. L. (2021). Can peer production democratize technology and society? A critical review of the critiques. *Futures*, *131*, 102760. <https://doi.org/10.1016/j.futures.2021.102760>
- Kou, Y., & Gray, C. M. (2019). A Practice-Led Account of the Conceptual Evolution of UX Knowledge. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*, 1–13. <https://doi.org/10.1145/3290605.3300279>
- Kratochwill, T. R., & Levin, J. R. (Eds.). (2015). *Single-case research design and analysis: New directions for psychology and education*.
- Kraut, R. E., Resnick, P., & Kiesler, S. (2011). *Building successful online communities: Evidence-based social design*. MIT Press.
- Krötzsch, M., Vrandečić, D., & Völkel, M. (2006). Semantic MediaWiki. *The Semantic Web - ISWC 2006*, 935–942.
- Kullenberg, C., & Kasperowski, D. (2016). What Is Citizen Science? – A Scientometric Meta-Analysis. *PLOS ONE*, *11*(1), e0147152. <https://doi.org/10.1371/journal.pone.0147152>
- Larsen, J. E. (2018, September 22). *My Headaches from Tracking Headaches* [Show & Tell Talk]. 2018 QS Global Conference. <https://quantifiedself.com/show-and-tell/?project=1102>
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Lave, J., & Wenger, E. (2002). Legitimate peripheral participation in communities of practice. In *Supporting lifelong learning*. RoutledgeFalmer : Open University.
- Law, E., Williams, A. C., Wiggins, A., Brier, J., Preece, J., Shirk, J., & Newman, G. (2017). The Science of Citizen Science: Theories, Methodologies and Platforms. *Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 395–400. <https://doi.org/10.1145/3022198.3022652>
- Lehenaff, C., Greshake Tzovaras, B., & Price Ball, M. (2021). Nothing about us, without us: Are we asking the right questions in transgender research? *Physiology News*, *Autumn 123*. <https://doi.org/10.36866/pn.123.24>

- Lewis, D., & Leibrand, S. (2016). Real-World Use of Open Source Artificial Pancreas Systems. *Journal of Diabetes Science and Technology*, 10(6), 1411–1411.
<https://doi.org/10.1177/1932296816665635>
- Lewis, D. M. (2020). Do-It-Yourself Artificial Pancreas System and the OpenAPS Movement. *Endocrinology and Metabolism Clinics of North America*, 49(1), 203–213.
<https://doi.org/10.1016/j.ecl.2019.10.005>
- Lewis, D. M., Leibrand, S., Street, T. J., & Phatak, S. S. (2018). Detecting Insulin Sensitivity Changes for Individuals with Type 1 Diabetes. *Diabetes*, 67(Supplement_1), 79-LB.
<https://doi.org/10.2337/db18-79-LB>
- Li, I., Dey, A., & Forlizzi, J. (2010). A stage-based model of personal informatics systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 557–566). Association for Computing Machinery.
<https://doi.org/10.1145/1753326.1753409>
- Lintott, C. J., Schawinski, K., Keel, W., van Arkel, H., Bennert, N., Edmondson, E., Thomas, D., Smith, D. J. B., Herbert, P. D., Jarvis, M. J., Virani, S., Andreescu, D., Bamford, S. P., Land, K., Murray, P., Nichol, R. C., Raddick, M. J., Slosar, A., Szalay, A., & Vandenberg, J. (2009). Galaxy Zoo: ‘Hanny’s Voorwerp’, a quasar light echo? *Monthly Notices of the Royal Astronomical Society*, 399(1), 129–140.
<https://doi.org/10.1111/j.1365-2966.2009.15299.x>
- Lorenz, D. (2014, May 10). *Does Diet Affect My Sleep?* [Show & Tell Talk]. 2014 QS Europe Conference. <https://quantifiedself.com/show-and-tell/?project=110>
- Loubser, M. M. (2010). Organisational Mechanisms in Peer Production: The Case of Wikipedia. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.1737535>
- Loutonen, A. (1995, May). *WIT - WWW Interactive Talk*. <https://www.w3.org/WIT/>
- Luck, R. (2018). What is it that makes participation in design participatory design? *Design Studies*, 59, 1–8. <https://doi.org/10.1016/j.destud.2018.10.002>

- Lukyanenko, R., Parsons, J., Wiersma, Y., Sieber, R., & Maddah, M. (2016). Participatory Design for User-generated Content: Understanding the challenges and moving forward. *Scandinavian Journal of Information Systems*, 28(1).
- Lupton, D. (2016). *The quantified self: A sociology of self-tracking*. Polity.
- Lupton, D. (2019). 'It's made me a lot more aware': A new materialist analysis of health self-tracking. *Media International Australia*, 171(1), 66–79.
<https://doi.org/10.1177/1329878X19844042>
- Macintyre, R. (2016). *Approaching Participatory Design in "Citizen Science."* Design for Learning: 5th International Conference designing new learning ecologies, Copenhagen.
- Mahr, D., & Dickel, S. (2019). Citizen science beyond invited participation: Nineteenth century amateur naturalists, epistemic autonomy, and big data approaches avant la lettre. *History and Philosophy of the Life Sciences*, 41(4), 1–19.
<https://doi.org/10.1007/s40656-019-0280-z>
- Matei, S. A., & Britt, B. C. (2017). *Structural Differentiation in Social Media*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-64425-7>
- McInnis, B., Centivany, A., Kim, J., Poblet, M., Levy, K., & Leshed, G. (2017). Crowdsourcing Law and Policy: A Design-Thinking Approach to Crowd-Civic Systems. *Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 355–361.
<https://doi.org/10.1145/3022198.3022656>
- Merton, R. K. (1973). *The Sociology of Science: Theoretical and Empirical Investigations*. University of Chicago Press.
- Metaxiotis, K., Ergazakis, K., & Psarras, J. (2005). Exploring the world of knowledge management: Agreements and disagreements in the academic/practitioner community. *Journal of Knowledge Management*, 9(2), 6–18.
<https://doi.org/10.1108/13673270510590182>

- Meyer, L. (2011, November 27). *Tracking My Hearing Loss* [Show & Tell Talk]. Quantified Self Bay Area Meetup. <https://quantifiedself.com/show-and-tell/?project=424>
- Michener, W. K., Allard, S., Budden, A., Cook, R. B., Douglass, K., Frame, M., Kelling, S., Koskela, R., Tenopir, C., & Vieglaiss, D. A. (2012). Participatory design of DataONE—Enabling cyberinfrastructure for the biological and environmental sciences. *Ecological Informatics*, *11*, 5–15. <https://doi.org/10.1016/j.ecoinf.2011.08.007>
- Milton, A., Ajmani, L., DeVito, M. A., & Chancellor, S. (2023). “I See Me Here”: Mental Health Content, Community, and Algorithmic Curation on TikTok. *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, 1–17. <https://doi.org/10.1145/3544548.3581489>
- Mugar, G., Østerlund, C., Hassman, K. D., Crowston, K., & Jackson, C. B. (2014). Planet hunters and seafloor explorers: Legitimate peripheral participation through practice proxies in online citizen science. *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 109–119. <https://doi.org/10.1145/2531602.2531721>
- Munson, S. A., Schroeder, J., Karkar, R., Kientz, J. A., Chung, C.-F., & Fogarty, J. (2020). The Importance of Starting With Goals in N-of-1 Studies. *Frontiers in Digital Health*, *2*, 3. <https://doi.org/10.3389/fdgth.2020.00003>
- Nafus, D., & Sherman, J. (2014). This One Does Not Go Up to 11: The Quantified Self Movement as an Alternative Big Data Practice. *International Journal of Communication*, *8*, 1784–1794.
- Navarrette, T. (2020). Crowdsourcing the digital transformation of heritage. In Massi, Vecco, & Lin (Eds.), *Digital Transformation in the Cultural and Creative Industries* (pp. 99–116). Routledge.
- Nichols, D. M., & Twidale, M. B. (2006). Usability processes in open source projects. *Software Process: Improvement and Practice*, *11*(2), 149–162. <https://doi.org/10.1002/spip.256>

Nielsen, J. (2005). *Ten Usability Heuristics*.

<https://pdfs.semanticscholar.org/5f03/b251093aee730ab9772db2e1a8a7eb8522cb.pdf>.

Nielsen, J. (2001, August 4). First Rule of Usability? Don't Listen to Users. *NN/g Nielsen*

Norman Group. <https://www.nngroup.com/articles/first-rule-of-usability-dont-listen-to-users/>

Nielsen, J. (2012, June 3). How Many Test Users in a Usability Study? *NN/g Nielsen*

Norman Group. <https://www.nngroup.com/articles/how-many-test-users/>

Nielsen, J., & Levy, J. (1994). Measuring usability—Preference vs. Performance.

Communications of the ACM, 37(4), 66–75.

Noble, J. A. (2012). *Minority voices of crowdsourcing: Why we should pay attention to every member of the crowd*. CSCW'12, Seattle, Washington, USA.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford University Press.

Opryshko, T., & Nazarovets, S. (2021). Case Study: Citizen Science in Digital Humanities context. *Digital Humanities Workshop*, 198–203.

<https://doi.org/10.1145/3526242.3526246>

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action* (1st ed.). Cambridge University Press.

<https://doi.org/10.1017/CBO9780511807763>

Pages to date. (2023). Wikimedia Statistics. https://stats.wikimedia.org/#/all-wikipedia-projects/content/pages-to-date/normal|table|2001-01-01~2023-08-01|page_type~content|monthly

Paul, C. (2014). Analyzing Card-Sorting Data Using Graph Visualization. *Journal of Usability Studies*, 9(3), 87–104.

Peng, C., Goswami, P., & Bai, G. (2020). A literature review of current technologies on health data integration for patient-centered health management. *Health Informatics Journal*, 26(3), 1926–1951. <https://doi.org/10.1177/1460458219892387>

- Peters, I., & Weller, K. (2008). Tag Gardening for Folksonomy Enrichment and Maintenance. *Webology*, 5(3).
- Peters, M. A., Besley, T., & Arndt, S. (2019). Experimenting with academic subjectivity: Collective writing, peer production and collective intelligence. *Open Review of Educational Research*, 6(1), 26–40. <https://doi.org/10.1080/23265507.2018.1557072>
- Pierce, D. (2023, July 3). So where are we all supposed to go now? *The Verge*. <https://www.theverge.com/2023/7/3/23782607/social-web-public-apps-end-reddit-twitter-mastodon>
- Pierre, J., Crooks, R., Currie, M., Paris, B., & Pasquetto, I. (2021). Getting Ourselves Together: Data-centered participatory design research & epistemic burden. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–11. <https://doi.org/10.1145/3411764.3445103>
- Ploderer, B., Smith, W., Howard, S., Pearce, J., & Borland, R. (2013). Patterns of support in an online community for smoking cessation. *Proceedings of the 6th International Conference on Communities and Technologies*, 26–35. <https://doi.org/10.1145/2482991.2482992>
- Polanyi, M. (1958). *Personal Knowledge. Towards a Post-Critical Philosophy*. University of Chicago Press.
- Pretorius, C., Chambers, D., & Coyle, D. (2019). Young People’s Online Help-Seeking and Mental Health Difficulties: Systematic Narrative Review. *Journal of Medical Internet Research*, 21(11), e13873. <https://doi.org/10.2196/13873>
- Quintas, P., Lefrere, P., & Jones, G. (1997). Knowledge Management: A Strategic Agenda. *Long Range Planning*, 30(3), 385–391.
- Ramos, J. (2016, May 27). Cosmo-localism and the futures of material production. *Action Foresight*. <https://actionforesight.net/cosmo-localism-and-the-futures-of-material-production/>

- Rapp, A., Cena, F., & Marcengo, A. (2018). Editorial of the Special Issue on Quantified Self and Personal Informatics. *Computers*, 7(1), 14.
<https://doi.org/10.3390/computers7010014>
- Raymond, E. (1999). The cathedral and the bazaar. *Knowledge, Technology & Policy*, 12(3), 23–49.
- Reeves, N., Tinati, R., Zerr, S., Van Kleek, M. G., & Simperl, E. (2017). From Crowd to Community: A Survey of Online Community Features in Citizen Science Projects. *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 2137–2152. <https://doi.org/10.1145/2998181.2998302>
- Reid, E. M. (1991). *Electropolis: Communication and Community On Internet Relay Chat* [University of Melbourne, Department of History].
<http://www.aluluei.com/electropolis.htm>
- Resnick, M., & Silverman, B. (2005). Some reflections on designing construction kits for kids. *Proceedings of the 2005 Conference on Interaction Design and Children*, 117–122.
<https://doi.org/10.1145/1109540.1109556>
- Rey-Mazón, P., Keysar, H., Dosemagen, S., D'Ignazio, C., & Blair, D. (2018). Public Lab: Community-Based Approaches to Urban and Environmental Health and Justice. *Science and Engineering Ethics*, 24(3), 971–997. <https://doi.org/10.1007/s11948-018-0059-8>
- Riggare, S., & Hägglund, M. (2018). Precision Medicine in Parkinson's Disease – Exploring Patient-Initiated Self-Tracking. *Journal of Parkinson's Disease*, 8(3), 441–446.
<https://doi.org/10.3233/JPD-181314>
- Riggare, S., Hägglund, M., Bredenoord, A. L., De Groot, M., & Bloem, B. R. (2021). Ethical Aspects of Personal Science for Persons with Parkinson's Disease: What Happens When Self-Tracking Goes from Selfcare to Publication? *Journal of Parkinson's Disease*, 11(4), 1927–1933. <https://doi.org/10.3233/JPD-212647>

- Riggare, S., Stamford, J., & Hägglund, M. (2021). A Long Way to Go: Patient Perspectives on Digital Health for Parkinson's Disease. *Journal of Parkinson's Disease*, 11(s1), S5–S10. <https://doi.org/10.3233/JPD-202408>
- Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4, 155–169.
- Roberts, S. (2004). Self-experimentation as a source of new ideas: Ten examples about sleep, mood, health, and weight. *Behavioral and Brain Sciences*, 27(02). <https://doi.org/10.1017/S0140525X04000068>
- Roche, J., Bell, L., Galvão, C., Golumbic, Y. N., Kloetzer, L., Knoblen, N., Laakso, M., Lorke, J., Mannion, G., Massetti, L., Mauchline, A., Pata, K., Ruck, A., Taraba, P., & Winter, S. (2020). Citizen Science, Education, and Learning: Challenges and Opportunities. *Frontiers in Sociology*, 5, 613814. <https://doi.org/10.3389/fsoc.2020.613814>
- Rosser, H., & Wiggins, A. (2018). Tutorial Designs and Task Types in Zooniverse. *Companion of the 2018 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 177–180. <https://doi.org/10.1145/3272973.3274049>
- Sax, B. (2006). Storytelling and the “information overload.” *On the Horizon*, 14(4), 165–170. <https://doi.org/10.1108/10748120610708078>
- Schilcher, D. C. (2009). Tacit Knowledge and Storytelling. *Proceedings of The 13th World Multi-Conference on Systemics, Cybernetics and Informatics*, 150–154.
- Schrögel, P., & Kolleck, A. (2018). The Many Faces of Participation in Science. *Science & Technology Studies*, 77–99. <https://doi.org/10.23987/sts.59519>
- Schweik, C. M., & English, R. C. (2012a). *Internet success: A study of open-source software commons*. MIT Press.
- Schweik, C. M., & English, R. C. (2012b). *Internet success: A study of open-source software commons*. MIT Press.
- Senabre Hidalgo, E., Ball, M. P., Opoix, M., & Greshake Tzovaras, B. (2021). *Shared motivations, goals and values in the practice of personal science—A community*

perspective on self-tracking for empirical knowledge [Preprint]. SocArXiv.

<https://doi.org/10.31235/osf.io/78yfm>

Senabre Hidalgo, E., Ball, M. P., Opoix, M., & Greshake Tzovaras, B. (2022). Shared motivations, goals and values in the practice of personal science: A community perspective on self-tracking for empirical knowledge. *Humanities and Social Sciences Communications*, 9(1), 182. <https://doi.org/10.1057/s41599-022-01199-0>

Senabre Hidalgo, E., Ferran-Ferrer, N., & Perelló, J. (2018). Participatory design of citizen science experiments—Diseño participativo de experimentos de ciencia ciudadana. *Comunicar, Comunicar 54*(Ciencia y saber compartidos. . Acceso abierto, tecnologías y educación), 29–38.

Senabre Hidalgo, E., Perelló, J., Becker, F., Bonhoure, I., Legris, M., & Cigarini, A. (2021). Participation and Co-creation in Citizen Science. In K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht (Eds.), *The Science of Citizen Science* (pp. 199–218). Springer International Publishing. https://doi.org/10.1007/978-3-030-58278-4_11

Shaw, A., & Hill, B. M. (2014). Laboratories of Oligarchy? How the Iron Law Extends to Peer Production: Laboratories of Oligarchy. *Journal of Communication*, 64(2), 215–238. <https://doi.org/10.1111/jcom.12082>

Sherwin, K. (2018, March 18). Card Sorting: Uncover Users' Mental Models for Better Information Architecture. *NN/g Nielsen Norman Group*. <https://www.nngroup.com/articles/card-sorting-definition/>

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E., & Bonney, R. (2012). Public Participation in Scientific Research: A Framework for Deliberate Design. *Ecology and Society*, 7(2), 29. <http://dx.doi.org/10.5751/ES-04705-170229>

Shrestha, N., Barik, T., & Parnin, C. (2021). Remote, but Connected: How #TidyTuesday Provides an Online Community of Practice for Data Scientists. *Proceedings of the*

ACM on Human-Computer Interaction, 5(CSCW1), 1–31.

<https://doi.org/10.1145/3449126>

Simperl, E., Thurlow, I., Warren, P., Dengler, F., Davies, J., Grobelnik, M., Mladenic, D., Gomez-Perez, J. M., & Moreno, C. R. (2010). Overcoming Information Overload in the Enterprise: The Active Approach. *IEEE Internet Computing*, 14(6), 39–46.

<https://doi.org/10.1109/MIC.2010.146>

Smith, D. A. (2020). Situating Wikipedia as a health information resource in various contexts: A scoping review. *PLOS ONE*, 15(2), e0228786.

<https://doi.org/10.1371/journal.pone.0228786>

Spencer, D., & Garrett, J. J. (2009). *Card sorting: Designing usable categories*. Rosenfeld Media.

Spinuzzi, C. (2005). The Methodology of Participatory Design. *Technical Communication*, 52(2).

Starosielski, N. (2015). *The undersea network*. Duke University Press.

Stevenson, M. (2020). Cultures of Peer Production. In *The Handbook of Peer Production* (pp. 56–69). Wiley-Blackwell.

Strasser, B. J., Baudry, J., Mahr, D., Sanchez, G., & Tancoigne, E. (2018). “Citizen Science”? Rethinking Science and Public Participation. *Science & Technology Studies*, 52–76. <https://doi.org/10.23987/sts.60425>

Strotbaum, V., Pobiruchin, M., Schreiweis, B., Wiesner, M., & Strahwald, B. (2019). Your data is gold – Data donation for better healthcare? *It - Information Technology*, 61(5–6), 219–229. <https://doi.org/10.1515/itit-2019-0024>

Swan, M. (2009). Emerging Patient-Driven Health Care Models: An Examination of Health Social Networks, Consumer Personalized Medicine and Quantified Self-Tracking. *International Journal of Environmental Research and Public Health*, 6(2), 492–525. <https://doi.org/10.3390/ijerph6020492>

- Swan, M. (2012). Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0. *Journal of Sensor and Actuator Networks*, 1(3), 217–253. <https://doi.org/10.3390/jsan1030217>
- Swire-Thompson, B., & Lazer, D. (2020). Public Health and Online Misinformation: Challenges and Recommendations. *Annual Review of Public Health*, 41(1), 433–451. <https://doi.org/10.1146/annurev-publhealth-040119-094127>
- Taheri, M., Unterholzer, T., & Meinel, C. (2016). Design Thinking At Scale: A Report on Best Practices of Online Courses. In *Design Thinking Research. Understanding Innovation*. (pp. 217–235). Springer.
- The Pandas Development Team. (2023). *pandas-dev/pandas: Pandas (v2.0.3)* [Computer software]. Zenodo. <https://doi.org/10.5281/ZENODO.8092754>
- Tschimmel, K. (2012). Design Thinking as an effective Toolkit for Innovation. *Proceedings of the XXIII ISPIM Conference: Action for Innovation: Innovating from Experience*. ISPIM, Barcelona.
- usability.gov. (n.d.a). *Card Sorting*. Usability.Gov. <https://www.usability.gov/how-to-and-tools/methods/card-sorting.html>
- usability.gov. (n.d.b). *Usability Testing*. Usability.Gov. <https://www.usability.gov/how-to-and-tools/methods/usability-testing.html>
- Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., Van Der Walt, S. J., Brett, M., Wilson, J., Millman, K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R., Larson, E., ... Vázquez-Baeza, Y. (2020). SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, 17(3), 261–272. <https://doi.org/10.1038/s41592-019-0686-2>
- Vo, A. N., Huso, G., Gunnarsli, H., Nyvoll, K., & Schirmer-Mikalsen, S. (2022). Analyzing the Preference and Usage of Real-Time Digital Collaboration Technologies among IT Professionals. *Proceedings of EReMCIS 2022*.

- Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., Ponti, M., Samson, R., & Wagenknecht, K. (Eds.). (2021). Learning in Citizen Science. In *The Science of Citizen Science* (pp. 283–308). Springer International Publishing.
<https://doi.org/10.1007/978-3-030-58278-4>
- Von Krogh, G., Spaeth, S., & Lakhani, K. R. (2003). Community, joining, and specialization in open source software innovation: A case study. *Research Policy*, 32(7), 1217–1241. [https://doi.org/10.1016/S0048-7333\(03\)00050-7](https://doi.org/10.1016/S0048-7333(03)00050-7)
- W3C Web Accessibility Initiative. (2019). *How to Meet WCAG (Quick Reference): A customizable quick reference to Web Content Accessibility Guidelines (WCAG) 2 requirements (success criteria) and techniques*.
<https://www.w3.org/WAI/WCAG21/quickref/?showtechniques=245#qr-navigation-mechanisms-mult-loc>
- Wac, K. (2018). From Quantified Self to Quality of Life. In H. Rivas & K. Wac (Eds.), *Digital Health: Scaling Healthcare to the World* (pp. 83–108). Springer International Publishing. https://doi.org/10.1007/978-3-319-61446-5_7
- Wac, K. (2022). The Future of Quantifying Behaviors, Health, and Quality of Life. In K. Wac & S. Wulfovich (Eds.), *Quantifying quality of life: Incorporating daily life into medicine*. Springer.
- Wan, R., Levonian, Z., & Yarosh, S. (2020). How much is a “like” worth? Engagement and Retention in an Online Health Community. *Conference Companion Publication of the 2020 on Computer Supported Cooperative Work and Social Computing*, 413–417.
<https://doi.org/10.1145/3406865.3418320>
- Wannheden, C., Riggare, S., Luckhaus, J. L., Jansson, H., Sjunnestrand, M., Stenfors, T., Savage, C., Reinius, M., & Hasson, H. (2023). A rocky road but worth the drive: A longitudinal qualitative study of patient innovators and researchers cocreating research. *Health Expectations*, hex.13790. <https://doi.org/10.1111/hex.13790>

- West, J., & Gallagher, S. (2006). Challenges of open innovation: The paradox of firm investment in open-source software. *R and D Management*, 36(3), 319–331. <https://doi.org/10.1111/j.1467-9310.2006.00436.x>
- Wicks, P., Massagli, M., Frost, J., Brownstein, C., Okun, S., Vaughan, T., Bradley, R., & Heywood, J. (2010). Sharing Health Data for Better Outcomes on PatientsLikeMe. *Journal of Medical Internet Research*, 12(2), e19. <https://doi.org/10.2196/jmir.1549>
- Wiggins, A., & Wilbanks, J. (2019). The Rise of Citizen Science in Health and Biomedical Research. *The American Journal of Bioethics*, 19(8), 3–14. <https://doi.org/10.1080/15265161.2019.1619859>
- Williams, O., Sarre, S., Papoulias, S. C., Knowles, S., Robert, G., Beresford, P., Rose, D., Carr, S., Kaur, M., & Palmer, V. J. (2020). Lost in the shadows: Reflections on the dark side of co-production. *Health Research Policy and Systems*, 18(1), 43. <https://doi.org/10.1186/s12961-020-00558-0>
- Wolf, G. I. (2022). *Personal Science—Learning to Observe*. Leanpub.
- Wolf, G. I., & De Groot, M. (2020). A Conceptual Framework for Personal Science. *Frontiers in Computer Science*, 2, 21. <https://doi.org/10.3389/fcomp.2020.00021>
- Wood, J. R., & Wood, L. E. (2008). Card Sorting: Current Practices and Beyond. *Journal of Usability Studies*, 4(1), 1–6.
- Wubishet, Z. S., Bygstad, B., & Tsiavos, P. (2013). A Participation Paradox: Seeking the Missing Link between Free/Open Source Software and Participatory Design. *Journal of Advances in Information Technology*, 4(4), 181–193. <https://doi.org/10.4304/jait.4.4.181-193>
- Zhang, J. (2017). Supporting Information Needs of Transitional Phases in Diabetes Management Through Online Health Communities. *Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 107–111. <https://doi.org/10.1145/3022198.3024942>

A. Appendix

A.1 Links to Platform Features Referenced in the Case Studies

Section	Link	Last accessed	Platform
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Five_pillars	23.09.2022	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:New_pages_patrol/Reviewers	25.04.2023	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Page_mover	25.04.2023	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style	23.09.2022	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Content_assessment	23.09.2022	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Assume_good_faith	23.09.2022	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Red_link	23.09.2022	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Citation_needed	23.09.2022	Wikipedia
Results - Working Model of Peer Production	https://en.wikipedia.org/wiki/Wikipedia:Stub	23.09.2022	Wikipedia
Results - Case Studies	https://www.inaturalist.org/pages/what+is+it	26.09.2022	iNaturalist
Results - Case Studies	https://www.inaturalist.org/pages/about	26.09.2022	iNaturalist
Results - Case Studies	https://www.inaturalist.org/stats	26.09.2022	iNaturalist
Results - Case Studies	https://publiclab.org/about	26.09.2022	Public Lab
Results - Case Studies	https://publiclab.org/people	26.09.2022	Public Lab
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/about	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/how+can+i+use+it	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/getting+started	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/help#identification	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/help#quality	26.09.2022	iNaturalist

Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/curator+guide	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/help#geoprivacy	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/help#projects1	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/managing-projects	26.09.2022	iNaturalist
Results - Case Studies - iNaturalist	https://www.inaturalist.org/pages/bio-blitz+guide	26.09.2022	iNaturalist
Results - Case Studies - Public Lab	https://publiclab.org/wiki/welcome	26.09.2022	Public Lab
Results - Case Studies - Public Lab	https://publiclab.org/notes/kgradow/11-08-2020/how-to-build-a-bucket-air-monitor	26.09.2022	Public Lab
Results - Case Studies - Public Lab	https://publiclab.org/wiki/about-tags	26.09.2022	Public Lab
Results - Case Studies - Public Lab	https://publiclab.org/wiki/issue-brief	26.09.2022	Public Lab
Results - Case Studies - Public Lab	https://publiclab.org/questions	26.09.2022	Public Lab
Results - Case Studies - Public Lab	https://publiclab.org/methods	26.09.2022	Public Lab
Results - Case Studies - Public Lab	https://publiclab.org/tag/seeks:replications	26.09.2022	Public Lab
Results - Case Studies	https://www.zooniverse.org/about	23.09.2022	Zooniverse
Results - Case Studies	https://www.zooniverse.org/about/donate	23.09.2022	Zooniverse
Results - Case Studies - Zooniverse	https://www.zooniverse.org/projects/zookeeper/galaxy-zoo/	26.09.2022	Zooniverse
Results - Case Studies - Zooniverse	https://www.zooniverse.org/projects/pmlogan/poets-and-lovers	26.09.2022	Zooniverse
Results - Case Studies - Zooniverse	https://www.zooniverse.org/projects/reinforce/deep-sea-explorers	26.09.2022	Zooniverse
Results - Case Studies	https://help.zooniverse.org/getting-started/lab-policies/	11.08.2023	Zooniverse
Results - Case Studies - Zooniverse	https://www.zooniverse.org/about	26.09.2022	Zooniverse
Results - Case Studies - Zooniverse	https://www.zooniverse.org/get-involved	26.09.2022	Zooniverse
Results - Case Studies - Zooniverse	https://help.zooniverse.org/next-steps/subject-selection/	26.09.2022	Zooniverse
Results - Case Studies - Zooniverse	https://www.zooniverse.org/talk	26.09.2022	Zooniverse

Zooniverse			
Discussion	https://www.zooniverse.org/about	15.12.2022	Zooniverse
Discussion	https://www.inaturalist.org/pages/wh at+is+it	15.12.2022	iNaturalist
Discussion	https://publiclab.org/about	15.12.2022	Public Lab

A.2 Screenshots of Platform Features

A.2.1 Communal Validation iNaturalist

The screenshot displays an iNaturalist observation interface. At the top left is a photograph of a black lady beetle with two orange spots on its back, resting on a green leaf. To the right is a map of Paris, France, with numerous orange location pins indicating other observations in the area. Below the photo is an 'Activity' section showing two entries: 'jolipapa suggested an ID' for 'Two-spotted Lady Beetle (*Adalia bipunctata*)' and 'gijwans suggested an ID*' for 'Asian Lady Beetle (*Harmonia axyridis*)'. The 'Community Taxon' section on the right shows 'Asian Lady Beetle (*Harmonia axyridis*)' with a progress bar indicating 'Cumulative IDs: 3 of 4' and buttons for 'Agree', 'Compare', and 'About'. A note at the bottom of the activity section states '*gijwans disagrees this is Two-spotted Lady Beetle (*Adalia bipunctata*)'.

An observation on iNaturalist, misclassified as “Two-spotted Lady Beetle” at first, then corrected by other users as “Asian Lady Beetle” (Source: <https://www.inaturalist.org/observations/127825597>, accessed 23.09.2022)

A.2.2 Reuse Features on Public Lab



a

I did this Help out by offering feedback! [Browse other activities for "open-air"](#)

People who did this (6)

Title	Author	Updated	Likes	Comments
Building Snake Plant Air Remediation kit in Bangalore, India	@ [redacted]	over 1 year ago	6	9
Building a plant-based air purifier kit at Barnraising	@ [redacted]	over 2 years ago	3	21
Snake Plant Air Remediation Build & Partial Teardown	@ [redacted]	over 4 years	6	9

b

 [redacted] commented 4 months ago 

@ [redacted] - are you interested in outdoor or indoor monitoring? Both?

Is this a question? [Click here](#) to post it to the [Questions page](#).

[Reply to this comment...](#)

a A feature on Public Lab encouraging people to replicate existing activities and report their experiences. Replications are automatically collected in a list titled “People who did this” (Source: <https://publiclab.org/notes/nshapiro/09-26-2016/build-a-plant-based-air-purifier>, accessed 21.05.2021)

b A question in a comment section of Public Lab with an affordance encouraging people to reuse the comment as a question artifact (Source: <https://publiclab.org/questions/purl/01-26-2021/what-are-some-affordable-methods-of-air-quality-monitoring-in-new-orleans>, accessed 21.05.2021)

A.2.3 Support Features for New Users

The image consists of two side-by-side screenshots, labeled 'a' and 'b'.
Screenshot 'a' shows the 'Issue Brief Template' page. At the top, it says 'Issue Brief Template' with a user profile icon, a notification bell, and the number '6'. Below that is a navigation bar with a link '« Back to templates'. The main content area has four sections, each with a heading and a paragraph of placeholder text:
1. 'Introduction:' followed by 'Replace this text with some context for what you are sharing. For example, you can provide a brief introduction to your community, and give some context for the issue you're posting about.'
2. 'Our main concern:' followed by 'Replace this text with one or two sentences on the main concern.'
3. 'Obstacles and supporting information:' followed by 'Are there known obstacles you have in understanding more about this issue right now? Do you have more information you would like to share for example, if you have any information about how the issue is currently regulated that could be helpful. You can replace this text and add text or links here to help explain.'
4. 'Who is engaged in this concern:'
Screenshot 'b' shows a 'Post Comment' form. At the top, it has a title 'Post Comment' and a rich text editor toolbar with buttons for Bold (B), Italic (I), Highlight (H), Link (🔗), Image (🖼️), Undo (↶), and Redo (↷). Below the toolbar is a text area containing the placeholder text: 'Help the author refine their post, or point them at other helpful information on the site. Mention users by @username to notify them of this thread by email'. Below the text area is a drag-and-drop area with the text 'Drag and drop to add an image or file, or choose one'. At the bottom of the form are two buttons: 'Publish' (highlighted in blue) and 'Preview'. To the right of the buttons, it says 'Logged in as' followed by a user profile icon and a notification bell icon.

a Extract of the issue brief template on Public Lab (Source: <https://publiclab.org/wiki/issue-brief>, accessed 09.04.2021),

b A placeholder text with instructions on how to write helpful comments on Public Lab (Source: <https://publiclab.org/questions/purl/01-26-2021/what-are-some-affordable-methods-of-air-quality-monitoring-in-new-orleans>, accessed 21.05.2021)

A.3 Peer Production in Citizen Science Design Guide


PEER PRODUCTION IN CITIZEN SCIENCE DESIGN GUIDE	
Common research object	
Guiding questions	<ul style="list-style-type: none"> • What object/s is/are collaboratively produced? How do they relate to the goal of the project? • Are the objects published with an open license? Why?
CBPP heuristic guideline	<ul style="list-style-type: none"> • Common research objects are published with open license, so they can be reused and adapted by the community
Motivations and trade-offs	<ul style="list-style-type: none"> • Open common research objects can be useful if reuse and remix is essential to the process, e.g. when users create their own research projects by reusing methods of others, or if a goal is to help users familiarize themselves with a domain through free exploration, reuse, and contribution to a database • Reasons against an open common research object might include a need for exclusive proprietary rights of the project organizers to use the data
Range of tasks	
Guiding questions	<ul style="list-style-type: none"> • What tasks can contributors engage in? • How do these tasks relate to different steps in the research process (Ideation/design, data collection, data processing, analysis, interpretation, action)?
CBPP heuristic guideline	<ul style="list-style-type: none"> • The range of tasks allows contributors to engage in several or all steps of the research process
Motivations and trade-offs	<ul style="list-style-type: none"> • Covering several or all steps of the research process can attract contributors with a wide range of motivations and skills, and facilitate bottom-up research projects • On the other hand, crowdsourcing contributions to neatly-specified tasks leaves full control in the hand of project organizers and can help projects scale up significantly
Granularity and modularity	
Guiding questions	<ul style="list-style-type: none"> • Are the research objects and tasks split into modules of varying size and complexity? • How are individual modules integrated into the whole system?
CBPP heuristic guideline	<ul style="list-style-type: none"> • Modules of different size are available, from simple routine tasks to complex creative tasks
Motivations and trade-offs	<ul style="list-style-type: none"> • Modules of various size can cater for various motivations, skills, time-capacities, and can cover simple rule-based, as well as creative tasks

	<ul style="list-style-type: none"> • Rule-based microtasks allow for easy large-scale aggregation and punctual engagement, while the integration of bigger, less standardized models might need more manual work
Equipotential self-selection	
Guiding questions	<ul style="list-style-type: none"> • Are any formal credentials (e.g. a university degree) required to participate in certain tasks? Why? • Can contributors self-select tasks? How can they discover or determine these tasks?
CBPP heuristic guideline	<ul style="list-style-type: none"> • No formal entry-credentials determine a-priori a contributor's capability to do a task • Contributors can self-select tasks based on their own skills and motivations
Motivations and trade-offs	<ul style="list-style-type: none"> • Self-selection can be crucial if specific expertise is needed for certain tasks • It moves the focus from formal credentials and values skills • If contributors can choose freely which data points to contribute to a database, there is a risk to introduce sampling biases; on the other hand unexpected valuable data points might be added in this way
Quality control	
Guiding questions	<ul style="list-style-type: none"> • What quality control mechanisms are in place? • What roles does the community play in these?
CBPP heuristic guideline	<ul style="list-style-type: none"> • Communal validation processes for quality control are in place • Community members can take maintenance roles e.g. to protect the system from vandalism
Motivations and trade-offs	<ul style="list-style-type: none"> • "Given many eyeballs, all bugs are shallow" (Linus' law) • Contributors can learn from the feedback and answers of others • If answers/data annotations from other contributors are visible, this might influence the independence of results
Learning trajectories	
Guiding questions	<ul style="list-style-type: none"> • How do newcomers learn to contribute to (basic) tasks? • Are there ways for contributors to learn to do more advanced tasks and to take more advanced roles?
CBPP heuristic guideline	<ul style="list-style-type: none"> • The range of tasks, learning materials, and visible traces of work of others allow newcomers to learn to contribute to easy tasks, integrate in the community and gradually take more advanced roles
Motivations and trade-offs	<ul style="list-style-type: none"> • Community members can be empowered by learning new skills, and have the potential to gradually contribute more complex and creative work

Direct and indirect coordination	
Guiding questions	<ul style="list-style-type: none"> ● How can contributors discover open work? ● Is the current status of the research objects visible, so contributors can discover open work by themselves? Are there other interface features that allow signaling of open work? ● Are there direct, text-based communication features to give feedback and communicate beyond stigmergic collaboration?
CBPP heuristic guideline	<ul style="list-style-type: none"> ● Direct communication features like forums are available, as well as indirect coordination features that signal open tasks, so they can be discovered and self-assigned by community members
Motivations and trade-offs	<ul style="list-style-type: none"> ● Stigmergy can replace direct communication in guiding contributors to open work ● Direct communication features help to gather further feedback and getting in touch beyond knowledge-production workflows on the platform


A.4 List of Personas

Note: These personas function as archetypes. Although they are informed by experiences within the personal science community, they are not intended to represent specific individuals. Real people may embody multiple personas, and the degree of resemblance can fluctuate depending on the context, such as the type of self-research they are pursuing, and this resemblance may also evolve over time.

1	Taylor the Techie									
	<p><i>“What can I do?”</i></p> <p>Taylor is a software engineer who is interested in playing with technology at large, including playing around with hardware. Taylor loves collecting data, even if they are not 100% sure what it could be used for.</p>									
Motivation	Internally motivated, excited about technology, likes to spend time on it in their freetime									
Challenges	Finding a purpose to apply their skills and interests									
Community	Self-research chats, likes to help people with their technology- and data-related questions									
Skills	<table border="0"> <tr> <td>Meta</td> <td>research:</td> <td>beginner</td> </tr> <tr> <td>Data</td> <td>analysis:</td> <td>intermediate</td> </tr> <tr> <td>Coding: expert</td> <td></td> <td></td> </tr> </table>	Meta	research:	beginner	Data	analysis:	intermediate	Coding: expert		
Meta	research:	beginner								
Data	analysis:	intermediate								
Coding: expert										

2	Dannie the Data-Nerd
---	-----------------------------


Community	
Skills	Meta research: beginner Data analysis: beginner Coding: beginner

7	Dylan the Discovering Patient
	<p><i>"This is way more interesting than I thought! Maybe, if I take it step by step, it is not that hard?"</i></p> <p>Dylan was recommended by their doctor to try self-monitoring in order to learn which factors influence the symptoms of their chronic migraine. This was their first point of contact with tracking and data, let alone coding! With growing interest, Dylan is starting to discover the possibilities of self-research by reading about and trying out some trackers and apps.</p>
Motivation	
Challenges	<ul style="list-style-type: none"> - Where to start? - No tech or research background
Community	
Skills	Meta research: no experience Data analysis: no experience Coding: no experience


8	Sawyer the Student
----------	---------------------------


Community	
Skills	Meta research: beginner Data analysis: beginner Coding: intermediate

Personas underneath this line are not prioritized


10	Ryan the Reluctant Patient
	<p><i>"I really have to force myself to track all these things."</i></p> <p>Ryan was advised by their doctor to try self-tracking to monitor their blood pressure, nutrition and physical activity. They find it really tedious and laborious to implement a tracking routine in everyday life and want to invest as little time and effort as possible.</p>
Motivation	
Challenges	
Community	
Skills	Meta research: no experience Data analysis: no experience Coding: no experience

11	Sam the Scientist
-----------	--------------------------

	<p><i>“Is it feasible to use self-tracking data collected by individuals for our large-scale studies?”</i></p> <p>Sam is a medical researcher in the field of autoimmune diseases. They have considered using self-tracking data for some studies. They are not really interested in getting involved with the community: For their purposes, it would be best if people followed their research protocol and send them the recorded data afterwards.</p>
<p>Motivation</p>	
<p>Challenges</p>	
<p>Community</p>	
<p>Skills</p>	<p>Meta Data Coding: beginner</p> <p>research: analysis: expert</p>

<p>12</p>	<p>Drew the Data Donor</p>
	<p><i>“I’m sure all my data could be useful for science.”</i></p> <p>Drew has been tracking their heart rate, sleep and exercise over several years and has accumulated quite some data. While not particularly interested in analysing the data for themselves beyond the conclusions they learned to draw intuitively, Drew would like to donate their data to research.</p>
<p>Motivation</p>	<p>Donating to science, doing something useful as a side effect of the self-tracking they have incorporated in everyday-life</p>

Challenges	Finding research projects that are interested in their data
Community	
Skills	Meta research: no experience Data analysis: no experience Coding: no experience

13	Charlie the Casual Tracker
	<p><i>"It is so easy to track all these things with my Apple watch! Amazing what these gadgets are capable of these days."</i></p> <p>Charlie gradually got more into self-tracking with the advancement of the mobile devices they use in daily life. They are satisfied with the default settings and casually having a look at their step count or pulse. Charlie also finds the prompts reminding them to move more in daily life quite useful and is satisfied with their new device.</p>
Motivation	Self-tracks because it is convenient and the devices "do it automatically", so there is little work involved
Challenges	
Community	Casually speaks with their friends about their self-tracking habits
Skills	Meta research: no experience Data analysis: no experience Coding: no experience

A.5 Community Rose-Bud-Thorn and Prioritization (Copy from Miro Board)

Legend	
Color coding	Meaning
Pink	Positive (interviewee perspective, presumed)
Light green	Potential (interviewee perspective, presumed)
Blue	Negative (interviewee perspective, presumed)
Dark green	Focus area / potential (team discussion)
Orange	Could work with constraints / no short term goal (team discussion)
Red	does not work / no focus (team discussion)

Card text	ID inter- view	Cluster	RBT inter- view	Discussion
Having a community feels great	10	Community and independence at the same time	Rose	
Really likes the community part	6	Community and independence at the same time	Rose	
Finding like-minded people/a community	14	Community and independence at the same time	Rose	
"Being independent, doing what I'm interested in for myself"	14	Community and independence at the same time	Rose	
Working individually, but getting community help when stuck	18	Community and independence at the same time	Rose	
You show what you have and get feedback (is the data good, what could you do with it, what have other people tried) --> motivating	9	Community and independence at the same time	Rose	
Reach out to community for ideas, data science & technical knowledge	10	Community and independence at the same time	Rose	
People rarely track exactly the same thing, but a lot is generalizable	6	Community and independence at the same time	Rose	

