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Citizen science for social physics: digital tools and participation

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Abstract Social physics is an active and diverse field in which many scientists with formal training in physics study a broad class of complex social phenomena. Social physics investigates societal problems but most often does not count on the active and conscious participation of the citizens. We here want to support the idea that citizen science, and more particularly citizen social science, can contribute to the broad field of social physics. The current manuscript is not a review paper of citizen science projects from the context of social physics as there are still too few experiences in this context. We, in contrast, present a selection of our own experiences during the last decade to extract key learnings and further reflect on citizen science practices for social physics. We first describe several human mobility experiments in urban contexts with the participation of concerned young students, old women, or other different groups of neighbors. We second share how we have studied community mental healthcare provision in collaboration with a civil society organization and with the intense involvement of persons with lived experience in mental health. In both cases, we narrow down the discussion to digital tools being used and the involved participatory dynamics. In this way, we share key learnings to enhance a synergistic relationship between social physics and citizen science and with the aim of increasing the societal impact of the research on complex social phenomena.

1 Introduction

Human behavior research topics can today be grounded on a data-driven basis which was inconceivable only 20 years ago. Digital transformation of our societies with the broad use of the internet has led to a variety of digital interactive platforms and fully equipped mobile phones. These devices can store extensively and intensively human movements, decision making processes, or emotional reactions. They have opened the door to analyze and model both individual and aggregated human behaviors in an unprecedented manner.

This sort of data-driven research has deep interdisciplinary and multidisciplinary roots. Many of the academics contributing to a better understanding of the related social phenomena are physicists [1], generally with a strong background in statistical physics [2–6] and complex systems science [7, 8]. Complex systems are most commonly defined as "systems composed of many elements and displaying emergent phenomena" [7]. Networks have a fundamental role in encoding the structure of complex systems, and there is a ubiquitous presence of stochasticity, randomness, and nonlinearities. Complex social phenomena related to human mobility and social interactions are some of the highlighted contexts in a recent editorial on complex systems science after the 2021 Nobel Prize of Physics [7]. Taking this perspective, physicists have seen the need of cutting across academic boundaries. Their curiosity has led them to look outside their traditional domains [9, 10] expecting to unveil laws similar to those in physics [11]. Jusup and co-authors [1] define social physics "as a collection of active research topics aiming to resolve societal problems to which scientists with formal training in physics have contributed and continue to contribute substantially." The authors also qualify social physics as an extremely active and diverse field which broadly includes human behavior and interaction, but also human cooperation or human mobility to just name a few of topics [1–12].

Citizen science is also being a growing research practice during the last decade [13]. Citizen science broadly refers to the active engagement of the general public in scientific research tasks [14]. In citizen science, scientists and citizens collaborate to produce new knowledge for science and society. Crowdsourced data can be collected with Apps on mobile phones or web-based platforms. Amateurs have volunteered to take pictures of, for instance, bird species and nationwide bird census [15, 16], invasive marine species [17], or tiger mosquitoes [18–20].

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There are several ways to classify citizen science projects, and the classifications may dismiss many of the subtleties behind citizen science practices [21, 22]. In any case, one possible way to classify citizen science projects is to consider the following three wide classes: contributory projects, collaborative projects, and co-created projects [23]. The contributory projects are considered those in which participants take part in data gathering, analyze the data at certain points in the project, and help to disseminate the results. The collaborative projects increase the level of participation as the participants also analyze samples and, on occasions, help to design the study, more intensively interpret data, and draw conclusions. The most extended level of participation is for co-created projects in which the participants collaborate in all stages of the project, including the definition of the research questions, the development of hypotheses, and the discussion of results and respond to further research issues that might arise during the research process.

The outcomes of this joint research effort is already showing relevant scientific impact [13]. In the particular field of physics, participants have classified millions of galaxies thanks to a well-documented website and a carefully guided interaction. The articulated effort has been key in numerous scientific publications [24]. In another level, but still within the context of physics, local communities have created a network of low-cost earthquake sensors [25] or became key actors in the quick reaction after the Fukushima disaster collecting extensive and highly dense radiation measurements [26]. A scientific research can be organized by building collaborative networks of participants. These networks serve to effectively report volcano observations in Europe or eventually in all parts of the world [27]. All these cases are just few examples of the wide set of initiatives flourishing worldwide following very different formats and strategies.