Holistic' community talk great to not 'get yourself pigeonholed', but groups for special interests would be good, too	8	Community and independence at the same time	Bud	
inspiration, presentation of experience better than raw data	8	Sharing and learning	Rose	<ul style="list-style-type: none"> - potential! - findability of things that were done - feature for discoverability for people who are not in the meetings - already happening on other platforms, like reddit, Quantified Self forum, we won't do any better - sharing shouldn't be additional work - it is hard to find at the moment what others have done
"oh, I never thought about it."	8	Sharing and learning	Rose	
sharing data sets and communicate studies	4	Sharing and learning	Rose	
motivation for sharing: others might learn from it, like I did	11	Sharing and learning	Rose	
hearing about new self-tracking devices in areas of interest	10	Sharing and learning	Rose	
iterative process, "see something, put something on top"	5	Sharing and learning	Rose	
focus thanks to knowing that one will present	11	Sharing and learning	Rose	
get community input on what is worth looking at	10	Sharing and learning	Bud	
being directly told what data is capable of, from what Open Humans already knows	10	Sharing and learning	Bud	
place to put finalized polished output of the work + discussion/feedback feature	7	Sharing and learning	Bud	
support for realizing idea: show work, get grant, help in every step, published	21	Realizing project thanks to process help/infrastructure	Rose	
connected application with open humans, went well, 50 people collecting data through Open Humans	21	Realizing project thanks to process help/infrastructure	Rose	
the lived conviction of democratizing data and science	13	Other	Rose	
having privacy protected and control over data	20	Other	Rose	

incentives to engage rather than being passive	13	Other	Rose	
granting projects anonymous data access	20	Other	Rose	
Open Humans removes barriers: reusing notebooks, dev environment/API there	6	Reuse = less barriers	Rose	
reusing notebooks	10	Reuse = less barriers	Rose	
not a (data) scientist/programmer, managed to create scripts and store them on github	20	Reuse = less barriers	Rose	
better ways to reproduce personal experiments	2	Reuse = less barriers	Bud	
"you only need to login and press play"	6	Reuse = less barriers	Rose	
sharing API connections to manipulate one's own	6	Reuse = less barriers	Rose	- APIs change a lot, maintenance is hard
ability to get "heart rate" or "music" data, no matter from which device exactly (aggregation layer)	4	Aggregation from different devices	Bud	
putting data from different devices into same format	4	Aggregation from different devices	Bud	- collect experiences first from people who want to connect data, then think about how to generate data
getting data from different devices (diabetes example)	20	Aggregation from different devices	Rose	- how to get the data (in the right format)
aggregating same data types from different devices	12	Aggregation from different devices	Bud	- merging data
infrastructure great, juno lab really helps, would be great if it was used by more people	10	Platform is good, just needs to scale up	Bud	
good ui, good analytics, right underlying principles of transparency, needs to scale up	17	Platform is good, just needs to scale up	Bud	- transparency as a value
Frustration: No idea what to do with spreadsheet apart from own insights on a daily basis	12	Accessibility, confusion where to start	Thorn	
Lots of people that want to do self-tracking, but they don't know what the steps are	11	Accessibility, confusion where to start	Thorn	

more straightforward platform to lower entry barrier. users need to do a lot of work to understand it	10	Accessibility, confusion where to start	Bud	
code: make it less intimidating at first sight	6	Accessibility, confusion where to start	Bud	
more documentation on how community & platform work	18	Accessibility, confusion where to start	Bud	
easier communication: transfer 'word of mouth' to 'a code way'	4	Accessibility, confusion where to start	Bud	
own data collection setup not clean and "not very difficult to analyse"	7	Reasons to not use Open Humans platform	Thorn	
technological or data literacy needed to engage with Open Humans in meaningful ways	13	Reasons to not use Open Humans platform	Thorn	
threshold of starting + their research isn't "really data-driven", more "observations"	15	Reasons to not use Open Humans platform	Thorn	
not clear if all data (a lot) can be put on Open Humans and in which format	19	Reasons to not use Open Humans platform	Thorn	
did not connect fitbit data, because no continuous tracking, only to explore specific issues	15	Reasons to not use Open Humans platform	Thorn	
"everyone has their own format and it's hard to integrate everything "	19	Reasons to not use Open Humans platform	Thorn	
Focus of Open Humans? human body/experience? where is the line?	19	Reasons to not use Open Humans platform	Thorn	
no time to attend community meetings	10	General problems	Thorn	- meetings create social connectedness
some data too private/not easily de-personalizable to share it	10	General problems	Thorn	
a lot of duplicate work happens	16	General problems	Thorn	
Would like to give data to a bigger study	12	Feature requests	Thorn	- not focus anymore; reusing existing data is hard, "donating your body to science without having to die", people want these studies to happen, but don't want to lead them; data is not as 'valuable' as people think, not as

				easy to handle
would like to get automated feedback or notifications on tracked data	18	Feature requests	Thorn	- depends on which feedback; automated pancreas system works like this; long term goal
Open Humans ID as possible entry to Wikidata	18	Feature requests	Bud	- marked red (no comments)
incentives for people to collect data, like points or payment	13	Feature requests	Bud	- marked red (no comments)
creating a data commons that people can voluntarily contribute data to	17	Feature requests	Bud	- marked red (no comments)

A.6 Ideation (Copy from Miro Board)

Legend	
Color coding	Meaning
Orange	Priority / central idea of cluster
Red	Potential issues to keep in mind

Cart text	Cluster	Comment
something that supports people to share early and often + to share difficulties	Something that encourages people to share their progress	
positive feedback for BOTH success and struggle	Something that encourages people to share their progress	
a way to signal a need for help / advise from others	Something that encourages people to share their progress	
make iterations / failures visible	Something that encourages people to share their progress	
encourage critical thinking / scepticism	Something that encourages people to share their progress	
sharing shouldn't be additional work	Something that encourages people to share their progress	
share research protocol, tools used & how well they worked for the use case	Something that encourages people to share their progress	
share notebooks	Something that encourages people to share their progress	
"I did this" + "This is how I did it"	Something that encourages people to share their progress	
step by step documentation	Something that encourages people to share their progress	
presentation of end-results only can give false sense of narrative	Something that encourages people to share their progress	
provide tools & support, so people don't reinvent the wheel	Something that encourages people to share their progress	between this cluster and "some sort of cross-referenced information system"
privacy issues: removed information rests in history in case of wiki	Something that encourages people to share their progress	between this cluster and "some sort of cross-referenced information system"
for a given variable, which tools / methods can you use?	Some sort of cross-referenced information system	
For a given tool, what can you use it for ?	Some sort of cross-referenced information system	

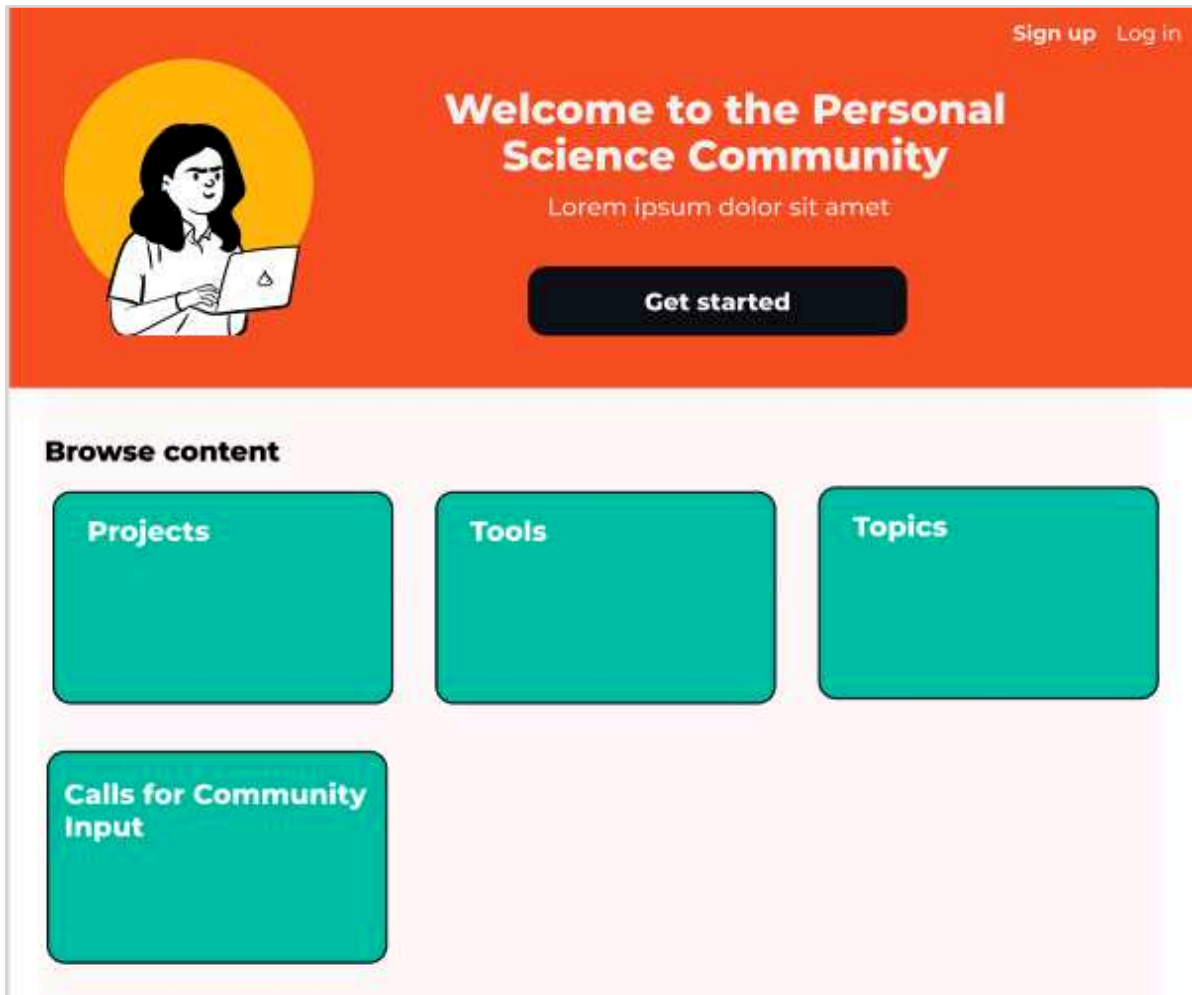
for given topic, what methods can you use? works vs didn't	Some sort of cross-referenced information system	
find ways to signal people	Some sort of cross-referenced information system	
problems with lists of tools: maintenance, spam (advertisement for startup apps...)	Some sort of cross-referenced information system	
a way to find what has been done / the knowledge that already exists in an unstructured way	Some sort of cross-referenced information system	
how is our approach different than forums / reddit ?	Some sort of cross-referenced information system	
help people to find people with experience / interest in topic they need for their analysis	Some sort of cross-referenced information system	
guidelines for appropriate content	Some sort of cross-referenced information system	
against spam: collection of actual experiences with the tool	Some sort of cross-referenced information system	
wiki-pages for topics, tools, variables	Some sort of cross-referenced information system	
make processes / tacit knowledge explicit	Some sort of cross-referenced information system	
tool rating: how well did it measure & how convenient was it to use	Some sort of cross-referenced information system	
previous lists might not have been open	Some sort of cross-referenced information system	
find a better way to introduce tools than a forum entry/wiki page (ratings, use cases, negative experiences...)	Some sort of cross-referenced information system	
How do other niche communities set up their wikis ? (paper https://osf.io/preprints/socarxiv/g95pr/)	Some sort of cross-referenced information system	
helping w/ other infrastructure too	Some sort of cross-referenced information system	between this cluster and "analysis assistance"
"somewhere inbetween stackoverflow and protocols"	Some sort of cross-referenced information system	between this cluster and "analysis assistance"
support methodological diversity (also low tech tracking methodologies)	Analysis assistance	
easier to get data (in usable format)	Analysis assistance	
easier to use data, check if it's working	Analysis assistance	
easier to re-use others' solutions	Analysis assistance	
easier to help others?	Analysis assistance	

reusable widgets for notebooks for importing data	Analysis assistance	
improving health conditions & well-being	Main topics	
health, own bodies & behaviours, own environment (physical, digital, social)	Main topics	
input / support	Social network	
form long term social motivations	Social network	
connected-ness	Social network	
building on experience of others	Social network	
presentation serves as motivation to get things done	Social network	
asynchronous complement for self-research chats	Social network	
Creating a bio: chats people attended, projects, topics of interest, list of things published elsewhere; A system for reporting projects that is visible in the bio; Filling in during the self-research chat	Social network	between this cluster and "other"
"linkedin" - signaling people that are interested / are experts in / have worked on a certain topic	Social network	
make it easier to find people based on topics / prior activities	Social network	between this cluster and "other"
rethink structure of self research chats	Social network	between this cluster and "other"
meta: test interventions in self-research chats	Other	
Onboarding help: make it less daunting	Other	

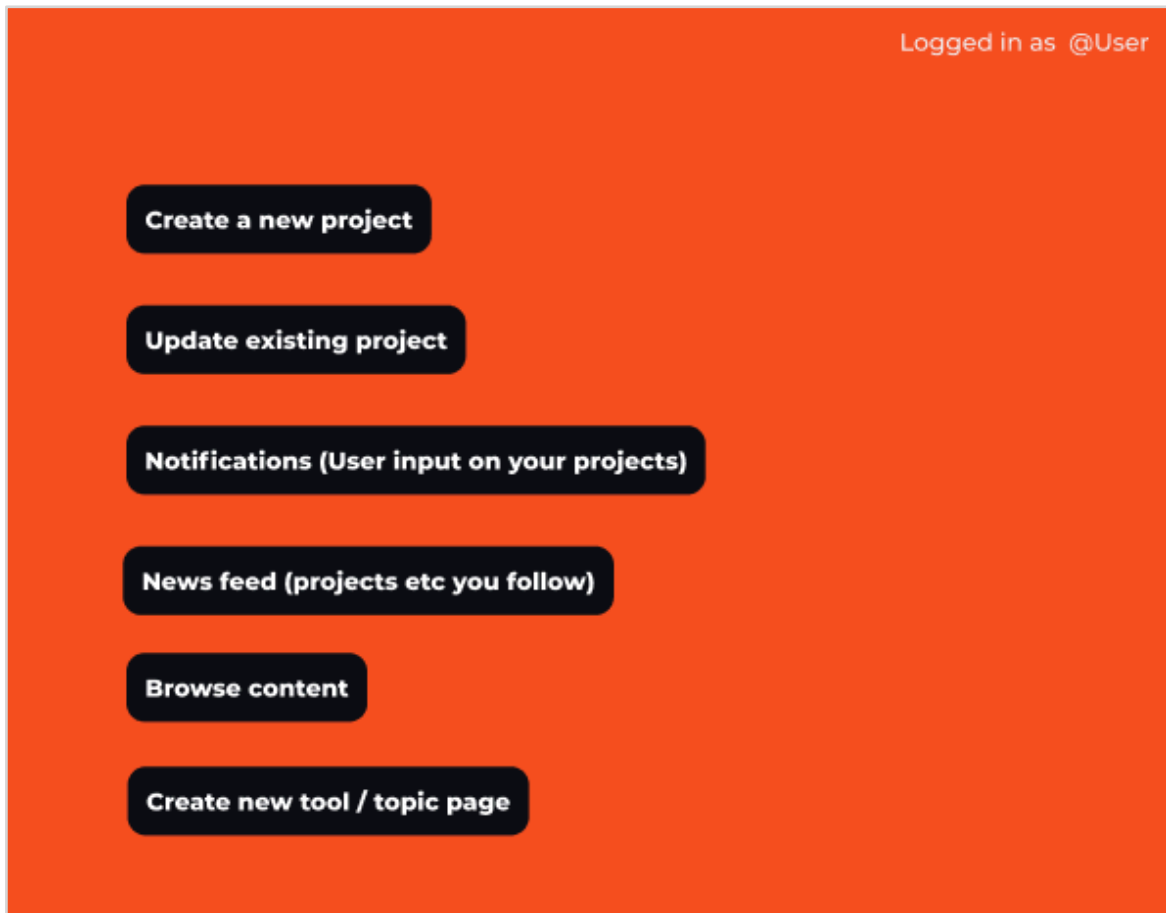
A.7 Screenshots of Personal Science Community/Project Platform

Source for components: Contra wireframe kit, <https://contrauikit.com/>, last accessed 09.05.2023

A.7.1 Homepage mockup



A.7.2 Actions when logged in (mockup)



A.7.3 Project page mockup (top)

Project

Impact of ingredients on blood glucose

active 67 followers

Last update 12 March '21

by **@Eden_ePatient**
Regular User

Research Diary entries **12** Calls for community input **5** Notebooks **5**

Overall satisfaction with project 😊 Updated 12 March '21

Summary

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in. Nullam efficitur augue eu libero dapibus, sit amet ultricies urna viverra. (More...)

Research Updates

Latest Research Diary Entries

Call for Community Input

Can someone recommend a good blood glucose tracker?

by @Eden_ePatient · 12 March, 21 · Project: Impact of ingredients on blood glucose

👍 13 💬 10

Latest Protocol

Research Protocol 😊 Attribute this protocol in your project

by @Eden_ePatient · 12 March, 21 · Project: Impact of ingredients on blood glucose

Description

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in.

Data Preview

Variables, Preview, link if applicable Reuse this

Tools

Freestyle Libre Satisfaction: ★★★★★

Jupyter Notebooks Satisfaction: ★★★★★

Notebooks

Preview with link Reuse this

👍 13 💬 10

A.7.4 Project page mockup (bottom)

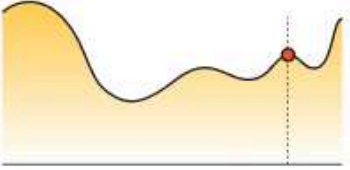
Highlights

Proof of the impact of ingredient X on BG

by @Eden_ePatient · 12 March, 21 · Project: Impact of ingredients on blood glucose

[Research Protocol Link](#) [Tools](#) [Freestyle Freedom Lite](#) [Jupyter Notebooks](#)


Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in.



[Reuse this](#)

♥ 13 💬 10

Comments



@Taylor_the_Techie
12 March, 21 ·

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in.

♥ 13 💬 10

A.7.5 Topic page mockup (User content tab)

Topic

Diabetes

Follow

User Content Tool Ratings Wiki

Type Sort by

Call for Community Input

Can someone recommend a good blood glucose tracker?

by @Taylor_the_Techie · 12 March, 21 · Project: Impact of ingredients on blood glucose

13 10

Research Diary

Just tried my new research protocol, turns out it is taking too much time... (more)

by @Taylor_the_Techie · 10 March, 21 · Project: Impact of ingredients on blood glucose

2 1

Project

Testing OpenAPS

by @Eden_ePatient · 10 March, 21 · Project: Impact of ingredients on blood glucose

5 2 1

Research Diary

Just tried my new research protocol, turns out it is taking too much time... (more)

by @Taylor_the_Techie · 10 March, 21 · Project: Impact of ingredients on blood glucose

2 1

24 Users

3 Related Topics

3 Tools

3 Projects

78 Contributions

Filter

Related Topic

- Blood glucose (33)
- Insuline (20)
- Nutrition (14)

Tool

- Freestyle Free...(16)
- Freestyle Libr.. (14)
- OpenAPS (4)

User

- @Taylor_the... (23)
- @Eden_ePati...(12)
- @Avery_Impro...(3)
- @user (2)
- @user (1)

[show more](#)

xxxi

A.7.6 Topic page mockup (Tool ratings tab)


Topic



Diabetes



Follow


User Content **Tool Ratings** Wiki



24 Users
3 Related Topics
3 Tools
3 Projects
78 Contributions



 **Freestyle Freedom Lite**
Wearable

Diabetes Users **12** Projects **5** Rating  (5) 

All topics Users **34** Projects **7** Rating  (6) 



 **Freestyle Libre**
Wearable

Diabetes Users **12** Projects **5** Rating  (3) 

 **@Eden_ePatient**
 **Works well**
12 March, 21 • Project: Impact of ingredients on blood glucose



Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in.

Diabetes **Blood Glucose**

 **@Avery_Improver**
 **Ok for my usecase**
12 March, 21 • Project: Managing diabetes

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in.

Diabetes **Blood Glucose**

All topics Users **34** Projects **7** Rating  (6) 

A.7.7 Topic page mockup (Wiki tab)

The mockup shows a topic page for "Diabetes". At the top left, the word "Topic" is in small teal text above the word "Diabetes" in a large, bold black font. To the right of "Diabetes" is a rounded rectangular button with the word "Follow" in black text. Below this, there are three tabs: "User Content", "Tool Ratings", and "Wiki". The "Wiki" tab is highlighted with a teal background and white text. To the right of the tabs, there is a vertical list of statistics in teal text: "24 Users", "3 Related Topics", "3 Tools", "3 Projects", and "78 Contributions". Below the tabs, there is a horizontal line. Underneath the line, there is a paragraph of placeholder text: "General information on diabetes tracking / summary of community knowledge / wiki editable by all users / empty at first / needs a template". This is followed by two more paragraphs of Lorem Ipsum placeholder text.

Topic
Diabetes [Follow](#)

[User Content](#) [Tool Ratings](#) [Wiki](#)

24 Users
3 Related Topics
3 Tools
3 Projects
78 Contributions

General information on diabetes tracking / summary of community knowledge / wiki editable by all users / empty at first / needs a template

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed hendrerit risus nec ligula aliquam sodales. Maecenas feugiat ligula tellus, at mattis velit vulputate in. Nullam efficitur augue eu libero dapibus, sit amet ultricies urna viverra. Duis venenatis porttitor mauris at finibus. Etiam ac ipsum ut urna semper commodo quis vitae sapien.

Proin lacinia purus eget nisi auctor, ut convallis leo porttitor. Proin sed diam vitae risus maximus semper at nec ex. Sed in massa ligula. Quisque dignissim nulla ut elit interdum pulvinar. Cras posuere mi in dolor volutpat, eleifend ornare lacus faucibus. Sed iaculis ante sed eros porttitor porttitor.