However, it is not that frequent to find citizen science projects within the specific field of social physics. Human-related activities and human behavior topics make less clear the roles and the position of the participants in front of the social topic under investigation which very often is related to social concerns that are at stake [28, 29]. There is a sophistication and a subtlety in the research that contrasts with more established citizen science practices on biodiversity monitoring or astronomy observation.

Without being framed in the context of social physics or complex systems and also without the ambition of being exhaustive, we can, for instance, report important contributions related to one popular topic in social physics: human mobility. Transport citizen science projects allow citizens to monitor the traffic in their streets with a minimal involvement of citizens [30], while others can explore disruptive scenarios in, for instance, rural areas [31]. Travel data can indeed be collected in a bottom-up approach in a way that becomes valuable for policymakers [32]. Some projects are particularly interested in one mode of transport and require, for instance, the active involvement of cyclists [33, 34]. Being focused on behavioral aspects, pedestrian routes have also being analyzed with gamification strategies to study walkability [35] and eventually put all focus on specific communities with impediments (e.g., old people) [36]. The citizen science project "Straatvinken" is a co-created level of citizen science that monitors the evolution of the modal split in Antwerp to see whether the challenge to increase sustainable modes of transport is being met, and this is done by counting the number of road users in their street during one hour on one day. Another Flemish project "CurieuzeNeuzen" has explored other indirect data with low-cost passive samplers for nitrogen dioxide to measure air quality (mostly due to car emissions) [37], and other cities (e.g., Barcelona) have developed similar experiences [38]. In another level, the efforts to create accurate early warning information on mosquito-borne diseases are strongly related to human mobility patterns with cars [19]. Recent outbreaks of Zika, chikungunya, and dengue highlight the importance of better understanding the spread of disease-carrying mosquitoes across multiple spatio-temporal scales, and there are relevant works that show how a scalable citizen science project can provide a powerful alternative to traditional methods which can be vital for public health services [20]. Also, in relation to fauna conservation, there are citizen science projects related to human mobility that offer complete data for safer transportation and mitigation of roadkill hotspots [39, 40]. Finally, spatio-temporal distribution of observations reported by participants involved in biodiversity monitoring is an aspect that needs to be carefully considered when analyzing data collected by a citizen science project [41].

We want here to further support the idea that citizen science practices can effectively bring everyone into the important task of better understanding complex social phenomena [1]. To encourage researchers from social physics to further embrace citizen science, more reflection is needed. There are not enough spaces for sharing experiences from which to extract key learnings. These spaces can help to further reflect in the configuration of the related digital tools which needs to be adaptive to participants' perspective, skills, concerns, and motivation. The building or adaptation of digital tools for crowdsourced data collection is not the only one aspect to be considered in citizen science practices. To favor a citizen science for social physics, it is also necessary to further reflect on why and how citizens can be involved and carefully structure participation in research activities. At least part of the reflection can be nurtured by the so-called citizen social science or social citizen science [28, 29] which enhances social dimensions in citizen science projects and increments participatory research on social shared concerns with communities, sometimes in a vulnerable situation.

Our OpenSystems research group [42] has been developing during the last decade in urban contexts and mostly in the Barcelona (Spain) metropolitan area [29, 38, 42–55]. The current manuscript is not a review paper of citizen science projects from the context of social physics as there are still too few citizen science experiences in this context. We will restrict the paper to the presentation of a selection of our own experiences during the last decade on two distinct themes with the aim to describe, in very practical terms, the development and the implementation of digital tools to collect crowdsourced data, and the ways and reasons to incorporate citizens' participation into the research activities described. The first theme, as said above, is being traditionally extensively explored in the context of social physics: human mobility [1, 12]. The second theme focuses on community mental healthcare provision, and it shows its link to social interactions [3], human cooperation [4, 5], and complex systems science in general [7, 8]. Table 1 outlines the

Table 1 Summary of the different projects reported in terms of the level of engagement of their participants

Project	Contributory	Collaborative	Co-created
Social physics theme: Human mobility			
Beepath in a science festival	YES	NO	NO
Beepath with a community center	YES	YES	NO
Beepath with schools	YES	YES	YES
Beepath and civic placemaking	YES	YES	NO
Social physics theme: Human behaviour			
Games for Mental Health	YES	YES	YES
CoAct for Mental Health	YES	YES	YES

Outline of the different experiences being presented on human mobility and on human behavior. We structure the list in terms of whether the project can be considered a contributory, a collaborative, or a co-created project. Participants of contributory projects take part in data gathering, data simple analysis, and results dissemination. The collaborative projects increase the level of participation as the participants also analyze samples and, on occasions, help to design the study, more intensively interpret data, and draw conclusions. The most extended level of participation is for co-created projects in which the participants collaborate in all stages of the project, including the definition of the questions, development of hypotheses, discussion of results, and answer to further research questions that might arise [23]

experiences we present according to the level of engagement of their participants. Discussion and conclusion section summarizes and reflects on main aspects presented.

2 Human mobility

Human mobility has been gaining attention within the physics community [12]. Contributions have analyzed location data to learn about existing patterns [56]. Some of them have also provided new models or, alternatively, improved or assessed the existing ones [57–59]. Some of the papers have also brought out relevant insights about urban contextual issues like walkability or COVID response policies [60, 61].

Census data have been for decades the (public) data source, the same for all the academic community. It has been able to assess the quality of well-known models in the literature such as the radiation model [59]. However, census data might be unsatisfactory for the actual research agenda. Higher level of data granularity is very much often required, with higher time and space resolution. The wide use of mobile phones and their related technologies give the capacity to collect the location data [62]. Social media accesses/posts collected by the researchers themselves [63] or mobile phone call data records (CDR) provided to specific research groups are an alternative to gain knowledge on human mobility patterns at a mesoscopic level [64]. If it is of interest to look at an even higher resolution scale, then other tracking systems might be necessary. This can be, for instance, the case of specific mobile applications (Apps) tracking systems [65].

Highest-resolution mobility data are generally owned by private companies. However, in some cases, societal challenges and humanitarian purposes have motivated a closer collaboration with academia. A mobile company worked with academic researchers, and the researchers analyzed the movements of 1.9 million mobile phone users around Port au Prince city before and after the Haiti earthquake in 2010 [66]. Some companies opted to launch open calls for receiving specific academic demands (related to humanitarian purposes), and the companies selected an identified group of scientists to have access to very valuable location data [67]. Hackathons and similar gatherings had also been a strategy by telecommunications companies in Africa to mobilize the academic community toward sustainable or societal challenges by releasing partial data from some countries [62] but without questioning ethical and privacy-related issues.

All in all, it is still difficult to find open mobility data. Data reuse is thus representing an obstacle for scientific reproducibility and the further advancement of the related science [68]. Research agenda is thus mostly driven on which data a researcher has access to. In scientific papers, raw data are most often said to be not available to other researchers, and only an anonymized and coarse-grained dataset might be offered upon request (see, for instance, the cases of Refs. [58, 60, 64, 65]). Some scientific papers alternatively recommend contacting the company owning the data if the reader wants to access and perform new research over the same data.

2.1 Digital tools: crowdsourced data collection and human mobility

Concerns within human mobility research community are not limited to data accessibility and scientific reproducibility. There is also an intricate ethical debate that involves informed consent by the owners of the mobile phones. The debate indeed puts at the center of the discussion whether it is feasible to use highly sensitive data as a public good [67].