A.8 List of Cards for Card Sorting Task

Card	Label
15 Weeks of Self Tracking - 40 Pounds Lost	This is a Show & Tell talk by Justin Foo [...].The talk was given on 2012/08/29 and is about Food tracking, Diet and weight loss, Productivity, and Activity tracking.
A Decade of Tracking Headaches	A Decade Of Tracking Headaches is a Show & Tell talk by Stephen Maher [...].The talk was given on 2018/09/22 and is about Pills intake, Sleep, and Stress.
Activity tracking	Activity tracking typically describes the act of tracking physical activity[1] and is frequently measured through metrics such as steps, calories burned, distance walked/run, heart rate and [...]
All-potato diet	The all-potato diet is a diet in which one eats (almost) nothing but potatoes for a few weeks or months. Successful weight-loss has been reported in several anecdotes[1].
Ambient Environment and Room Weather	Tracking the ambient environment can include a number of parameters and metrics that can be useful for different personal research questions.
Anki	This is an open source Spaced Repetition SRS app. It may be usable for Cognitive Testing. Spacing is very useful in learning.[1]
Autoethnography using one button tracker and Jupyter notebook	This page provides a step-by-step guide on how one can use a one-button tracker such as the Puck.js to do an autoethnography that combines qualitative and quantitative data.
Bangle.js	The Bangle.js[1] is the name of a series of open source smartwatches that are made by Espruino under the leadership by Gordon Williams, who also designed the Puck.js open source hardware that can[...]
Biofeedback	Biofeedback is the process of becoming aware of various physiological functions using instruments that provide information on the activity of those same systems, with a goal of being able to mani[...]
Bitesnap	App to log meals and diet tracking.[1] Free. Exports easily. Allows notes and titles for meals. Copy meals from timeline. Easily find foods I often eat. Can copy a meal.
Blood Oxygen On Mt. Everest	Blood Oxygen On Mt. Everest is a Show & Tell talk by Fahh S. [...] The talk [...] is about Travel, Metabolism, Heart rate, Cardiovascular, Sleep, Activity tracking, and Personal microbiome.
Blood glucose tracking	Blood glucose tracking involves methods and tools to measure blood glucose levels, commonly in the context of diabetes but also by non-diabetic users.
Blood pressure	Blood pressure describes the pressure of the blood against the walls of the blood vessels which is mostly a result of the heart pumping.
Body temperature tracking	Measuring body temperature can be useful to do ovulatory cycle tracking, seeing signs of fevers but can also be used as a general measurement of recovery.
Breaking the TV Habit	Breaking the TV Habit is a Show & Tell talk by Valerie Lanard[...].The talk [...] is about Productivity, Social interactions, and 'TV urges'.
Circadian rhythm	The circadian rhythm is a natural process that regulates the sleep-wake cycle over a period of roughly 24 hours, driven by a biological, circadian clock[1].
Communities	Personal Science Community Meet Ups All the quantified self local meetups mentioned in Category:Show and Tell.
Dates and Times	Virtually all data one might want to collect as part of doing personal science, has some form of timestamp associated with it; that is, the moment when the data was collected.
Diabetes Viz	Diabetes Viz is a Show & Tell talk by Peter Kok [...].The talk [...] is about Chronic disease, Blood glucose tracking, Insulin intake, and Activity tracking.
Diet tracking tools	Diet tracking tools help when engaging in the common practice of diet tracking, whether for weight-loss or in relation to health issues and chronic conditions that require particular diets.

EEG (Electroencephalography)	Electroencephalography (EEG) is a method to record an electrogram of the spontaneous electrical activity of the brain.
Excel	Excel is one of most widely used softwares to interact with digital spreadsheets.
Finding relations between variables in time series	A frequent need when engaging in personal science is finding relationships between different variables across a time series, an example could be the question "does eating chocolate improve focus?".
FODMAP	FODMAP is a type of Diet related to Small intestine bacterial overgrowth[1]
Fitbit	Fitbit is a manufacturer of wearable devices and provider of fitness/wellness related services.
FreeStyle Libre	The FreeStyle Libre is a continuous glucose monitor (CGM) by Abbott, which is based on a wearable sensor that can be worn 24/7 for up to 14 days after installation.
Genetic testing	Genetic testing, also known as DNA testing, analyzes an individual's genome to identify variations in DNA sequence and chromosome structure.
Heart rate tracking	Heart rate tracking helps to understand how the heart behaves, it can be measured continuously or while exercising.
How do controls on antigen COVID tests work?	Do they indicate that the person taking the test did correctly swab their nose to take a sample? Or do they only indicate that the test itself was correctly loaded and that liquid is present?
Impact of work-related stress	A post-hoc self-research project that uses retrospective data to evaluate whether typically stress-associated physiological variables show any deviation from a baseline after the experience of int[...]
Is it chance? Use a T-Test to identify how likely an intervention worked	A frequent problem in personal science is that you tried an intervention and want to see if it worked. But you are unsure whether any differences you observed are maybe just by chance.
Keating Memorial	The Keating Memorial is an ongoing effort to support people in doing personal science or self-research in a collaborative group setting.
Lessons from a year of heart rate data	Lessons from a year of heart rate data is a Show & Tell talk by Kiel Gilleade [...].The talk was [...] is about Heart rate, Cardiovascular, and Social life and social media.
Location tracking	Phones have GPS and so many projects include it as data. its very useful for Lifelogging. Travel naturally makes lots of this data.
Meditation	Meditation is a practice in which an individual uses a technique – such as mindfulness, or focusing the mind on a particular object, thought, or activity – to train attention and awareness, and [...]
Microbiome	The term microbiome describes the community of microorganisms which are living together in a habitat. In the context of personal science, the human microbiome is of interest, [...]
Mood	mood, emotion, mental health[1][2] Usually tracked through self survey and less quantitatively through journaling.
MySymptoms	MySymptoms is a symptom tracking app that is available for Android and iOS phones[1] [2].
One Button Tracker	One Button Trackers are small hardware devices that record discrete observations on the press of the button by recording when the button was pressed, and typically also for how long [...]
Open Humans	Open Humans is an online community and digital infrastructure that provides support for self-research, tools for personal data access and aggregating data, and data analysis notebooks [...]
Oura Ring	The Oura Ring is a wearable that is worn on a finger as a ring which tracks sleep, activity and readiness.
Personal Science (book)	A book written by Gary Isaac Wolf in collaboration with [...] The book aims to provide a step-by-step approach to generating personal knowledge by applying empirical methods.

Piotr Wozniak	Piotr Wozniak is a Polish computer scientist known for creating systems to track and optimize many aspects of his life. His contributions to memory and sleep are most widely known.
R	R is an open source programming language that has a focus on doing statistics and data visualizations.
Reasons for and against self tracking and quantification	A collection and discussion of arguments for and against self tracking.
RescueTime	RescueTime is a freemium tool that records your digital device use and how much time you spend in different applications and websites.
Self-research chats	Open Humans self-research chats are weekly online videochats that grew out of the Steven Keating Memorial Self-Research Project on Open Humans.
Serimmune antibody analysis results	The Serimmune COVID-19 Study is a longitudinal research study conducted by the Serimmune company.
Seth Roberts	Seth Roberts was an evolutionary psychology university professor, writer, blogger and well known for his work in self-experimentation regarding sleep, diet and mood, among other topics.
Sleep recordings: Oura vs Fitbit	In this project I investigate how do the Oura Ring and Fitbit handle the storage of sleep data.
Sleep tracking	Sleep plays an important role in restoration and memory processing and overall health[1]. Normally, sleep is governed by a circadian rhythm of around 24 hours but a variety of disorders can affect[..]
Smartphone Disengagement	Smartphone disengagement is a self-research project for which – moved by the question "Is it possible to have a different relationship with my smartphone?"
Spaced Repetition	Spacing out learning and especially flashcards to improve learning.
Stress	In psychology, stress is a feeling of emotional strain and pressure.[1] Stress is a type of psychological pain. Small amounts of stress may be beneficial, as it can improve athletic performance, [...]
Supplements	A dietary supplement is a manufactured product intended to supplement one's diet by taking a pill, capsule, tablet, powder, or liquid. A supplement can provide nutrients either extracted from food[..]
Time tracking	Time tracking is the practice of recording of how time is spent. It is commonly associated with professionals who bill their time by the hour, but it can also be used to gain a better understandi[...]
Tools for journaling, thoughts and note taking	Journaling or note taking is an approach that can be used in cases where you are interested in collecting qualitative data rather than quantitative data.
Tracking Parkinsons & Medication	Tracking Parkinsons & Medication is a Show & Tell talk by Sara Riggare that has been imported from the Quantified Self Show & Tell library. The talk was given on 2013/09/25 and is about Chronic disease
Tremor	A tremor is an involuntary,[1] somewhat rhythmic, muscle contraction and relaxation involving oscillations or twitching movements of one or more body parts.
Xiaomi Mi Band	Xiaomi Mi produces a number of wearables and smart watches with different form factors.

A.9 Usability Tests

A.9.1 List of Issues from the First Usability Test Iteration

Issue	Category	Priority	Addressed
Users don't find "linked content on this wiki", don't scroll there	Linked content	High	yes
Users look for aggregations/different org scheme (e.g. all projects on topic X, all devices to track X). Not obvious to go to sleep tracking topic page first and then find related content.	Linked content	High	yes
Project list under 'linked content' too long, unstructured, discouraging. Some structure/hierarchy/narrative/table would be good	Linked content	High	yes
Many red links in self researcher list (user ignores; also: no motivation to create person page)	Linked content	High	yes
Not clear that tools are listed in infobox of projects (2 participants, they search for the word instead)	Linked content	Medium	No
In case of redundancy of 'Linked content on this wiki' and sections in body of content page, user scrolls only to section (e.g. devices to record sleep) and then stops and does not assume that there is another section with that.	Linked content	Medium	No
People section is least attractive: Potentially it could be sufficient if people pages are only accessible via projects, otherwise maybe not interesting ('would not click on a name randomly' without context; inefficient, tedious); also: content pages of people often don't have obvious content related to topic on their page	Linked content	Medium	No
User does not click on category overview pages, don't understand they are a central part (links not obvious, search convention from wikipedia) → bad guidance/info scent	Homepage	High	Yes
Homepage should have a section that highlights community activities, show more obviously that wiki is part of an active community	Homepage	High	Yes
List of examples for categories on homepage is confusing (is it all there is?)	Homepage	High	Yes
Content that seems to be missing/would be interesting: How to information about how to use tools (general info is on wikipedia; is indirectly on project pages but tedious to filter), reimbursement option for medical tools like freestyle; how to approach written text in qualitative way (maybe in form of external links); standard spreadsheet for sleep tracking.	Content	Medium	No
Interventions are missing/no direct way to find them (what did people do to improve x? Search keyword improving)	Content	Medium	Partly
Not enough editorial content yet to be very useful to get overview of topic, important content missing (e.g. on sleep tracking, interventions)	Content	Medium	No
Wiki is in concurrence to wikipedia, where there is a lot more information on lots of the topics in the personal science wiki. Highlight what is unique about it. Information sometimes repeated, wikipedia is more attractive because more complete information.	Content	Medium	No
Titles not always indicative of content. Also: naming conventions (diff. Between sleep tracking/sleep tracking tools/sleep; confusion active/activity tracking)	Titles	Medium	No

Naming convention firstname lastname expected, not usernames	Titles	Low	No
Design could be better (theme, color coding, icons). Not very attractive. Logo gives impression of WIP	Design	Low	No
Search function is not complex, not possible to filter etc	Search	Low (not feasible)	No
Wiki search results has filter 'gadgets', can be confusing in ps wiki context	Search	Low (not feasible)	No
Confusing that direct jumping to page when typing in search bar (wiki issue, might move to low prio)	Search	Low (not feasible)	No

A.9.2 List of Issues from the Second Usability Test Iteration

Issue	Category	Priority
Key information from show and tell talks is hard to be extracted quickly just from tags and transcripts (something like: "goal: improve sleep, intervention: x, data-collection method: y, result: z, timeframe: z months....., linked notebooks: yes/no/link)	Content / finding relevant content	Medium/high priority
It is hard to find out which projects (especially show and tell talks) are relevant to own interest (sleep too broad, no hierarchy, watching reading takes too long, hack: ctrl f)	Content / finding relevant content	Medium/high priority
Not enough content for it to be really useful (better go to other resource)	Content / finding relevant content	More general/long-term issues
General: usefulness with regards to large language models?	Content / finding relevant content	More general/long-term issues
Introduction to personal science for beginners on homepage is missing / not obvious to find	Homepage	"Low-hanging fruit"
Design: Layout on homepage not perfectly aligned	Homepage	Low priority
Same info with different formatting confusing (subcat sleep projects and linked projects under sleep tracking)	Linked content	General wiki issue / hard to solve
Infobox with backlinks still not found by everyone (but more find it. And if they don't, they use alternative way via subcats)	Linked content	Low priority
Infobox not noticed in case there is a section with the same heading (eg. projects using a tool; no assumption that similar content there twice)	Linked content	Low priority
Backlinks and properties difference in infobox unclear	Linked content	Low priority
Access to notebooks/data would be appreciated (already linked in some projects, matter of amount of content)	Notebooks	Low priority
Content not easy to read on very wide screens	Responsiveness	Low priority
Confusing: subcategories are not always the same	Subcategories	High priority
Organizational system in topics is confusing (could be split in health topics and tracking/analysis processes; same in tools (hard/software on same level as topics)	Subcategories	High priority
Confusing: no subcategories for people (maybe related to task; not many people pages yet and less focus on them for now)	Subcategories	Low priority
Search results are not always relevant	Search	General wiki issue / hard

		to solve
Titles don't represent what project is about (would need to hover over all links or click on everything)	Titles/Naming conventions	Medium/high priority
Bug: no linked content for diet tracking tools page (is tool page but fulfills function of topic page, thus should be transformed into topic page)	Titles/Naming conventions	"Low-hanging fruit"
Active vs activity tracking (maybe they should not be in same category)	Titles/Naming conventions	Low priority

A.9.3 Comparison of Results from Usability Test Iterations 1 and 2

Task 1: <i>Please quickly inspect the home page. What do you expect to find on this wiki? Who do you think might use this wiki, and what for?</i>	
Usability test 1	Usability test 2
<p>What?</p> <ul style="list-style-type: none"> - Information about tools and how to track (5) - What personal science is (4) - Community meetings (1) - Open to contributions (2) - Topics, tools, projects, people (1) <p>Who?</p> <ul style="list-style-type: none"> - People interested in personal science - General public interested in health, or people into data and science <p>Issues/wishes</p> <ul style="list-style-type: none"> - Would expect/want introduction on what personal science is (e.g. what is it, what can you do with it/goals, history) (3) 	<p>What?</p> <ul style="list-style-type: none"> - Topics, tools, projects, people (2) - Information about tools and tutorials on how to generate and analyze data about personal health habits (1) - Resource for people planning their own experiments (1) <p>Who?</p> <ul style="list-style-type: none"> - Ideally, the whole self-tracking community should use it, anyone who 'uses more than a fitbit to watch and track their runs', but anyone could benefit (1) - Anyone interested in self-tracking (2) - People who want better understanding of how their habits and surroundings impact their health (1) - People planning their own experiments (1) <p>Issues/wishes</p> <ul style="list-style-type: none"> - Definition of self-research is missing on homepage for new users (1) - Wishes to quickly find experiments that are relevant to topics of interest and that they can adapt to their needs (1)
Conclusion	
<ul style="list-style-type: none"> - Expectations have not changed much, even though in round 2, expectations revolve more practically around tracking activities - Link to definition to personal science for beginners - Not necessarily directly clear if it is possible to find experiments that relate to areas of interest 	

Task 2: <i>Please look for a device that records sleep data.</i>	
Usability test 1	Usability test 2
<p>In the end:</p> <ul style="list-style-type: none"> - On 'Sleep tracking' page → scrolls to 'Devices for sleep tracking' section (5 of 5) <p>How they got there:</p> <ul style="list-style-type: none"> - Quick: - Types 'sleep' in search bar → sleep tracking page (1) - Clicks on Topics → sleep tracking page (1) - Slow: - Does not find 'sleep' keyword on homepage, would 	<ul style="list-style-type: none"> - Quickly clicks on Tools → Sleep tracking tools subcategory (4 of 5) - Types 'sleep tracking' in search bar, clicks on tools link in infobox (1 of 5, power user)

<p>have expected it in list of examples, then tries search (1) / considers search but does Topics → Sleep tracking (1)</p> <ul style="list-style-type: none"> - Tries complex search terms 'Sleep recording data' and 'sleep record devices'. Second search leads to sleep tracking page (1) 	
Conclusion	
<ul style="list-style-type: none"> - Task completion a lot faster in round 2, primarily thanks to new subcategories of Tools category - Everyone in round 1 passes via Sleep tracking page, only 1 person in round 2 (power user) - No one in round 1 scrolls down to 'linked content', they stop at the devices section on the page (in round 2 no one but the power user use the Sleep tracking page) - Search used a lot more often in round 1 	

Task 3: <i>Please look for projects other people have done related to sleep tracking</i>	
Usability test 1	Usability test 2
<ul style="list-style-type: none"> - 3 are already on Sleep tracking page, scroll down and find projects in linked content <ul style="list-style-type: none"> - Of which 1 does not find linked content directly and would not have expected it below references - 1 types complex search term ('projects sleep tracking') in search bar, does not find satisfying results, then types 'sleep tracking' and jumps to page → does not find linked projects without hint (would not have expected info below references) - 1 gets a bit lost by starting search via Fitbit page, then types sleep in search bar and jumps to page, but does not find linked projects without hint (would not have expected info below references) 	<ul style="list-style-type: none"> - 1 s already on Sleep tracking page, clicks on project link in infobox (power user) - 3 click on Sleep tracking link in subcategory Sleep tracking tools overview page <ul style="list-style-type: none"> - 2 hesitate a bit, but then find link to projects in infobox - 1 does not find link / infobox, goes to 'projects' in side menu instead, and to subcategory sleep projects - 1 clicks on projects in side menu → sleep projects subcategory
Conclusion	
<ul style="list-style-type: none"> - Task completion is a lot faster in round 2 - Infobox with project links found by more participants, but still some hesitation for some - Sleep tracking page link in sleep tools subcategory is noticed and used by several participants - Alternative way via projects → sleep projects is used 	

Task 4: <i>Please look for people who have worked on activity tracking.</i>	
Usability test 1	Usability test 2
<p>5 find it via linked content on Activity tracking page (2 of them after hint)</p> <p>Journeys:</p> <ul style="list-style-type: none"> - 1 goes to Topics → activity tracking, scrolls down (quick) - 3 type 'activity' in search bar, on page scrolls down (1 quick, one slower, one after hint) 	<p>5 find it via infobox on Activity tracking page</p> <p>Journeys:</p> <ul style="list-style-type: none"> - 1 types 'activity tracking' in search bar, clicks People link in infobox (power user) - 3 go to People category → surprised to not find subcategories; then try Topics → Activity tracking <ul style="list-style-type: none"> - 1 of them tries Projects first, but does not find Activity subcategory

<ul style="list-style-type: none"> - 1 types in search bar, on page tries to find people via projects. Finds person in project infobox but it is a red link; tries complex search; is then hinted to look in linked content <p>Other :</p> <ul style="list-style-type: none"> - 3 confused about 'active tracking' and 'activity tracking' - 1 confused because on profile of a person linked under 'activity tracking', there is no direct information about activity tracking - 1 tends to ignore red links, 1 surprised about red links - 1 would have found it easier to identify people if they were called by full name and not username, and found it confusing that people are called 'self-researchers' - 1 would only access people via projects, otherwise no interest 	<ul style="list-style-type: none"> - 1 goes to Projects → Subcategory 'heart rate and cardiovascular health projects' (but hesitates); goes back to homepage → Topics <p>Other:</p> <ul style="list-style-type: none"> - 3 confused about 'active tracking' and 'activity tracking'
Conclusion	
<ul style="list-style-type: none"> - Task completion not necessarily faster, because <ul style="list-style-type: none"> - Subcategories in People category were expected but not found - Most people access people via Activity tracking page - Some try via projects, but lack of keyword activity is confusing - Wording issues: <ul style="list-style-type: none"> - similarity of 'active tracking' and 'activity tracking' - 'Activity' vs 'Fitness' vs 'Physical activity' ... conventions? 	