Fig. 1 Screenshots of the mobile Apps being used to collect GPS data. Left image shows the information displayed by the BeePath App: time, latitude, longitude, GPS precision, username, and a button to finish the experiment. Right image shows the information displayed by the Wikiloc App: time, a map with the trajectory, and two buttons to restart (or pause) and to finish the journey recording. Texts are in Catalan
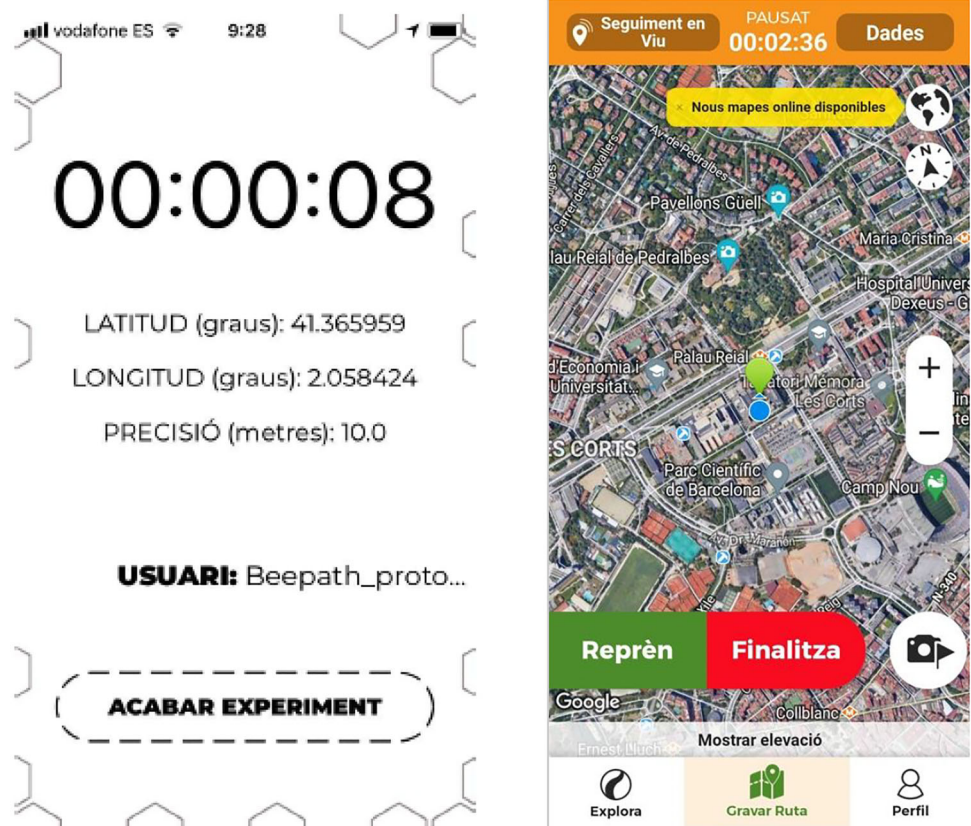
There are initiatives that have built the whole research around a digital tool avoiding the researchers' intermediation with telecommunication companies [69]. This approach is deeply linked with citizen science practices and can overcome privacy and ethical problems, as participants are clearly informed and specifically consent to their data being used.

2.1.1 Building and updating an App

Under this more open crowdsourcing basis, some of us and other collaborators started new citizen science research in human mobility by building from scratch an App called BeePath (see a screenshot in Fig. 1). The App worked in iOs and Android mobile phones, and the first version was used in 2012 and left open in GitHub [70]. We were able to collect high-resolution GPS data every second and sent them to our university servers. The data were also shown in real time in an anonymized manner on a screen placed in a hotspot within the Barcelona Science Festival (Festa de la Ciència, in Catalan) located at Parc de la Ciutadella (4 ha, Barcelona). Visitors were recruited as participants of the mobility experiment. This action was part of the efforts to promote citizen science within the frame of the Barcelona Citizen Science Office [71] (an initiative led by the Barcelona municipality).

We updated and modified the BeePath App several times since then. Several other citizen science investigations developed were valuable to participants themselves but less relevant for academic audiences and scientific journals. In 2017, we finally decided to run a large-scale pedestrian mobility experiment in a broader level, in urban contexts around 10 schools in the Barcelona metropolitan area (see Sect. 2.2.1 below for further details). The data collected are carefully described and fully accessible in Ref. [55]. We considered pedestrian mobility in a neighborhood level, covering a typical distance range of hundreds of meters ($\approx$ 700 m) around the participating schools in the experiment. The typical journey duration was about 8 min [55].

This latter version allowed participants to take further ownership of data collected. We built some basic protocols that must be followed by the participants to deanonymize GPS datasets from early start. They are carefully described in Ref. [55]. The data from this experiment were sent to our server, and the participants could consult a brief report on their own data and download the data in a *.csv* format file. The data collected had however some additional potential risks to identify participants as natural persons inferring their home addresses. The risk thus needed to be handled with extra work made by professional scientists and using geo-masking techniques ($k-$anonimity) which are described and extensively discussed in Ref. [55]. Privacy protection was also the reason why we did not collect gender identity or any other socio-demographic trait. All these measures can become a limitation in the scientific outcomes expected from participatory mobility experiments.