Task 5: <i>Please look for projects that use a Fitbit device.</i>	
Usability test 1	Usability test 2
<p>4 scroll down to linked content on Fitbit page / 1 after hint</p> <p>Journeys:</p> <ul style="list-style-type: none"> - 1 wants to use search (interviewer asks to try via categories this time) → Tools → Fitbit (quick) - 1 goes to Tools → Fitbit → finds section with projects that use fitbit → scrolls down to linked content → wonders what difference between lists is and if they could be linked - 1 uses complex search 'fitbit project' → results in 'oura vs fitbit' and 'activity tracking and weight loss' projects → concludes that second talk uses fitbit, because it is in transcript (ctrl f) → finds fitbit link in infobox on hint of interviewer - 1 goes projects → ctrl f 'fitbit' (not many results, project category only shows few projects directly that are not in show and tell subcategory) → goes to Oura vs Fitbit talk → section 'projects that use fitbit' → scrolls to linked content but says he might not have done it if he hadn't learned it before 	<p>4 find it via Projects links in Infobox on Fitbit page</p> <p>Journeys:</p> <ul style="list-style-type: none"> - 1 types 'Fitbit' in search bar - 1 goes to homepage → Tools → Fitbit - 1 goes to homepage → Tools → Subcategory 'Fitness and heart rate tracking tools' → Fitbit - 1 goes to homepage → Tools → hesitates to click on subcategory 'Fitness and heart rate tracking tools' → scrolls down to Fitbit on main tool page <p>1 tries two ways</p> <ul style="list-style-type: none"> - Projects → no crumbs leading to Fitbit - Tools → Fitbit → Section 'Personal science projects that use Fitbits'

<ul style="list-style-type: none"> - 1 is on activity tracking page → clicks on internal link in section 'tools for activity tracking' → Fitbit <p>Other:</p> <ul style="list-style-type: none"> - 1 finds lists of projects overwhelming 	
Conclusion	
<ul style="list-style-type: none"> - In v1 2 participants struggle, in v2 no one - After users learned that linked content is on the bottom (v1), most of them scroll until there - Project infobox with backlinks (v2) is found quicker 	

<p>Task 6: <i>Imagine you would like to improve your sleep, and stumbled across this wiki. Please explore the wiki in order to see if and how it could help you to implement your project.</i></p>	
Usability test 1	Usability test 2
<p>5 go to 'Sleep tracking' page</p> <p>Journeys:</p> <ul style="list-style-type: none"> - 3 via search (1 quick, 2 via complex search 'sleep tracking device' or 'improving sleep' that let them pass by other pages until finding sleep tracking) - 1 via homepage → topics → Sleep tracking - 1 via homepage → Sleep tracking in list of examples <p>Information they wish to find:</p> <ul style="list-style-type: none"> - overview/bigger picture about how sleep tracking is done (sleep tracking and other related wiki pages), and devices - Tracking tools and projects to see how other people did it - Tool and a manual on how to use it to track sleep (not available on oura ring page); would like how-to's on top of projects (e.g. distilled information from the projects for an easy start, for not having to watch all talks), would also like some support on how to do dta analysis (wants to know if tool could be useful before buying it) - Tools that are useful, and would watch videos, e.g. 'tracking and improving my sleep' - Looks for tools, and would like to find more information about things that affect sleep and which apps they could use on the sleep tracking page <p>Other feedback:</p> <ul style="list-style-type: none"> - 2 people try to ctrl f 'improve' either in search bar or on pages - 1 tries to find projects via linked people, but people pages don't always list projects or link with a specific topic (frustrating) 	<p>4 go to 'Sleep tracking' page</p> <p>Journeys:</p> <ul style="list-style-type: none"> - 2 type 'sleep' in search bar - 2 go Topics → Sleep tracking <p>1 goes Projects → sleep projects → ctrl f 'improve' → only few results have improve in title → would continue by typing 'improving sleep' in search bar</p> <p>Information they wish to find:</p> <ul style="list-style-type: none"> - 1 projects obviously related to 'improving sleep' - 2 would read sleep tracking page first, would try to find a device and try interventions. Would expect curated information on sleep tracking page (e.g. very relevant projects, expects info on topic page to be more relevant than automatic list); too many projects otherwise, many of which not relevant - 1 would read sleep tracking page, but finds that there is not enough information yet; finds that there are too many projects, many of which not relevant - 1 would read sleep tracking page, would like information about interventions be integrated and not in external link, would consult projects but there are too many <p>Other feedback:</p> <ul style="list-style-type: none"> - 1 confusing different formatting for same thing (sleep projects subcategory and search results) - 4 think there are too many projects and no way to tell which are relevant
Conclusion	
<ul style="list-style-type: none"> - Problem: titles don't represent what the project is about (how to know if a project is about 'improving sleep'?) - Problem: too many pages are tagged with 'sleep', too tedious to look for relevant ones. Some obviously only marginally related to sleep, no hierarchy. - In v2 people actually inspect projects list, in v1 no one does - Sleep tracking topic page is used a lot as entry point 	

Task 7: Based on experience/interests of participant: Imagine you would like to make a project about condition X/about topic X and you stumbled across this wiki. How would you try to find information that might be useful for you?

Usability test 1	Usability test 2
<p>Apple watch</p> <ul style="list-style-type: none"> - Has one, thus interested - Finds new interesting information (about sensors and data export) - Feels motivated to add recent model <p>Blood glucose / diabetes</p> <ul style="list-style-type: none"> - Has diabetes, thus interested - Looks for their device (freestyle libre) - Finds interesting information (about new version) - Finds information is missing about things they had issues with in the beginning (how to put on/remove device; how to get new free sensor if damaged) <p>Note taking / diaries</p> <ul style="list-style-type: none"> - Does it themselves and is interested in this as research method - Goes to 'journaling and note taking tools' page - Mostly interested in how to quantify and analyze written text, learns about some approaches they didn't know of - Would like more information about how to digitize written text, and feels motivated to add their tool (ReMarkable) <p>Diet tracking</p> <ul style="list-style-type: none"> - Interested because they are doing it at the moment - Serendipitous find ('salt and sea carbs' in examples on home page), caught interest because participant learned they eat too much salt too. Would read it if there was time - Checks other examples on homepage, nothing related to food - Topics → diet and weight loss → diet tracking tools - Finds interesting information (Finds tools they use and overview table comparing sensors) <p>1 participant did not do the task</p>	<p>Cognitive testing</p> <ul style="list-style-type: none"> - Interest: thinks there could be a great benefit in tracking cognitive functions as regularly as physical values - Participant is author of page - Would wish for more input from other people <p>Fitness / Weight loss</p> <ul style="list-style-type: none"> - Interest: Started tracking to lose weight some years ago, lost a lot of weight; now training for long-distance run - Projects → Fitness and Physical activity projects / Diet, digestion, and weight loss projects → ctrl f to find keywords of interest - Finds transcript formatting inaccessible, would probably have summary generated by chatgpt - Looks at slides, finds them helpful - Would not watch video (listening to music most of the time, and video watching is time consuming) - Would want goal/outcome in project infobox, e.g. improved performance by 50%, to learn about relevance <p>Chronic pain</p> <ul style="list-style-type: none"> - Interest: family history of chronic pain, meta research about non-adherence to personal science of people with chronic pain - Does not necessarily expect topic to be there at all, but finds chronic condition under topics (but stub, and only few projects linked, does not notice infobox by themselves) - Finds that project names are not always clear, hover popups help, but time consuming, would like subtitles or other meta information directly available <p>Fitness / Weight gain</p> <ul style="list-style-type: none"> - Interest: actively trying to gain muscular weight at the moment - Topics → weight tracking → diet tracking tools - Finds information on both pages interesting and relevant, as well as linked projects (in section) <p>Microbiome</p> <ul style="list-style-type: none"> - Interest: did projects analyzing own microbiome - Search → microbiome → sees nothing on probiotics → search → finds some projects in results list - Thinks systems like chatgpt would yield better results (gives links, conversation can be continued) - Future directions: something like chatgpt plus integration of personal data - Wonders about connection with notebooks - Thinks people might like approaches based on github more
<p>Conclusion</p>	

- Interest particularly in tools and how to use them in v1, in v2 more topic pages and projects
- Bug (?): nothing linked in diet tracking tools infobox

Other feedback

Usability test 1

General comments

- 3 similarities to wikipedia make it easy to use, but there are also expectations tied to it
- 1 would like more know how/how tos
- 1 example list confusing
- 1 finds t

Comparison information architectures

- 1 similar
- 1 likes existing more because simpler
- 1 would like a category for community/what is going on, and a space for how to's/protocols
- 1 thinks people/projects is redundant, would like category for big topics (e.g. sleep, diet, where you find information attached to it)
- 1 did not reply

Most interesting parts of wiki

- 1 tools, projects (because they are not findable anywhere else), condensed information
- 1 tools, people least interesting
- 1 tools, projects (but would not spend too much time watching videos), would like how to/protocols to use tools
- 1 projects (because unique), other things could be found on wikipedia; would like guides not only on how to track, but also on interventions (e.g. how to eat well)
- 1 space to share protocols (past) and WIP (present work), option to update things is good, project content is attractive and unique, would like community part, would like to have it easier for newcomers

Usability test 2

General comments

-
- Comparison information architectures**
- 1 thinks there should be two ways: existing categories, and categories that allow easy entry for beginners, approves new subcategory system in that sense (power user)
- 2 think overall system can be used without issues, but topics is too broad, could have subcategories like 'factors', or one for something like 'health and wellness' and one for 'processes', i.e. tracking processes, data analysis
- 1 thinks overall systems are similar, notices social category that they also made and approves; strange that hardware/software are at same level as 'diet tracking tools'
- 1 thinks that different systems could work, just projects need to be easy to find

Most interesting parts of wiki

- 1 Projects and tools
 - Would like to have direct access to notebooks, and see what data other people used in metadata
- 1 Topics and tools
 - People come with e.g. chronic conditions, they need to find topic quickly and then find what other people have used, what kind of tools are available, what kind of projects
- 1 projects
 - Need for a centralized resource where people interested in personal science can find other experiments that they can modify for their own purposes
 - You should be immediately able to find the experiments that relate to the problem you are trying to solve
- 2 did not reply

Conclusion

A.10 User-Generated Labels for Clusters of Cards (Summary)

Cluster ID (color)	Cards in cluster	Participant-generated labels for full cluster of sub-clusters (manually clustered by perceived similarity)
1 (pink)	'Circadian rhythm', 'Blood pressure', 'Microbiome', 'EEG (Electroencephalography)', 'Mood', 'Stress', 'Meditation', 'Blood glucose tracking', 'Heart rate tracking', 'Activity tracking', 'Sleep tracking', 'Time tracking', 'FODMAP', 'Supplements'	'Experiments', 'Tracking methods', 'Tracking', 'Self-research techniques', 'Methods' 'Self-research variables (what can be tracked)', 'Sources/Factors', 'Biomarkers', 'Physical monitoring', 'Body values', 'Things to track', 'Examples of parameters', 'what you can track', 'Metrics to track', 'Things to track' 'Personal improvement', 'Interventions', 'solution', 'Buttons You Can Push', 'Interventions and activities' 'Health/Wellbeing/Medical Topics', 'Topics', 'Definitions', 'specific health problems' 'The psychology of health', 'Emotions', 'Mental health improvement', 'Mental Health' 'Diet and Nutrition', 'Nutrition', 'Food', 'Fitness and diet', 'Food/Diet', 'Diet and Foods', 'Diet', 'Fitness'
2 (brown)	'Smartphone Disengagement', 'Impact of work-related stress', 'Sleep recordings: Oura vs Fitbit', 'Serimmune antibody analysis results', 'How do controls on antigen COVID tests work?', 'A Decade of Tracking Headaches', 'Lessons from a year of heart rate data', 'Breaking the TV Habit', 'Tracking Parkinsons & Medication'	'Projects', 'Personal experience/projects', 'Science project', 'Experiments', 'Self-studies No Peer Review', 'Studies', 'Research', 'historical research', 'Experiences', 'Personal experience/projects' 'Return on experience / testimony', 'Studies and discussions', 'Lessons learned', 'Discussion/Topics' 'Show & Tell Talk', 'Show & Tell', 'Resources', 'media', 'References', 'Shows/Books', 'Self-research related materials' 'Community blog', 'Sociality - Persons/ Creators, Organizations', 'Advice/Tips/Blog' 'The psychology of health', 'Emotions', 'Mental Health' 'specific health problems', 'Medical improvement'
3 (violet)	'Is it chance? Use a T-Test to identify how likely an intervention worked', 'Finding relations between variables in time series', 'R', 'Reasons for and against self tracking and quantification'	'Data analysis', 'Programming, Statistics, Maths', 'Methods of analysis', 'Methods', 'method', 'Personal science approaches and people', 'Self-research research questions', 'Research Questions', 'Tools for personal science' 'general skills and info', 'FAQ', 'Meta', 'what you can track', 'Self Tracking' 'Self-studies No Peer Review', 'Research', 'Studies and discussions' 'Community blog', 'Sociality - Persons/ Creators, Organizations', 'Blog', 'Advice/Tips/Blog' 'Resources', 'Publications / to read', 'References'
4 (red)	'Ambient Environment and Room Weather', 'Dates and Times', 'Spaced Repetition'	'Parameters', 'Variables/Parameters', 'Entity', 'Self-research variables (what can be tracked)', 'Sources/Factors', 'Metrics to track' 'Analytical approaches and measurements', 'Data Collection', 'Methods', 'Methodology', 'method', 'Methods / protocol', 'Practice', 'Techniques for analysis', 'Tools and techniques', 'Tools for personal science', 'Equipment' 'Tools for learning', 'cognitive ability' (only card 'Spaced Repetition') 'Interventions', 'Interventions and activities', 'Buttons You Can Push' (only card 'Spaced Repetition')
5 (green)	'Diet tracking tools',	'Technologies', 'Tools', 'Tools and apps', 'Apps',

	'Tools for journaling, thoughts and note taking', 'Bangle.js', 'One Button Tracker', 'Fitbit', 'Oura Ring', 'FreeStyle Libre', 'RescueTime', 'MySymptoms'	'Tools/Accessories/Hardware', 'Gadgets and hardware tools', 'Devices', 'Tracking devices/apps', 'Tracking device', 'Self-research devices', 'Wearables', 'Equipment', 'Tools & Techniques', 'Tools for collection', 'Tools for measurement', 'Tools for tracking' 'Tracking methods', 'Methods of tracking', 'Tracking', 'Analytical approaches and measurements', 'Personal measurements', 'tracking of time usage and events' 'General Health and Fitness' 'Mental health improvement'
6 (orange)	'Piotr Wozniak', 'Seth Roberts', 'Personal Science (book)', 'Open Humans', 'Communities', 'Keating Memorial'	'Reference/Community', 'About / Community', 'Personal Science Communities', 'Communities of practice and events', 'Communities', 'community', 'Community / what's going on / Shared', 'Community building', 'Social', 'Human resources', 'Self-research communities and projects', 'Infrastructures', 'Self-research promotion', 'Personal science', 'Personal science approaches and people' 'Personal Scientists', 'Self-researchers', 'People', 'Researchers', 'Scientists', 'historical person', 'Sociality - Persons/ Creators, Organizations' 'References', 'Resources/Further Learning', 'Resources', 'Return on experience / testimony', 'general skills and info', 'Meta'

A.11 Process Recommendations

The reflections from chapters 5.1. and 5.2. are summarized below as process recommendations for designing knowledge management systems for and with communities of practice in citizen science.

A.11.1 Process Recommendations for Designing Knowledge Management Systems for and with Communities of Practice in Citizen Science

- **Understanding objectives.** What is the purpose of the knowledge management system? Why are existing solutions not sufficient? Try to understand the general problem that the approach is thought to solve. Then try to understand this problem in more detail.
- **Understanding and involving users.** To this end, try to engage with a variety of community stakeholders, from newcomers to experienced members. Individuals with community management experience might have valuable insights into failed attempts, as well as common issues and motivations, and can inform the prioritization of issues. It might also be insightful to talk with people who have stopped engaging in the CoP, or people who have not (yet) started to understand barriers. Try to understand the target audience and think of both the consumers and contributors. Who enters and

consumes information, what are their incentives, and why would they use your system instead of existing ones? Creating a solution that caters to every user group might not be achievable. To navigate this, consider giving precedence to specific user groups and customizing the solution to match their needs. Including potential future users at every phase of the design process can go beyond seeking feedback, and might also include design or leadership roles. Either way, try to maintain transparency about how individuals can get involved and try to document the design process as openly as possible to make it easier for new people to engage.

- **Prototyping and iterating.** It can be easier to start discussions and gain feedback when interacting with prototypes, than by contemplating abstract ideas. Statements of community members such as interview extracts or forum contributions can serve as discussion starters in the beginning, non-functional and functional prototypes at later stages. Be open to early and frequent iterations, presenting unfinished ideas, and being willing to discard or revise approaches as needed. Introducing a functional prototype early in the process can provide valuable insights into real-world usage under realistic conditions. However, a drawback of this approach is that implementing changes in an already operational system can be more challenging. In that case, it is important to ensure that measures are in place to prevent the loss of user-generated content.
- **Structuring information.** A suitable information architecture is important so people can discover relevant information. Keep in mind that your imagination of a reasonable organization of the information might not represent mental models held by other community members. The same counts for information architectures that are already in use in other systems. If you start building a knowledge management system from existing resources, be open to adapt information architectures or information representation according to user feedback or observations. You can for example start by using a category structure that is already in use if you have a functional prototype, and see during usage how well it fits with the generated content, then adapt it as necessary. Try to provide tools that allow users to influence or adapt information architectures, e.g. by letting them use custom tags. If there is already a certain quantity of content, there are user study methods like card sorting or tree testing to develop or test information architectures with users. Start somewhere, e.g. something already in use and test it. There might be various ways to structure knowledge efficiently, and some ways might be better for one user group or another. If possible, offer several complementary pathways to provide alternative pathways for discovery.
- **Tacit knowledge.** Learning and sharing experiences about a particular practice is frequently at the center of a community of practice. A significant portion of this

information resides in tacit knowledge, encompassing skills, know-how, and contextual nuances. Presenting this information in a beneficial manner might not be immediately apparent. A format effective in one context might not translate well into another context. Allowing users to contribute diverse types of artifacts and soliciting feedback from current users on running a user study can aid in assessing usability and identifying potential issues. Making artifacts editable can provide users with the opportunity to distill important information. In any context but particularly in contexts related to research and citizen science it is also vital to consider quality standards, along with mechanisms in place for their oversight, and how users can engage in this process.

- **Measuring success.** Developing ways to measure success can be a complex task, especially for early stages of the project, in which the knowledge management system does not have a large user base. Meaningful measures may vary for each project. For example, try to understand which functionalities it provides that did not exist before, and in which use cases, contexts and by which user types the system is used.
- **Embracing change.** Knowledge relevant in communities of practice, especially if it is an emerging practice, will change frequently. Therefore, view the knowledge management system as a dynamic entity, with its structures evolving in response to usage patterns over time. Try to see the knowledge management task as partly independent from its technical implementation. Insights about mental models, architectures or formats might be transferable to other systems, and the content within the knowledge base can become a valuable object of research by itself.

A.11.2 Process Recommendations for the Participatory Design of Peer Production Systems

- **Choosing a collaborative approach based on objectives.** Peer production can be a suitable approach if your goal is providing a system of mutual support for design and planning phases of research projects, encouraging reuse and adaptation of existing resources and practices, and harnessing collective creativity of contributors with diverse motivations and skills.
- **Building a community.** Providing a peer production infrastructure, even if it addresses a useful niche, is insufficient. Community-building, maintenance effort, and the attainment of a critical mass of content need considerations and resources. Implementing a peer production approach might be easier if there is already an existing community that shares peer-to-peer values.
- **Attracting early contributors.** It is advantageous if the platform can serve a valuable function for the initial core contributors, independent of having a critical mass of

content. For instance, if it provides an accessible and open space for documenting and sharing personal projects or best practices.

- **Understanding motivations for participatory design.** participatory design can have several motivations, like redistributing power dynamics, creating shared ownership, or effectively addressing community requirements. Participatory methods need to be carefully selected and reflected in the function of these goals. Existing dynamics within the community and between the community and the people launching the design process need to be considered, too. participatory design is related to costs, such as time and effort, for all stakeholders involved. Think about your motivations for a participatory approach, and the community's motivations to contribute. Try to find ways, if possible together with community members, for meaningful engagement that respect the capacities and motivations of the individuals involved.
- **Developing engagement methods.** Effective participatory design requires careful planning. Think about how stakeholders can engage in the project throughout the whole process, and how they learn about these opportunities. Without explicitly assigning or choosing methods, roles, and communication infrastructures, the leadership of the design process tends to be assumed by a small circle of core team members, often those who can dedicate the most time to it, such as individuals acting in professional capacity.
- **Leveraging peer production to facilitate long-term engagement.** Peer production infrastructures enable continuous and asynchronous engagement that extends beyond traditional participatory design methods. Try to consider pathways that allow users to receive updates on recent changes and discussions, provide feedback, and contribute to platform improvement to make use of these synergies.

A.12 Articles

A.12.1 A Peer Production Model for Citizen Science: Comparative Analysis of Three Online Platforms

Title: A Peer Production Model for Citizen Science: Comparative Analysis of Three Online Platforms

Authors: Katharina KLOPPENBORG, Mad PRICE BALL, Bastian GRESHAKE TZOVARAS

Status: In preparation for submission. Preprint available on SocArXiv.

Citation:

Kloppenborg, K., Ball, M. P., & Greshake Tzouvaras, B. (2021, May 23). A peer production model for citizen science: comparative analysis of three online platforms.

<https://doi.org/10.31235/osf.io/rw58y>

A peer production model for citizen science: comparative analysis of three online platforms

Katharina Kloppenborg^{1,4,*}, Mad Price Ball^{2,*}, and Bastian Greshake Tzovaras^{1,2,3*}

¹Learning Planet Institute / Inserm U1284, Université Paris Cité, Paris, France

²Open Humans Foundation, United States

³The Alan Turing Institute, London, United Kingdom

⁴Lead contact

*Correspondence: katharina.kloppenborg@cri-paris.org (K.K.), mad@openhumans.org (M.P.B.), bgreshaketzovaras@turing.ac.uk (B.G.T.)

Summary

As a data-based practice, citizen science involves volunteers in various stages of research, often including the collection and processing of data through online platforms. Citizen science projects frequently combine epistemic goals with societal benefit goals, such as democratizing science. However, it is not well understood how to design such participation architectures to enable volunteer engagement in support of these goals. In this study, we introduce a working model of peer production for citizen science for analysis and comparison of key design features for participation and their consequences. To test this model, we apply it to three citizen science case studies and show that it helps move beyond existing classification approaches, supports the structured analysis of key features across different approaches, and their implications. This work represents a step towards understanding and informed decision-making of participation architectures for existing as well as future online infrastructures for citizen science.

Data Science Maturity

DSML 1: Concept

Keywords

citizen science, peer production, participation architecture, data infrastructures, social computing

Introduction

Citizen science is a growing practice across various academic disciplines, with a frequent focus on aggregating and processing large datasets. As such, citizen science is a field that employs data science techniques to guide the collection and analysis of data. Beyond its use as a format for data collection, citizen science is also seen as having potential societal benefits, including through improving scientific literacy¹, democratizing science², improving data justice³, and enabling “undone science”, which refers to areas of research that are considered important by civil society, but that lack funding⁴. As a result, citizen science projects often combine epistemic objectives with societal benefit goals, and can differ considerably in how they balance and prioritize these.

The ways in which volunteers participate in citizen science projects also vary widely – indeed, the term “citizen science” itself has been used to describe very different contexts, and there is often a lack of consensus regarding when the term is appropriate⁵. Among projects labeled as citizen science, the most common form are “contributory” projects⁶, alternatively described as “crowdsourcing”⁷, where large numbers of volunteers contribute to data collection or processing in projects designed by professional scientists. While the scope of volunteer involvement is limited in such projects, other forms of citizen science include volunteers in other aspects of research, like problem definition or data interpretation. Bottom-up citizen science projects may be initiated and accompanied by institutions or professional researchers in all or most steps, like in the case of “Extreme Citizen Science” initiatives, which collaborate for example with indigenous communities in conservation projects⁸. Projects may also be initiated as community-led “grassroots” activities, with varying degrees of institutional involvement in project design and management, for example in environmental justice⁹, or patient advocacy¹⁰. This diversity in types of participation implies diversity in how projects are designed to engage participants.

Many citizen science projects rely heavily on online platforms and tools for collaborative knowledge production, and these platforms are themselves a subject of sociological and design research. Participation architectures, i.e. the opportunity structures available to external contributors¹¹, can vary greatly depending on the projects' goals and participation concepts. Such meta-research efforts on citizen science platforms have mostly focused on crowdsourcing aspects to investigate user behaviors, for example as they relate to learning norms of practice¹², coordinated action¹³, and data quality¹⁴, or to derive design claims¹⁵ and guidelines¹⁶ for creating successful projects. While there are dedicated platforms that support community-led citizen science projects, such as Public Lab¹⁷, they typically operate at a smaller scale than crowdsourcing platforms, and to date there has been less meta-research about them. In addition, bottom-up initiatives usually operate on a smaller scale, often developing or adapting data collection and analysis tools to their local context⁸.

Interestingly, among the works focusing on crowdsourcing, several suggest that projects may benefit from deeper participant engagement in pursuit of epistemic goals: They suggest providing features that help newcomers move from peripheral tasks to more impactful work¹², and new infrastructures that support more collaborative and advanced work, authority and legitimacy¹³. They argue with the proven competence of citizen scientists to handle complex tasks, like identifying glitches while image tagging, or resolving conflicts when determining new taxonomies¹³, and cite scientific discoveries, e.g. in astronomy, that have been achieved by citizen scientists engaging beyond the requirements of the predefined task^{13,15}. They go even further, suggesting redefining the role of volunteers as scientific assistants¹³, or establishing communities that function semi-autonomously¹⁵. Additionally, there have been calls for deeper, more meaningful engagement, referring to the potential to transform what knowledge is created, how it is created, and by whom². Regardless of motivation, the question of how to create participation architectures that enable greater volunteer engagement remains largely unanswered in literature. This poses significant barriers to the design or redesign of existing and future citizen science platforms. Practitioners need tools and guidance to help them gain a systematic understanding to make informed design decisions that are best suited for their topic and project goals.

To address this gap and provide practitioners with the needed support, we here introduce a model that operationalizes and applies the characteristics of “peer production” theory to the larger citizen science context.

Peer production as a mode of distributed knowledge production relies on self-organizing communities of individuals who collaborate online¹⁸ and is widely known from its applications in Wikipedia and open-source software development. Knowledge creation in citizen science often shows similarities to peer production: Volunteers with different skills and backgrounds produce knowledge artifacts collaboratively, typically online as a distributed community of individuals and with non-monetary motivations.

Given these similarities, there have been calls for peer-produced citizen science¹⁹ and we agree that peer production theory has the potential to help facilitate multifaceted engagement of volunteers in citizen science: In particular, peer production approaches enable new contributors to progress from simple routine tasks to complex, creative work, and to switch back and forth between them at their free choice, e.g. from micro tasks like fixing typos to complex tasks like writing software²⁰, reflecting the call for citizen science features to move newcomers from peripheral tasks to more impactful work^{12,13}.

As most peer-production literature related to citizen science tends to focus on political aspects, governance or intellectual property^{21,22}, we build our working model of peer production as a summary of key characteristics of online platforms that enable the peer production of knowledge, applied to the citizen science domain.

To demonstrate the use of the model, we apply it to three case studies – the citizen science platforms Zooniverse, iNaturalist, and Public Lab. We characterize and compare the platforms' participation architectures, and discuss the impact of different design choices.

In doing so, we intend to give citizen science practitioners a tool at hand to reflect participation architectures of existing and future platforms, and to provide support for taking informed design decisions with respect to peer production characteristics.

Results

Working Model of Peer Production

This working model is an effort to operationalize peer production for citizen science. It consists of a set of key characteristics of collaborative online knowledge production. It is intended to be used to analyze citizen science online platforms that offer functionality for user contributions.

The model was derived from existing peer production literature, largely from Kostakist and Bauwens²³, and Benkler²⁰. More details, and information on the background of this model can be found in the section *Experimental procedures* and *Supplementary Material A*. Figure 1 summarizes and illustrates the working model of peer production, including examples from Wikipedia, as one of the most successful and widely known peer production platforms. Links to the sources of the examples can be found in *Supplementary Material B*.








Peer production characteristic	Wikipedia example
Common research object 	Open encyclopedia
Range of tasks 	Creating, editing, discussing articles
Granularity and modularity 	Articles, sections, sentences, ...
Equipotential self-selection 	Users choose what and how much they want to edit
Quality control 	Talk pages for feedback, rollback function to undo changes
Learning trajectories 	Manuals, suggestions of easy tasks for beginners
Direct and indirect coordination 	Flags like "citation needed", red links, talk pages

Figure 1. Working model of peer production with examples from Wikipedia

A central feature of the model is the **common research object** that is collectively produced. It results from the goals of the project. A project can have one or more common research objects. Since they are something that is created collaboratively, they are usually composed of many parts (see “granularity and modularity”). In Wikipedia, the common research object is an open encyclopedia.

The **range of tasks** describes what types of work are accessible to users, i.e. tasks of which quality, size, and complexity. For online platforms, this can be analyzed by inspecting the interaction possibilities of the user interfaces. In Wikipedia, the range of tasks includes, amongst many more, creating, editing, or discussing articles.

Granularity and modularity refers to how tasks and the research object are broken down into smaller tasks and objects. Related is the cost of integration, which describes the effort required to integrate small elements into larger modules that make up the research object. On Wikipedia, the encyclopedia is made up of modules called articles, which in turn are composed of sections, sentences, etc. The editor allows low-effort integration of edits or new pages into the system. Creating a consistent narrative or putting articles in the right categories can equal higher integration effort.

Equipotential self-selection relates to which tasks are accessible to regular platform users, and to what extent they can choose and self-assign tasks. On Wikipedia, users can choose to create or edit any article of their choice, without the need to prove expertise with formal entry credentials, like a degree in a relevant field. They can also decide how much and which parts of an article they would like to edit, without waiting for anyone to assign them what to work on.

The **quality control** characteristic covers the mechanisms in place to judge the quality of user contributions. If done by the user community, it can also be referred to as “communal validation”²³. On Wikipedia, for example, users can give feedback on the “Talk” page of an article. There is also a rollback function to go back to former states, and users can become stewards for specific pages and topics and watch in more detail over their development.

Learning trajectories refers to how a newcomer learns to execute tasks, and which possibilities they have to learn and perform more advanced tasks. On Wikipedia, there are many guides to teach newcomers, for example the “Manual of Style”, and to document consensus on design guidelines. New users have the possibility to pick micro-tasks, like editing

spelling errors, before starting bigger tasks, and can thus learn by practice. There are also community guidelines in favor of treating newcomers or other users who might make mistakes with patience and benevolence (“Assume good faith”).

Direct and indirect coordination relates to features that help coordinate work, e.g. that signal open tasks, as well as features that allow for direct communication between users, like chat systems. In Wikipedia, for direct coordination, there are talk pages for articles and user pages. Features to signal open tasks are, for example, links in red color that indicate that a page that is linked in another page has not been created yet, section headings followed by little or no text, or flags like “citation needed”, or “stub”, which can be integrated into articles.

Case Studies

To evaluate the working model of peer production, we apply it to three citizen science platforms to identify how the different characteristics are implemented: Zooniverse, iNaturalist, and Public Lab. All three of these are online citizen science platforms with active user bases and jointly cover a wide range of different participation approaches that can be found in citizen science. A schematic representation that describes the knowledge production processes for each platform can be found in Figure 2. Links to sources for the case studies can be found in *Supplementary Material B*.

Knowledge production in the case studies

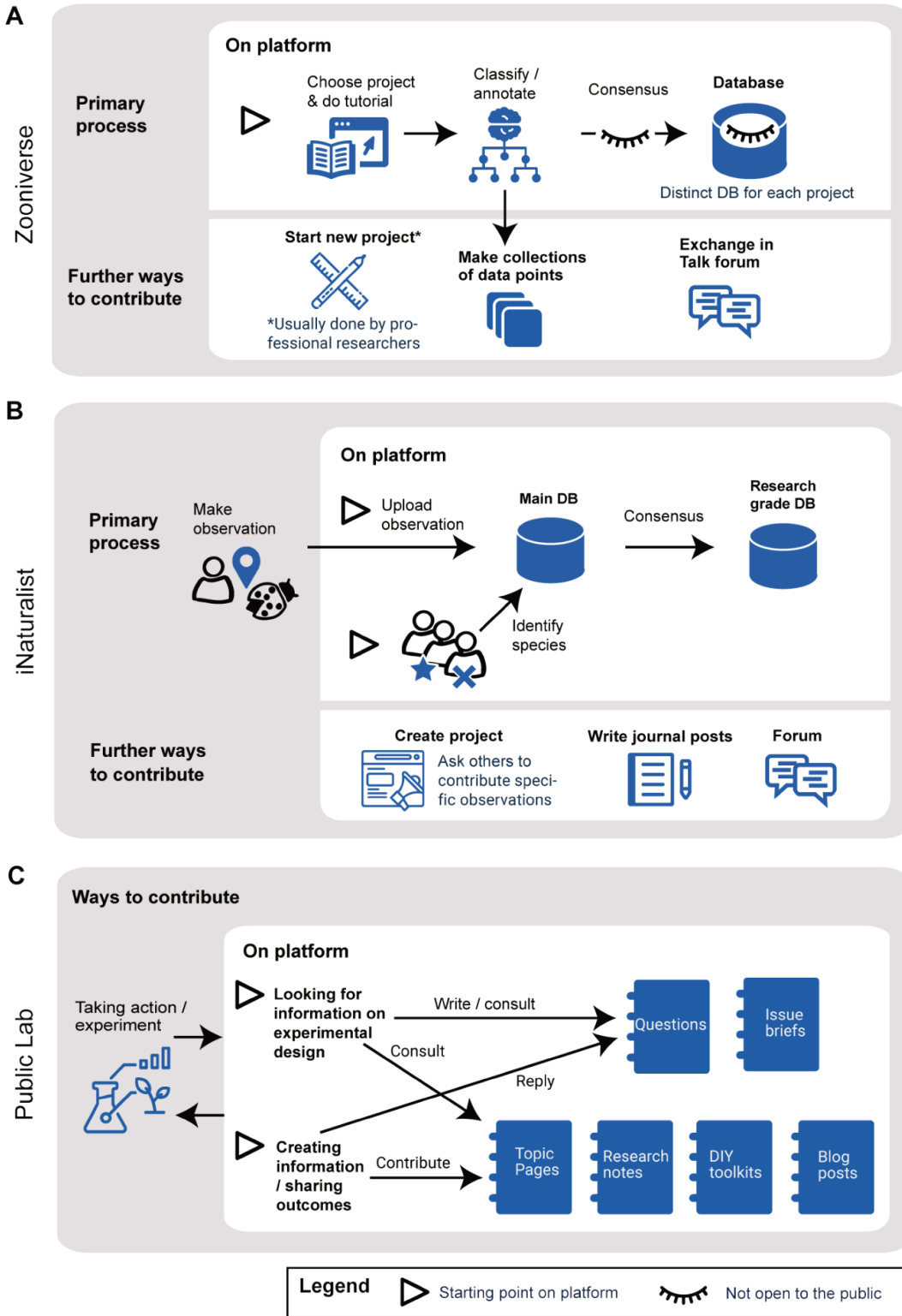


Figure 2. Schematic representation of knowledge production in the case studies.

Zooniverse²⁴ is a popular platform for crowdsourcing citizen science. Volunteers assist professional researchers from all kinds of domains, by collectively classifying data for their projects. Zooniverse developed from the Galaxy Zoo project and is now a collaboration between the University of Oxford, the University of Minnesota - Twin Cities (UMN) and Chicago's Adler Planetarium. With more than 2.5 million registered users, and almost 700 million classifications as of September 2022, it is one of the biggest online platforms for citizen science.

iNaturalist²⁵ is a social network and online platform for sharing, mapping and identifying biodiversity observations around the world. While collaboratively building a biodiversity database, they frame their primary aim as “connect[ing] people to nature”. iNaturalist began in 2008 as a Master's final project at the UC Berkeley's School of Information and is now a joint initiative between the California Academy of Sciences and the National Geographic Society, with almost 5.7 million registered users and over 115 million uploaded observations.

Public Lab²⁶, short for Public Laboratory for Open Technology and Science, is a community, non-profit organization and online platform, aiming to empower people to address environmental justice issues through community science and open technology. They focus on the collaborative development, sharing, reuse and adaptation of DIY scientific tools intended to enable community investigation of environmental concerns. Public Lab was formed after the BP oil disaster at the Gulf of Mexico in 2010, when residents documented damage in a grassroots mapping effort using weather balloons¹⁷. There are over 2,100 registered users, who contributed numerous topic pages, reports, and manuals for do-it-yourself environmental monitoring projects.

Zooniverse

Common research object For nearly all projects on Zooniverse, the main research objects are large datasets of images, videos or text that need to be annotated and which are typically provided by professional researchers. Projects span a wide range of topics and users are asked to annotate individual data points such as telescope images of galaxies, create transcriptions of historic diary pages, or identify noises of deep sea animals from acoustic samples.

Range of tasks The main task type is the annotation of a data point according to the instructions given for each individual project. Beyond this, users can make collections of data points they classified, and the platform offers forums for each project as well as talk pages for each individual data point (see Figure 2A). These talk pages can be used for leaving comments,

hashtags, adding data points to collections, and for participating in discussions for quality control and learning (see below). Committed users can become moderators of talk forums for specific projects.

Granularity and modularity Depending on the project, annotation tasks can differ in complexity and duration, e.g. ranging from selecting from predefined options to transcribing documents. Within one project, the granularity of annotation tasks is of similar size. Modularity is given by the automatic integration of user contributions to the database after annotation.

Equipotential self-selection Users choose which projects they want to contribute to based on their interests, and the quantity of data points they want to process, within the limits of available data. Beyond this, users do not self-select tasks as the data points are automatically assigned to the user one at a time. To engage further, users can take part in discussions on projects or individual data points using the aforementioned talk pages. Users can become talk forum moderators after being granted the rights by the project leads. Creating new projects requesting annotation is usually reserved to professional scientists.

Quality control Annotations of other users are hidden and the main quality control of contributions is done by project leads behind the scenes without further input by the contributors. However, post-classification, the user can access the data point's talk page to provide feedback or discuss with other users who have annotated the same data point.

Learning trajectories For each project, tutorials are provided by project leads in order to teach users how to annotate for a given project. Further engagement is possible on talk pages. Users can take up more advanced roles, e.g. becoming a moderator in a project talk forum. These more advanced roles are assigned by the project leads.

Direct and indirect coordination There is no coordination between users in the main data processing workflow, because the annotations of other users are hidden. However, after annotating, users can access a page dedicated to the respective data point, where they can add tags and comments, and see meta-information other users entered. For further communication there is a forum attached to each project.

iNaturalist

Common research object The main research object of iNaturalist is a public biodiversity database consisting of sightings of species with metadata like location, time, and photos.

Range of tasks iNaturalist includes a similar range of tasks as Zooniverse, expanded by some functions (see Figure 2B). Beyond annotating data, which consists in adding species identifications to observations, additional tasks include the collection of new data points along with metadata, as well as the possibility of writing journal posts, discussing in a forum, and creating data collection projects that encourage users to provide observations specific to certain areas or species. Users in the curator role can edit the taxonomy, create and edit wiki pages, resolve flags on taxa and user content, and hide comments and suspend users for violating community guidelines.

Granularity and modularity In iNaturalist tasks are usually of small size, ranging from identifying existing observations to uploading new observations. Modularity is provided on two levels: Observations are automatically added to the database and provide the data pool for future annotations. Secondly, once the species has been collectively identified (see quality control), the observation is automatically added to the Global Biodiversity Information Facility (GBIF) database²⁷.

Equipotential self-selection Users can select from the range of tasks mentioned above. Users are free to decide the type and quantity of observations they would like to annotate or add to the database, without automatic assignment. There is a curator role that is granted by iNaturalist staff for users who have engaged continuously over several months: curators have additional rights, e.g. to edit iNaturalist's taxonomy or to hide comments that violate community guidelines.

Quality control There is a communal validation process for species identification, using the following mechanism: New observations are automatically tagged with "needs ID". As the observations and annotations are generally publicly accessible, users can see other users' annotations, and can agree, disagree, or make a guess more specific. For example, if the person uploading the observation specified it as "ladybird", other users can either confirm this identification, specify what species of ladybird it is or disagree by identifying it as a different insect. The resulting annotation is called "community taxon" (see screenshot in *Supplementary Material C1*). To achieve research grade, the ID needs to be supported by at least two users,

and either have a community taxon at species level or lower. This research grade database is publicly accessible under an open license but some metadata, like specific location, can be obscured, to protect the privacy of underage users, or to protect endangered species.

Learning trajectories To learn how to contribute to the database, there is a “Getting started” guide with tutorials on uploading observations and species identification. Users are free to address bigger tasks, like creating their own projects, or offline data-collection events (“bioblitz”) for which there are also help pages, or become curators after having collected experience through regular engagement.

Direct and indirect coordination There are features to coordinate work, like “needs ID” tag in the communal validation process, projects that call for specific observations, or filters to help users identify observations in areas of their expertise. For direct communication, there is a forum, as well as comment and blog functionality.

Public Lab

Common research object On Public Lab, the research object is a catalog of experimental designs and project reports in the domain of DIY environmental science. Unlike on Zooniverse and iNaturalist, there is no data collection or annotation mechanism on the platform. Instead, artifacts include collections about DIY environmental monitoring and knowledge transfer, like topic pages, similar to wiki pages, e.g. on air quality, and research notes, similar to blog posts (e.g. “How to Build a Bucket Air Monitor”). There are artifacts for problem solving, like issue briefs, in which users explain their issue to support from other users, or more general question elements that other users can reply to.

Range of tasks Reflecting the diversity of research artifacts, Public Lab users can work on a range of tasks that can be split roughly in two categories: looking for information on experimental design, and sharing information or outcomes (see Figure 2C). To look for information, users can create dedicated artifacts, i.e. questions and issue briefs, or consult other existing artifacts on their topic of interest. To share outcomes or other information, users can create or contribute to topic or project pages, research notes, DIY toolkits, and blog posts. They can replicate other users’ experiments (“activities”), comment and reply to questions, issue briefs, or research notes.

Granularity and modularity The wide range of tasks have varying granularity, ranging from small edits on topic wiki pages to uploading larger building blocks such as experimental designs. Modularity is achieved by interlinking contributions on Public Lab through tags and backlinks. These tags need to be added to an artifact to link it to a topic or artifact category, to add backlink functionality (“i did this” / “seeks:replications”, “activity:”, “replication:”, “activity:infragram”) to integrate their artifacts / make them findable. Tags are pre-specified if an artifact is created by clicking on “add an activity”, “I did this”, “ask a question” from a related page (see screenshot in *Supplementary Material C2*).

Equipotential self-selection Similar to iNaturalist, Public Lab users have access to all content to self-select open tasks they are most interested in or add new content to their liking. On application, users can take on moderator or admin roles.

Quality control Due to the free, textual form of the research artifacts, there is no algorithmic quality control that measures consensus like in iNaturalist or Zooniverse. Rather, feedback is generally in written form of comments to other artifacts, or in the form of new blog entries, when users replicate each other’s activities and report their protocol and how it worked in their case.

Learning trajectories For new users, there are so-called issue brief artifacts to remove barriers and encourage users to get started (see screenshot in *Supplementary Material C3 a*), “first-time-posters” tag, templates and forms for artifacts, and helpful instructions in default texts of text boxes (see screenshot in *Supplementary Material C3 b*). There are also question objects to help resolve specific issues. It is possible to replicate existing experiments or ask other users to replicate one’s own experiment to get feedback and learn from one’s own or other people’s experiences. More experienced users can apply for moderation or administration roles.

Direct and indirect coordination There are several features that help signal open work, like the “I did this” button (see screenshot in *Supplementary Material C2 a*), that appears on pages tagged with “activity”, which depicts an invitation for other users to replicate the experiment, and at the same time serves to connect the original and replicated activity. Other ways to signal that help is needed are dedicated artifacts like “questions” or “issue briefs”. For direct communication, there is a comment functionality under all types of artifacts.

Discussion

The goal of this study was to develop a systematic approach to understanding the characteristics of online platforms that enable deeper volunteer engagement in citizen science, following literature highlighting its potential for achieving epistemic or societal goals. To this end, we leveraged principles of peer production, a form of distributed knowledge production that shares characteristics with some types of citizen science, and that has been successfully applied in other areas of knowledge production to involve volunteers in tasks of varying complexity.