2.1.2 Reusing existing Apps

The constant changes in mobile phones Apps technical requirements oblige to release periodic upgrades. Unfortunately, these improvements add new challenges to a citizen science research led by a university and/or any organization with limited resources. Besides, funding schemes by research agencies are most often not aligned with the necessary stable funding to maintain a long-term vision in citizen science projects, even if the amount of money is small. These funding schemes even sometimes determine that the expenses to keep an App alive might not be eligible as these sort of activities are still not seen as part of the daily research activity. A possible way out is to build a partnership with specific companies. They generally have the capacity and the flexibility to dedicate a stable taskforce to develop the new code and the related upgrades. This was, for instance, the case of some of the BeePath initiatives mentioned above.

Alternatively, it is also possible to take advantage of existing Apps in the market which have quite different purposes (e.g., trekking or other outdoor sports activities). We used this strategy to run a new mobility experiment with very few resources available and to set up the related logistics very quickly. Before running the experiment, we checked the GPS precision of the App. We also tested the procedure of how data are collected and on how stopping times were treated by one specific App (Wikiloc [72]) with reverse engineering, see a screenshot of the Wikiloc App in Fig. 1. This approach minimized the time needed to set up the digital infrastructure and the related taskforce, but it was required to redefine the privacy and consent protocols with care to comply with data privacy regulations (GDPR, in the European case). For privacy reasons, we opted to offer the mobile devices to the participants, but this in turn limited the amount of participants to the experiment. The devices already had an account activated so that we can easily collect data after the experiment. These aspects might however limit the scope and goals of the experiment.

2.2 Participation: engaging people in pedestrian mobility experiments

Existing research papers in the literature without active and conscious participation show very large amount of records. For instance, in Ref. [65], 67.0 billion GPS records from 4.5 million unique smartphones (from Cuebiq company, anonymized location data from applications of opted-in users in an anonymized way) are used to explore how mobility patterns relate to economic segregation in large US cities. Similarly, Ref. [60] reports the GPS locations of 1.62 million users in 10 US metropolitan areas with the aim to analyze the impact of COVID-19 pandemic response measures on walking behavior.

Our own citizen science experiences [45, 55] reported in Table 2 lack the large amounts of GPS records owned by telecommunication or digital companies that other scientific publications use. However, citizen science mobility experiments bring the opportunity to narrow down the scope of the research and obtain only the data that are more capable of responding to a predefined research question. We thus present below how to study purposed-based mobility and how to activate emergent uses of public space with a mobility experiment. Citizen science also offers the opportunity to work with specific communities so that specific socio-demographic groups can be identified beforehand. This sort of information can be precious to better understand mobility patterns.

Following subsections report our experience for purposed-based pedestrian mobility in urban contexts [45, 55] to take further inspiration about the kind of contributions that citizen science can bring into this field. Table 2 shows basic information from each of the citizen science experiments being developed in four different urban contexts.

2.2.1 Purposed-based pedestrian mobility

In Sect. 2.1, we already mentioned a very specific experimental setting within the Barcelona Science Festival and involving their visitors (101 participants). Scientific results are related to the exploration of the different spots in a public park and thus in a very well defined area. Active and reactive mobility patterns were identified [45]. Figure 2 shows a frame of the video explaining the experiment [73]. We complied with data privacy regulations and signed the related informed consent on paper. We were also able to talk and discuss with interested citizens in participating in the experiment. We wanted to raise public awareness about the fact that our mobile phones are constantly collecting location data. In this sense, the BeePath experiment in the Barcelona Science Festival sees participants as sensors and donors of their own data in a contributory citizen science project (see Table 1). The experiment was co-defined with the organizer of the Science Festival (the Barcelona City Council) which was also wanting to learn about the visitors' dynamics. We set an info point in an entrance of the public. Two researchers were always there to invite new participants and to explain results with real-time trajectories. When the experiment finished, we sent personalized reports to those participants that gave us their e-mail. We also organized a public event in a cultural center to present main results and open a discussion on the interpretation of the results.

Citizen science also brings the possibility to imagine repeated experiments with the same group. For healthy and well-being purposes, a group of about 10–15 old women used to come out together to walk for about an hour twice a week. The activity was part of a particular community center program (Centre Cívic Pere Quart, Les Corts, Barcelona) that belongs to the Barcelona City Council. The municipality facilitated the contact with the community, and as researchers, we met with old women to jointly decide how to perform the research. The experiment was done almost autonomously by the group of women. At least one member of the group activated the App in every journey. The journeys always started and ended at the two possible locations (depending on the day of the week). The women learn about new uses of their mobile phones. Also, the data collected served to identify most

Table 2 Pedestrian mobility citizen science experiments in different urban contexts