We developed a working model of peer production that encompasses hallmarks of knowledge production in peer production environments. Finally, we applied this model to three case studies to explore the usefulness of the model for a citizen science context and to provide an overview of how these citizen science projects implement participation.

This approach has two main limitations: First, our case studies focus on the main platforms of the citizen science projects at a static point in time. Further participation may occur outside of these platforms, for example, on coding platforms such as GitHub, in chat systems, or at online and offline community events. Additionally, looking at the status quo also risks ignoring differences in platform design over time, including design approaches that have been tried and discarded. Future research could complement our work by analyzing a longitudinal sample of platforms or by conducting interviews with long-time community members. Second, peer production literature is not specific to citizen science and the ecosystems for scientific knowledge production might come with their own particularities and requirements, potentially impacting the applicability of general peer production principles. Despite this, we note the similarities that some forms of citizen science projects share with peer production projects, as well as the potential of peer production approaches to engage volunteers in tasks of varying complexity²⁰. Importantly, peer production approaches have proven successful in coordinating the work of volunteers to create knowledge in science-adjacent fields such as the creation of encyclopedia articles or software code²⁸.

In line with this, the working model of peer production allowed us to identify and characterize participation architectures of three citizen science case studies along our seven key characteristics of peer production. In the following, we will make use of this structured approach to compare the case studies with regards to each characteristic. This will allow to highlight

similarities and differences, and reflect benefits, challenges, and applicability of various design decisions in different citizen science contexts. The case studies were selected to represent active online citizen science communities across a wide spectrum of participation approaches. These differences become already apparent in the self-stated goals of the platforms: Zooniverse's objective is to enable research projects at scale by giving research teams the opportunity to obtain crowdsourced data annotations. iNaturalist's goal is to "connect people to nature", and to promote conservation and biodiversity science. Public Lab aims to support communities in addressing environmental justice issues with scientific methods and open technology. While Zooniverse's goals are predominantly epistemic, iNaturalist, and notably Public Lab explicitly combine epistemic with societal benefit goals.

Different implications that these goals have on design decisions for the platforms can be found along all peer production characteristics we investigated, starting with the **(1) common research objects**: In Zooniverse, they constitute individual databases that research teams provide for their projects to be annotated by volunteers. Each research team has full decision-making power and control over the datasets and annotation process, including the exclusive right to consult the full dataset for the whole duration of the annotation project. In iNaturalist, the commonly created biodiversity database is public, and in turn can be consulted and reused by anyone. Public Lab focuses largely on mutual support with regards to research methods, with knowledge objects such as protocols for experiences, all shared under open licenses.

For the **(2) range of tasks** Zooniverse focuses mostly on a single type of tasks, i.e. annotating images or videos provided by researchers, in line with the contributory, or crowdsourcing nature. iNaturalist broadens this participation approach, as participants can annotate data points but also provide their own. Public Lab has a less structured approach, providing a more open-ended list of tasks related to experimental design. Those choices have downstream consequences on **(3) granularity and modularity**: In Zooniverse and iNaturalist tasks are of similar small granularity, as participants provide or annotate one data point at a time, which is automatically added to a database, leading to a low cost of integration. On Public Lab, where tasks are mostly text-based, there is more different granularity of tasks, and their aggregation into modules requires more effort due to the less-structured nature of participation: Data aggregation through tagging can require manual effort to connect individual contributions into a larger body of

knowledge to make them findable. To reduce the effort, Public Lab uses automatic assignment of tags, when users create artifacts from links.

Differences in the aforementioned characteristics also reflect on the **(4) equipotential self-selection** of tasks: With a focus on crowdsourcing⁷, Zooniverse automatically assigns data points to users, according to randomization rules determined during project creation, meaning no self-selection beyond picking a project the user wants to contribute to. This setting is helpful for newcomers needing expert guidance, which is provided by the controlled provision of data, tutorials and help features in Zooniverse projects²⁹. iNaturalist opens up the task selection by allowing users to choose which observations they would like to annotate, as well as to add new observations to the database. This freedom of choice helps users filter the database for observations of their interest and expertise, as a certain level of domain knowledge is necessary for species identification³⁰. A downside is that this can possibly lead to the introduction of sampling bias: Di Cecco et al.¹⁴ identify spatial, temporal, and taxonomic biases issuing from user observation patterns, e.g. because users tend to specialize on some species or groups, rarely observe a species twice, record observations in their free time, and close to where they live.

We also find different **(5) quality control** approaches, often in relation to data visibility, that are the result of differences in task design and main research objects. Zooniverse's focus on structured crowdsourcing favors an arithmetic quality control that is hidden from its users to avoid biasing future responses¹². Instead, users are given the chance to discuss their annotated data points post-classification. As iNaturalist focuses on creating a public database, all annotations are visible to everyone, with some allowances to obscure data to protect privacy or endangered species. While this communal validation approach could open the process to biases, research has found it leads to reliable classification quality³¹, potentially as species identification requires a certain level of expertise, and because the visibility of all annotations enables other participants to raise issues when noticing wrong annotations. Public Lab also uses communal validation. Given the platform's open-endedness, quality control is also more open-ended, often through qualitative feedback in written form on methods with the goal to help people collect "good enough data"³².

Different levels of visibility and transparency also affect **(6) learning trajectories** and the transition from novice to advanced tasks: In Zooniverse, project creators provide tutorials for

participants to learn the necessary skills. Given that other people's annotations remain hidden, learning from other participants is not enabled within the main annotation interface. Nevertheless, Mugar et al. found that meta-information left on the talk pages of data points serve as "practice proxies" that help inform users about norms of practice and can stimulate further engagement in higher-level analyses¹². While iNaturalist provides tutorials, users can also learn from the existing classifications that are publicly available, providing an additional pathway to onboarding and learning. Public Lab's mission is to empower communities to advocate for environmental justice, so it explicitly targets newcomers and encourages them to learn how to conduct their own studies. Endorsing trial-and-error as a key part of research¹⁷, the platform incorporates features that encourage asking questions, sketching problems and solution approaches, and reproducing each other's work.

Features for **(7) direct and indirect coordination** are used, for example, to signal open work to contributors, and are often a function, and part of other collaborative processes, like quality control. In Zooniverse open work is signaled by project leads. Users do not interact during the main annotation process, and annotations of other users are hidden, to avoid bias. In iNaturalist, users are guided to open work by flags that signal that a new observation needs to be identified, or by calls for participation to upload specific types of observations. In Public Lab, users can add specific artifacts that signal that they have a question or want feedback or guidance with regards to research protocols. All platforms have features that allow contributors to discuss topics further, either as comment functionality for specific instances of artifacts, forums, and chat systems. Naturally, there are more coordination features in projects where users need to find and allocate work to each other, or where users need to find work for their specific expertise. Discussion features attached to specific artifacts and projects are essential where unstructured feedback is needed, e.g. for entire research protocols. But also in crowdsourcing settings, their usefulness for deeper engagement and to leverage the creativity of citizen scientists for scientific discoveries has been praised^{12,13,33}, while also wishing for some more structured tools for coordination to scale up¹³.

Comparing the case studies, we find that the working model of peer production supports the identification and structured analysis of key differences among approaches and implementations of participation in citizen science projects. Shirk et al.'s⁶ framework of public participation in scientific research classifies our three case studies into different categories: Zooniverse most closely fits the definition of the "contributory" category, iNaturalist falls between "contributory"

and “collaborative”, and Public Lab is most closely “collegial”. Our model allows moving beyond such classifications by helping to understand the different design elements that help implement participation in citizen science: Many of these differences are a result of high-level design decisions regarding the goals and common research object of a given project, which in turn influence the types of participation that are enabled. For example, while the closed-ended goals of Zooniverse projects limit participation options, this approach in turn enables the automated large-scale integration of user-provided annotations while avoiding bias. Given iNaturalist’s goal of providing a public resource, some trade-offs were implemented regarding the potential for bias, but also enable new pathways to contribution while maintaining low integration-cost. Lastly, Public Lab’s open-ended nature provides a large set of potential contributions, but at the cost of a less-streamlined process for data integration.

In conclusion, the working model of peer production proved not only helpful for investigating and reflecting on individual projects, but also for comparing between, and understanding trade-offs and benefits of different designs. Our case studies are all examples of successful citizen science projects: Applying the model highlights how they use different engagement strategies to create value in different ways. While crowdsourcing and peer production are often contrasted in literature^{19,20}, we propose to conceptualize it rather as opposite ends of a spectrum. Our results suggest that already adding some peer production elements can make a big difference in terms of volunteer engagement. In peer production settings, individuals can choose to contribute to a range of tasks of different complexity, starting with micro-tasks as in crowdsourcing, or complex, creative tasks. The working model of peer production is thought to be applicable to a wide range of citizen science platforms, in order to situate the project based on peer production characteristics, to allow project leads to identify areas in which they might or might not integrate more collaborative approaches, depending on the characteristics and goals of their project.

Further research should apply the model to more citizen science projects, which is especially interesting given the wide range and loose definition of citizen science, to see how it applies to other contexts. It also needs to be explored to what extent the model is beneficial for the design of new or redesign existing platforms, and how it impacts the achievement of epistemic or societal goals. Potentially, the model could be extended by a set of guidelines, which could also integrate governance and intellectual property dimensions. Research on online infrastructures where data and knowledge is collaboratively created is underserved in citizen science literature, but especially important in this field where collaboration and user engagement are a core

element, and can ultimately influence how scientific knowledge is created. Extending on prior approaches to classifying citizen science projects, the present study goes beyond sorting projects into categories, allowing to understand the different design elements that help implement participation in citizen science across a wide range of approaches in online settings, from crowdsourcing to open-ended collegial projects. In doing so, the working model of peer production provides a systematic approach to help citizen science practitioners reflect on volunteer participation in data- and knowledge production with online infrastructures in use, as well as to inform the design of future projects.

Experimental procedures

Resource availability

Lead contact

Katharina Kloppenborg is the lead contact for this study and can be contacted at katharina.kloppenborg@cri-paris.org.

Data and code availability

This study did not generate any new datasets.

Materials availability

This study did not generate any materials.

Method details

Method 1: Working model

Peer production, while most commonly known from open source software or Wikipedia, is also applied in commercial tools such as TripAdvisor or Yelp. What unifies these is the underlying production process, i.e. decentralized task execution in an online environment, and the spanning of a wide range of possible tasks of varying complexity, from simple routine tasks to complex creative tasks, from which contributors are free to choose²⁰.

We derived the working model of peer production based on recent peer production literature, notably Kostakis and Bauwens²³, and Benkler²⁰, by identifying characteristics specifically related to knowledge production. The working model of peer production covers characteristics specific to peer production, as well as aspects of knowledge production that are not unique to peer production, but necessary to develop an understanding of how knowledge is created in an online environment. For more detailed information on the characteristics and the background of the model, see *Supplementary Material A*.

Method 2: Sampling and case studies

To identify citizen science platforms that might be relevant for analysis, we scanned project databases (eu-citizen.science, citzenscience.gov, scistarter.org, p2pvalue.eu), issues from 2016 to 2020 from the journal “Citizen Science: Theory and Practice”³⁴, and projects analyzed in a survey on the European citizen science landscape by Hecker et al. (2018). To select the cases, we used purposive sampling. The following conditions were considered: Each case had to be a citizen science platform, with an active, possibly large user base, and with a major part of knowledge creation happening online on the platform. Availability of secondary literature, especially if related to the keyword “peer production” was also considered. Beyond that, we tried to select platforms that cover a diversity of participation approaches. To get insights on participation approaches a priori, the “About” sections of the cases were consulted, as well as secondary literature. In the dataset used in Hecker et al. (2018), the projects were already annotated with Shirk et al. (2012)’s levels of participation.

To conduct our analysis, we applied the peer production working model to the three cases by inspecting the respective online platforms, complemented by supplementary literature if available. Links to features on the online platforms are available in *Supplementary Material B*.

We created a user account for each platform and walked through menu points and interaction possibilities to derive schematic knowledge creation processes. In the following, each peer production element from the model was applied to the case with respect to that knowledge production process. If secondary literature on specific design decisions was available, this helped to inform the platform comparison and discussion of benefits and challenges of different approaches.

Acknowledgements

We would like to thank Gary Wolf, Gwen Ottinger and Roland van Dierendonck for contributing to an early brainstorming on the role of peer production in citizen science. We would also like to thank Benjamin Mako Hill, Vineet Pandey, Molly Clare Wilson, Ariel Lindner and Enric Senabre for their discussions and feedback around this project. Furthermore, we thank Fotis Psomopoulos and the Open Life Science team for guidance and support during the realization of a peer production design practices blog based on the case studies. We also thank Susanne Hecker for kindly providing us with a list of the level of participation in European citizen science projects.

Thanks to the Bettencourt Schueller Foundation long term partnership, K.K. and B.G.T. were supported by a CRI Research Fellowship to Bastian Greshake Tzovaras. M.P.B. was supported by funding from Open Humans Foundation.

Author contributions

Conceptualization, K.K., M.P.B., and B.G.T.; Methodology, K.K., M.B.P., B.G.T.; Investigation, K.K., M.B.P., and B.G.T., Writing - Original Draft, K.K.; Writing - Review & Editing, K.K., M.P.B., and B.G.T., Visualization, K.K.; Supervision, B.G.T.; Funding Acquisition, B.G.T., and M.P.B.

Declaration of interests

The authors declare no competing interests.

References

1. Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., and Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience* 59, 977–984. [10.1525/bio.2009.59.11.9](https://doi.org/10.1525/bio.2009.59.11.9).
2. Strasser, B.J., Baudry, J., Mahr, D., Sanchez, G., and Tancoigne, E. (2018). “Citizen Science”? Rethinking Science and Public Participation. *Sci. Technol. Stud.*, 52–76. [10.23987/sts.60425](https://doi.org/10.23987/sts.60425).
3. Christine, D.I., and Thinyane, M. (2021). Citizen science as a data-based practice: A consideration of data justice. *Patterns* 2, 100224. [10.1016/j.patter.2021.100224](https://doi.org/10.1016/j.patter.2021.100224).
4. Frickel, S., Gibbon, S., Howard, J., Kempner, J., Ottinger, G., and Hess, D.J. (2010). Undone Science: Charting Social Movement and Civil Society Challenges to Research Agenda Setting. *Sci. Technol. Hum. Values* 35, 444–473. [10.1177/0162243909345836](https://doi.org/10.1177/0162243909345836).

5. Haklay, M., Fraisl, D., Greshake Tzovaras, B., Hecker, S., Gold, M., Hager, G., Ceccaroni, L., Kieslinger, B., Wehn, U., Woods, S., et al. (2021). Contours of citizen science: a vignette study. *R. Soc. Open Sci.* 8. <https://doi.org/10.1098/rsos.202108>.
6. Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E., et al. (2012). Public Participation in Scientific Research: a Framework for Deliberate Design. *Ecol. Soc.* 7, 29. <http://dx.doi.org/10.5751/ES-04705-170229>.
7. Howe, J. (2006). The Rise of Crowdsourcing. *Wired*.
8. Chiaravalloti, R.M., Skarlatidou, A., Hoyte, S., Badia, M.M., Haklay, M., and Lewis, J. (2022). Extreme citizen science: Lessons learned from initiatives around the globe. *Conserv. Sci. Pract.* 4. 10.1111/csp2.577.
9. Mah, A. (2017). Environmental justice in the age of big data: challenging toxic blind spots of voice, speed, and expertise. *Environ. Sociol.* 3, 122–133. 10.1080/23251042.2016.1220849.
10. Lewis, D.M. (2020). Do-It-Yourself Artificial Pancreas System and the OpenAPS Movement. *Endocrinol. Metab. Clin. North Am.* 49, 203–213. 10.1016/j.ecl.2019.10.005.
11. West, J., and O'mahony, S. (2008). The Role of Participation Architecture in Growing Sponsored Open Source Communities. *Ind. Innov.* 15, 145–168. 10.1080/13662710801970142.
12. Mugar, G., Østerlund, C., Hassman, K.D., Crowston, K., and Jackson, C.B. (2014). Planet hunters and seafloor explorers: legitimate peripheral participation through practice proxies in online citizen science. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing (ACM)*, pp. 109–119. 10.1145/2531602.2531721.
13. Jackson, C., Crowston, K., Østerlund, C., and Harandi, M. (2018). Folksonomies to Support Coordination and Coordination of Folksonomies. *Comput. Support. Coop. Work CSCW* 27, 647–678. 10.1007/s10606-018-9327-z.
14. Di Cecco, G.J., Barve, V., Belitz, M.W., Stucky, B.J., Guralnick, R.P., and Hurlbert, A.H. (2021). Observing the Observers: How Participants Contribute Data to iNaturalist and Implications for Biodiversity Science. *BioScience* 71, 1179–1188. 10.1093/biosci/biab093.
15. Tinati, R., Van Kleek, M., Simperl, E., Luczak-Rösch, M., Simpson, R., and Shadbolt, N. (2015). Designing for Citizen Data Analysis: A Cross-Sectional Case Study of a Multi-Domain Citizen Science Platform. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (ACM)*, pp. 4069–4078. 10.1145/2702123.2702420.
16. Yadav, P., and Darlington, J. (2016). Design Guidelines for the User-Centred Collaborative Citizen Science Platforms. *Hum. Comput.* 3, 205–211. 10.15346/hc.v3i1.15.
17. Breen, J., Dosemagen, S., Blair, D., and Barry, L. (2019). Public laboratory: Play and civic engagement. In *The Playful Citizen: Civic Engagement in a Mediatized Culture*, pp. 162–174.
18. Benkler, Y. (2006). *The Wealth of Networks: How Social Production Transforms Markets and Freedom* (Yale University Press).
19. Mahr, D., and Dickel, S. (2019). Citizen science beyond invited participation: nineteenth century amateur naturalists, epistemic autonomy, and big data approaches avant la lettre. *Hist. Philos. Life Sci.* 41, 1–19. 10.1007/s40656-019-0280-z.
20. Benkler, Y. (2016). Peer production and cooperation. In *Handbook on the Economics of the Internet*, J. Bauer and M. Latzer, eds. (Edward Elgar Publishing), pp. 91–119. 10.4337/9780857939852.
21. Fuster Morell, M., Senabre Hidalgo, E., and Cigarini, A. (2021). A framework for assessing the commons qualities of citizen science: comparative analysis of five digital platforms.
22. de Sherbinin, A., Bowser, A., Chuang, T.-R., Cooper, C., Danielsen, F., Edmunds, R., Elias, P., Faustman, E., Hultquist, C., Mondardini, R., et al. (2021). The Critical Importance of

- Citizen Science Data. *Front. Clim.* 3, 650760. 10.3389/fclim.2021.650760.
23. Kostakis, V., and Bauwens, M. (2021). Grammar of Peer Production. In *The Handbook of Peer Production*, M. O’Neil, C. Pentzold, and S. Toupin, eds. (Wiley), pp. 21–32.
 24. Zooniverse.org (n.d.). Zooniverse. <https://www.zooniverse.org/>.
 25. iNaturalist <https://www.inaturalist.org>.
 26. Public Lab <https://publiclab.org>.
 27. What is GBIF? (2022). GBIF Glob. Biodivers. Inf. Facil. <https://www.gbif.org/what-is-gbif>.
 28. Benkler, Y., Shaw, A., and Hill, B.M. (2015). Peer Production: A Form of Collective Intelligence. In *Handbook of Collective Intelligence* (MIT Press), p. 33.
 29. Østerlund, C., Mugar, G., Jackson, C., and Crowston, K. Typologies of Learning in Open Online Collaborative Communities. In *International Reports on Socio-Informatics (IRSI), Proceedings of the CSCW 2016 – Workshop: Toward a Typology of Participation in Crowdwork*, pp. 31–41.
 30. McMullin, R.T., and Allen, J.L. (2022). An assessment of data accuracy and best practice recommendations for observations of lichens and other taxonomically difficult taxa on iNaturalist. *Botany* 100, 491–497. 10.1139/cjb-2021-0160.
 31. Hochmair, H.H., Scheffrahn, R.H., Basille, M., and Boone, M. (2020). Evaluating the data quality of iNaturalist termite records. *PLOS ONE* 15, e0226534. 10.1371/journal.pone.0226534.
 32. Gabrys, J., Pritchard, H., and Barratt, B. (2016). Just good enough data: Figuring data citizenships through air pollution sensing and data stories. *Big Data Soc.* 3, 205395171667967. 10.1177/2053951716679677.
 33. Lintott, C.J., Schawinski, K., Keel, W., van Arkel, H., Bennert, N., Edmondson, E., Thomas, D., Smith, D.J.B., Herbert, P.D., Jarvis, M.J., et al. (2009). Galaxy Zoo: ‘Hanny’s Voorwerp’, a quasar light echo? *Mon. Not. R. Astron. Soc.* 399, 129–140. 10.1111/j.1365-2966.2009.15299.x.
 34. Citizen Science: Theory and Practice <https://theoryandpractice.citizen-science-association.org/>.

A.12.2 Peer-Producing a Common Knowledge Resource for Personal Science

Title: Peer-Producing a Common Knowledge Resource for Personal Science

Authors: Katharina KLOPPENBORG

Status: Published in “CSCW'22 Companion: Companion Publication of the 2022 Conference on Computer Supported Cooperative Work and Social Computing”

Citation:

Kloppenborg, K. (2022, November). Peer-Producing a Common Knowledge Resource for Personal Science. In *Companion Publication of the 2022 Conference on Computer Supported Cooperative Work and Social Computing* (pp. 223-227).

<https://doi.org/10.1145/3500868.3561403>



Peer-Producing a Common Knowledge Resource for Personal Science

Katharina Kloppenborg
katharina.kloppenborg@cri-paris.org
Université Paris Cité
Paris, France

ABSTRACT

Personal science, the practice of using empirical methods to explore personal questions, has potential to advance discovery in clinical and public health. Yet, this branch of grassroots citizen science experiences important entry barriers: People tend to start their projects from scratch, and have no structured way of accessing community knowledge. In order to accumulate knowledge, similar communities in other domains have successfully made use of peer production technologies, a form of decentralized creation relying on self-organizing communities known from Wikipedia or open source software. To date, literature on implementing peer production approaches in citizen science is rare, and the particularities of personal science, notably the lack of an epistemic need to collaborate, impose barriers to using off-the-shelf approaches. In order to fill this gap, this dissertation is devoted to exploring peer production as a means to create a collective knowledge resource for the personal science community. Specifically, I investigate 1) how citizen science projects implement peer production characteristics by creating a working model from literature and applying it to case studies; and 2) how to enable the peer production of knowledge in the personal science community by engaging in a participatory design approach with the community. In doing so, this work contributes to further the understanding of deepening participation in citizen science, to harness collective intelligence and empower communities to address undone research.

CCS CONCEPTS

• **Human-centered computing** → Wikis; Collaborative and social computing design and evaluation methods; • **Applied computing** → Health informatics.

KEYWORDS

citizen science, personal science, peer production, participatory design, distributed knowledge production

ACM Reference Format:

Katharina Kloppenborg. 2022. Peer-Producing a Common Knowledge Resource for Personal Science. In *Computer Supported Cooperative Work and Social Computing (CSCW'22 Companion)*, November 8–22, 2022, Virtual Event, Taiwan. ACM, New York, NY, USA, 5 pages. <https://doi.org/10.1145/3500868.3561403>

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

CSCW'22 Companion, November 8–22, 2022, Virtual Event, Taiwan

© 2022 Copyright held by the owner/author(s).

ACM ISBN 978-1-4503-9190-0/22/11.

<https://doi.org/10.1145/3500868.3561403>

1 BACKGROUND AND MOTIVATION

Personal science has been defined as "using empirical methods to explore personal questions" [25]. People who engage in this practice typically reason about individual problems or personal challenges in everyday life, for example understanding effects of changes in diet or activity on physical or mental health, identifying triggers or correlations to help manage productivity, well-being, or chronic disease [25]. This practice is mostly aimed at acquiring practical self-knowledge [10]. Nonetheless, it has potential to advance public and clinical health discoveries beyond the individual level, as patient-led research initiatives born from individual personal science practice show, for example in the management of diabetes [16], Parkinson's disease [22], or cluster headaches [13].

Personal Science can be seen as a case of community-led – or grassroots – research. These approaches have proven influential in addressing undone science [7] not only in the health domain, but also in other areas, notably environmental justice [17]. Such grassroots research approaches, in which citizens engage in the full breadth of research, from identifying issues and developing research questions and protocols, to collecting, analyzing, interpreting data, and taking action, sometimes without any institutions or professional scientists involved, are part of the larger field of citizen science [8]. Grassroots approaches are in contrast to crowdsourced citizen science, the predominant form of citizen science today [9]. There, professional scientists develop and lead the projects, and citizens engage predominantly in neatly-defined data-annotation or collection microtasks, as found on the popular platform Zooniverse [24].

What contrasts personal science from other grassroots movements is that the projects are usually self-directed, and not aimed at generating generalizable knowledge [10]. Thus, there is no epistemic need to coordinate. Since its beginnings around 2008, the community exchanges in forums, online meetings and offline events, notably in a series of "Show & Tell talks" organized by the Quantified Self community, in which people present their projects [25]. However, self-researchers would benefit from more accessible knowledge sharing: People usually start their projects from scratch, and have no structured means to access community knowledge, which imposes important barriers for widespread participation. A lack of and need for knowledge accumulation into a common stock of knowledge has been identified in literature on the personal science [10], and similar self-research communities [6].

So far, there has been little research on how computational tools can support personal science efforts. Most work on platform design in citizen science has focused on data-intensive infrastructures for crowdsourced citizen science, including work on transferring tacit knowledge [20], and coordination beyond microtasks [12]. Work

concerning platforms for grassroots research is more rare. Environmental justice projects like Public Lab use online infrastructures including wikis to facilitate knowledge sharing and coordination [21].

Wikis are one of the most prominent technologies enabling *peer production*. Peer production is a form of open creation performed by groups that coordinate online in a decentralized manner, engage participants in a wide range of tasks, including creative tasks, usually without monetary incentives [2]. Peer production enables people with diverse interests and commitment levels to coordinate and collaborate in a wide range of tasks, and has proven as a successful approach to build Free and Open Source Software (FOSS), or Wikipedia. Despite calls for peer-production in citizen science [3, 18] this framework for collective intelligence, has rarely been explicitly applied to the citizen science field.

This work aims to fill this gap by exploring a peer production approach for collective knowledge creation in personal science. Taking into consideration the specific challenges in this community, like the lack of epistemic need to coordinate, and the transfer of tacit, procedural knowledge, I will explore if and how implementing peer production characteristics can support this community of practice in creating a common knowledge base. In doing so, I aim to contribute to knowledge on how to harness collective intelligence via online tools, to remove entry barriers and empower personal science and other grassroots citizen science communities, in order to unlock the potential to catalyze discovery and address undone research in clinical and public health and beyond.

2 RESEARCH GOALS AND RESEARCH QUESTIONS

Motivated to advance knowledge on how to empower grassroots citizen science communities to reach their full potential, this dissertation aims to explore a peer production approach for collaborative knowledge production in personal science. The major questions addressed in this research are:

- RQ1: Which project characteristics and online platform features enable the peer production of knowledge in citizen science?
- RQ2: How to enable peer production of knowledge in the personal science community of practice?

To address each research question, this dissertation is divided into two phases. Phase 1 is largely finished, and phase 2 is in progress.

3 WORK IN PROGRESS

3.1 Phase 1: Understanding characteristics and online platform features that enable peer production in citizen science

The initial phase of my research aimed to understand online platform and project characteristics that enable peer production in citizen science (RQ1) in an effort to identify relevant design guidelines. These guidelines were desired, in part, to inform my specific work with the personal science community (Phase 2).

While other works use peer production to analyze citizen science projects regarding their governance and intellectual property

[3, 19], our work focuses on design practices that enable peer production. Developing a systematic understanding of how design decisions influence these aspects of knowledge production is crucial for enabling the implementation and use of online platforms for these purposes.

Based on literature on peer production [1, 14] and coordinated behavior [5], I set up a working model of peer production - a set of characteristics, including an explanation, and an exemplary implementation from Wikipedia for illustrative purposes.

The characteristics allow reflection on the knowledge production process as a whole: the common research object that is being collaboratively produced, the range of tasks available to users, how tasks are broken down into smaller tasks and then integrated later on, how tasks are distributed and selected, quality control, coordination and communication features, and learning trajectories for new to experienced users.

With this model I aim to summarize some major characteristics of peer production to an accessible format that can be used as a reference for researchers and practitioners who want to implement peer production in their projects.

In the following, I used this model to perform case studies on three active citizen science projects that use online platforms to produce knowledge: Zooniverse [24], iNaturalist [11], and Public Lab [21]. I chose a sample of projects with diverse participation concepts to be more likely to find differences, and to make the case studies more instructive for understanding characteristics of peer production platforms.

The findings confirm that Zooniverse, a platform using a crowdsourcing approach, implements peer production features to a lesser extent than platform Public Lab, which specializes in enabling grassroots projects, with the biodiversity platform iNaturalist inbetween. The structured approach using the working model of peer production allowed to highlight and illustrate differences between the platforms' participation approaches, and helped to reflect on possible consequences of design choices.

In particular, this work highlights design features appropriate for a community where individuals are engaged beyond crowdsourcing, which is characteristic of the personal science community.

3.2 Phase 2: Designing an infrastructure for peer production of knowledge in the personal science community

The second phase of my thesis aims to support knowledge production in the personal science community by developing a peer production infrastructure suitable for their needs (RQ2).

I started this phase by following a double diamond approach of design thinking [4], in order to explore existing problems in the community and iteratively work on solution approaches. I gathered insights on problems to solve by extracting issues, wishes, and ideas from 22 semi-structured interviews with the community that had been led by my team beforehand [23]. These served as discussion starters to identify and prioritize areas of interventions together with community experts.

In line with [10], I found the lack of a common knowledge resource to be one of the major problems, leading to entry barriers, because people tend to start their projects from scratch without

Oura Ring

Top of the page

The **Oura Ring** is a wearable that is worn on a finger as a ring which tracks **sleep**, **activity** and **readiness**. Since 2013 there have been three different versions of the ring, with the latest version (v3) being launched in November 2021. At the same time they changed their business model, requiring a monthly subscription for access to all metrics recorded.


While the sensor set of the rings have changed over the versions, generally they contain an **accelerometer**, a **temperature sensor** as well as an **optical heart rate** sensor. From these sensors the Oura calculates the following metrics:

Contents [hide]

- 1 Differences between models
- 2 Metrics provided
 - 2.1 Body temperature metrics
- 3 Exporting data
- 4 Subscription
- 5 Project using Oura Ring
- 6 References
- 7 Linked content on this wiki

Tool Infobox

Related topics [HRV \(Heart Rate Variability\)](#), [Activity tracking](#), [Sleep tracking](#), [Body temperature tracking](#)



Differences between models [edit] [edit source]

•
•
•

Linked content on this wiki [edit source]

(The content in the table below is automatically created. See [Template:Tool Queries](#) for details. If newly linked pages do not appear here, click on "More" and "Refresh".)

Projects that use this tool	[Collapse]
Impact of work-related stress, Sleep recordings: Oura vs Fitbit, What does clustering tell us	

Self researchers who used this tool	[Collapse]
Gedankenstuecke Gedankenstuecke, Gedankenstuecke, Gedankenstuecke	

We talked about this tool in the following meetings	[Collapse]
2021-12-02 Self-Research Chat, 2022-05-19 Self-Research Chat	

Category: [Tools](#)

Bottom of the page

Figure 1: Screenshot of a "Tool" page in the Personal Science Wiki for the tracking device "Oura Ring" (https://wiki.openhumans.org/wiki/Oura_Ring). The infobox on the top right contains semantic annotations. On the bottom, semantic links from other pages pointing to this page are automatically shown.

being able to learn from other people's experiences. The wish for an easier way to access existing knowledge in the community, the importance of procedural, tacit knowledge, sharing failures, and forming long-term motivations were highlighted.

Two iterations of prototyping platform wireframes and discussions with community experts to address these issues yielded the basic structure of the solution to be developed - the *Personal Science Wiki*.

We decided to use semantic MediaWiki technology [15], because wikis are a well-known way to enable knowledge peer production, they can be easily setup to get community feedback from real usage quickly, and are editable by anyone, which can solve maintenance bottlenecks that led to failures of prior attempts. The semantic extension could enhance findability and knowledge aggregation, and a similar approach had been used successfully in Public Lab, another grassroots citizen science community, as identified in Phase

1. The basic semantic structure was informed by metadata from talks in the Quantified Self Show & Tell talk archives.

The wiki was introduced to the community and its usage encouraged right after its deployment in October 2021, and since then the wiki has been iteratively improved based on feedback given in weekly community meetings, on talk pages, and on dedicated wiki pages for open issues.

Personal Science Wiki is publicly accessible under <https://wiki.openhumans.org/>, and is actively used by community members to share their projects and knowledge on tracking tools and other self-research topics. As of June 2022, the wiki has 518 content pages, 373 of which are pages dedicated to individual Show & Tell talks imported from the Quantified Self archives. There are 36 registered users, of which seven have been active in the last 30 days. The most active user has done a little over 1000 edits.

Figure 1 shows an example of a "Tool" page, containing knowledge on how and when to use the device "Oura Ring".

My experiences with this community-centered, participatory development approach imply that it is not enough to set up a wiki technology, but that it has to be adapted to fit the community needs with regards to page structure, semantic structure, governance, technical issues, and ways to communicate feedback. Releasing the platform early and improving it based on real-use community feedback has been proven useful to identify problems that a lab-based approach would not have revealed. The approach remains explorative, and coming challenges will be to improve the structure of the wiki in order to better reflect the information-seeking behavior of self-researchers, and to evaluate if the wiki resolves the problems identified during design thinking. Planned interventions are a card sorting workshop to improve the category system, usability studies, and tracing information-seeking journeys of community members to get an overview over relevant knowledge for personal science practice.

4 EXPECTED CONTRIBUTIONS

My dissertation aims to understand the barriers to collaborative knowledge production in personal science, and how digital interventions can help overcome these. The Personal Science Wiki, designed and deployed in the course of this thesis, supplies an infrastructure to peer-produce a common knowledge resource for the personal science community, and is already in active use. The design processes used as part of this work will also yield a better understanding of procedural knowledge relevant to enable personal science practice, which can help remove barriers for newcomers, to allow more widespread participation and achieve the potential of personal science to benefit individual well-being and clinical and public health discovery.

The lessons learned from the participatory design process will also give insights in best practices and challenges when adapting a peer production infrastructure to the needs of other communities that share some of the characteristics of personal science and can support them in harnessing collective intelligence in order to extract common knowledge from individual practices.

Lastly, by furthering the understanding of peer production as a means to enable deeper participation this work will contribute to the larger field of citizen science through design guidelines based on a working model of peer production and case studies that provide concrete implementations of peer production characteristics, as well as insights into usefulness and feasibility of a peer production approach in different types of citizen science projects.

ACKNOWLEDGMENTS

I would like to thank my PhD supervisors Bastian Greshake Tzovaras and Ariel Lindner, my team members Mad Price Ball and Enric Senabre Hidalgo for all-time support and mentorship during all phases of this project. I thank my committee members Mako Hill (and the Community Data Science Collective), Vineet Pandey, and Molly Clare Wilson for tremendously valuable feedback and encouragements. A big thank you goes to the personal science community, without who this work would not be possible, notably to Gary Wolf and Steven Jonas from Quantified Self for providing

feedback and data. And last but not least, I would like to thank our most active wiki user to date, DG, who just hit the 1000 edits mark.

REFERENCES

- [1] Yochai Benkler. 2016. Peer production and cooperation. In *Handbook on the Economics of the Internet*, Johannes Bauer and Michael Latzer (Eds.). Edward Elgar Publishing, 91–119. <https://doi.org/10.4337/9780857939852>
- [2] Yochai Benkler, Aaron Shaw, and Benjamin Mako Hill. 2015. Peer Production: A Form of Collective Intelligence. In *Handbook of Collective Intelligence*, Thomas Malone and Michael Bernstein (Eds.). MIT Press, Cambridge, Massachusetts, 33.
- [3] Shun-Ling Chen. 2019. How Empowering Is Citizen Science? Access, Credits, and Governance for the Crowd. *East Asian Science, Technology and Society* 13, 2 (June 2019), 215–234. <https://doi.org/10.1215/18752160-7497711>
- [4] Design Council. 2007. *Eleven lessons: managing design in eleven global brands. A study of the design process*. Technical Report. <https://www.designcouncil.org.uk/our-work/skills-learning/resources/11-lessons-managing-design-global-brands>
- [5] Aiden Dipple, Kerry Raymond, and Michael Docherty. 2012. Stigmergy in web 2.0: a model for site dynamics. In *Proceedings of the 3rd Annual ACM Web Science Conference on - WebSci '12*. ACM Press, Evanston, Illinois, 86–94. <https://doi.org/10.1145/2380718.2380731>
- [6] Markéta Dolejšová and Denisa Kera. 2017. Soylent Diet Self-Experimentation: Design Challenges in Extreme Citizen Science Projects. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. ACM, Portland Oregon USA, 2112–2123. <https://doi.org/10.1145/2998181.2998365>
- [7] Scott Frickel, Sahra Gibbon, Jeff Howard, Joanna Kempner, Gwen Ottinger, and David J. Hess. 2010. Undone Science: Charting Social Movement and Civil Society Challenges to Research Agenda Setting. *Science, Technology, & Human Values* 35, 4 (July 2010), 444–473. <https://doi.org/10.1177/0162243909345836>
- [8] Muki Haklay, Dilek Fraisl, Bastian Greshake Tzovaras, Susanne Hecker, Margaret Gold, Gerid Hager, Luigi Ceccaroni, Barbara Kieslinger, Uta Wehn, Sasha Woods, Christian Nold, Balint Balazs, Marzia Mazzonetto, Simone Rüfenacht, Lea Shanley, Katherin Wagenknecht, Alice Motion, Andrea Sforzi, Dorte Riemenschneider, Daniel Dörler, Florian Heigl, Teresa Schäfer, Ariel Lindner, Maike Weißpflug, Monika Mačiulienė, and Katrin Vohland. 2020. *Contours of citizen science: a vignette study*. preprint. SocArXiv. <https://doi.org/10.31235/osf.io/6u2ky>
- [9] Susanne Hecker, Lisa Garbe, and Bonn, Aletta. 2018. The European citizen science landscape - a snapshot. In *Citizen Science: Innovation in Open Science, Society and Policy*, Susanne Hecker, Haklay, Muki, Bowser, Anne, Makuch, Zen, Vogel, Johannes, and Bonn, Aletta (Eds.). UCL Press, London, 190–200.
- [10] Nils B. Heyen. 2020. From self-tracking to self-expertise: The production of self-related knowledge by doing personal science. *Public Understanding of Science* 29, 2 (Feb. 2020), 124–138. <https://doi.org/10.1177/0963662519888757>
- [11] Colleen Hitchcock, Jon Sullivan, and Kelly O'Donnell. 2021. Cultivating Bioliteracy, Biodiscovery, Data Literacy, and Ecological Monitoring in Undergraduate Courses with iNaturalist. *Citizen Science: Theory and Practice* 6, 1 (Dec. 2021), 26. <https://doi.org/10.5334/cstp.439>
- [12] Corey Jackson, Kevin Crowston, Carsten Østerlund, and Mahboobeh Harandi. 2018. Folksonomies to Support Coordination and Coordination of Folksonomies. *Computer Supported Cooperative Work (CSCW)* 27, 3-6 (Dec. 2018), 647–678. <https://doi.org/10.1007/s10606-018-9327-z>
- [13] Joanna Kempner and John Bailey. 2019. Collective self-experimentation in patient-led research: How online health communities foster innovation. *Social Science & Medicine* 238 (Oct. 2019), 112366. <https://doi.org/10.1016/j.socscimed.2019.112366>
- [14] Vasilis Kostakis and Michel Bauwens. 2021. Grammar of Peer Production. In *The Handbook of Peer Production* (1 ed.), Mathieu O'Neil, Christian Pentzold, and Sophie Toupin (Eds.). Wiley, 21–32.
- [15] Markus Krötzsch, Denny Vrandečić, and Max Völkel. 2006. Semantic MediaWiki. In *The Semantic Web - ISWC 2006*. Springer Berlin Heidelberg, 935–942.
- [16] Dana M. Lewis. 2020. Do-It-Yourself Artificial Pancreas System and the OpenAPS Movement. *Endocrinology and Metabolism Clinics of North America* 49, 1 (March 2020), 203–213. <https://doi.org/10.1016/j.ecl.2019.10.005>
- [17] Alice Mah. 2017. Environmental justice in the age of big data: challenging toxic blind spots of voice, speed, and expertise. *Environmental Sociology* 3, 2 (April 2017), 122–133. <https://doi.org/10.1080/23251042.2016.1220849>
- [18] Dana Mahr and Sascha Dickel. 2019. Citizen science beyond invited participation: nineteenth century amateur naturalists, epistemic autonomy, and big data approaches avant la lettre. *History and Philosophy of the Life Sciences* 41, 4 (Dec. 2019), 1–19. <https://doi.org/10.1007/s40656-019-0280-z>
- [19] Mayo F Morell, Anna Cigarini, and Enric Senabre Hidalgo. 2021. A framework for assessing the commons qualities of citizen science: comparative analysis of five digital platforms. (May 2021). <https://doi.org/10.31235/osf.io/pv78g>
- [20] Gabriel Mugar, Carsten Østerlund, Katie DeVries Hassman, Kevin Crowston, and Corey Brian Jackson. 2014. Planet hunters and seafloor explorers: legitimate peripheral participation through practice proxies in online citizen science. In *Proceedings of the 17th ACM conference on Computer supported cooperative work*

- & *social computing*. ACM, Baltimore Maryland USA, 109–119. <https://doi.org/10.1145/2531602.2531721>
- [21] Pablo Rey-Mazón, Hagit Keysar, Shannon Dosemagen, Catherine D'Ignazio, and Don Blair. 2018. Public Lab: Community-Based Approaches to Urban and Environmental Health and Justice. *Science and Engineering Ethics* 24, 3 (June 2018), 971–997. <https://doi.org/10.1007/s11948-018-0059-8>
- [22] Sara Riggare, Jon Stamford, and Maria Hägglund. 2021. A Long Way to Go: Patient Perspectives on Digital Health for Parkinson's Disease. *Journal of Parkinson's Disease* 11, s1 (July 2021), S5–S10. <https://doi.org/10.3233/JPD-202408>
- [23] Enric Senabre Hidalgo, Mad P. Ball, Morgane Opoix, and Bastian Greshake Tzovaras. 2022. Shared motivations, goals and values in the practice of personal science: a community perspective on self-tracking for empirical knowledge. *Humanities and Social Sciences Communications* 9, 1 (Dec. 2022), 182. <https://doi.org/10.1057/s41599-022-01199-0>
- [24] Robert Simpson, Kevin R. Page, and David De Roure. 2014. Zooniverse: observing the world's largest citizen science platform. In *Proceedings of the 23rd International Conference on World Wide Web*. ACM, Seoul Korea, 1049–1054. <https://doi.org/10.1145/2567948.2579215>
- [25] Gary Isaac Wolf and Martijn De Groot. 2020. A Conceptual Framework for Personal Science. *Frontiers in Computer Science* 2 (June 2020), 21. <https://doi.org/10.3389/fcomp.2020.00021>