Context	Digital tool	Participant's profile	N. part	GPS data
Mobility experiment #1				
Science Festival	BeePath App	General public	101	4994
Key term: navigation				
Question: How do the people move in a crowded environment with several hotspots?				
Outcome: Model in terms of waiting time, jump length distribution, and spot's attractiveness				
Mobility experiment #2				
Community center	BeePath App	Old women	10–15	45,136
Key term: walkability				
Question: Which are the most pleasant routes to walk?				
Outcome: Velocity and other mobility metrics correlated to granular context and walkability				
Mobility experiment #3				
Schools	BeePath App	Teenagers	458	41,053
Key term: walkability				
Question: Which paths do the students take to go from home to school?				
Outcome: Velocity and other mobility metrics correlated to granular context and walkability				
Mobility experiment #4				
Neighborhood	Wikiloc App	Kids class groups, teachers, old persons, and families	72	2981
Key term: urban planning				
Question: Which are the most liveable public spaces in the neighborhood?				
Outcome: Mobility patterns and waiting time to identify in which spaces intervene				

We report the key term, the main research question, and its most relevant scientific outcome of four mobility experiments. Columns refer to the context in which the experiments were organized, the digital tool being used (a mobile App collecting GPS locations), the profile of the participants, the number of participants involved, and the number of GPS records collected in each of the human mobility experiments

Fig. 2 Frame of the Barcelona Science Festival citizen science experiment promotional video. We show a representation of the potential wells that qualitatively visualizes the attraction level of the spots inside Parc de la Ciutadella and where scientific outreach activities were taking place. The video can be found in Vimeo [73]
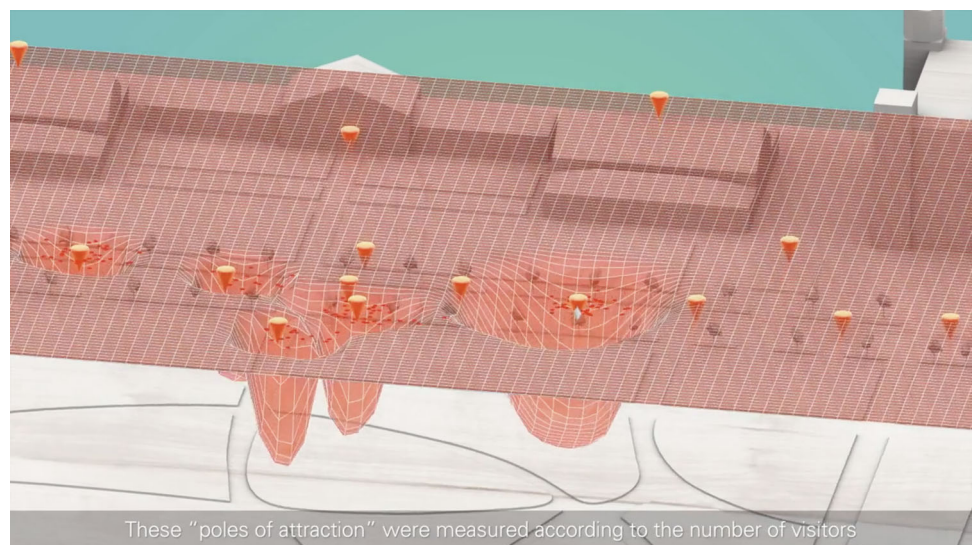
pleasant locations for a pedestrian (streets with green or tree shadows, wider side-walks...). A final workshop with the old women and the researchers made it possible to interpret the results. Also, we there discussed how to disseminate results in the neighborhood. Therefore, the research initiative could be defined as a collaborative project (see Table 1). The community center shared the routes taken by the group with the neighborhood under the form of maps (see one sample in Fig. 3). The joint effort appeared in the local TV, and two old women were able to explain the main results of the research to the audience [74]. Different scientific analyses were also made by one last-year graduate student in Physics from Universitat de Barcelona as part of his Bachelor's Degree Final Project.

Another experiment using the BeePath App involved teachers and students from 10 schools in the Barcelona metropolitan area. The effort was considered an innovative STEAM activity in formal education with the support of the Barcelona public schools consortia which helped to recruit the schools and the class groups. The experiment can be considered a co-created project, and the hugest challenge was to harmonize the interests from the 10 schools involved (see Table 1). Co-creation was made throughout a
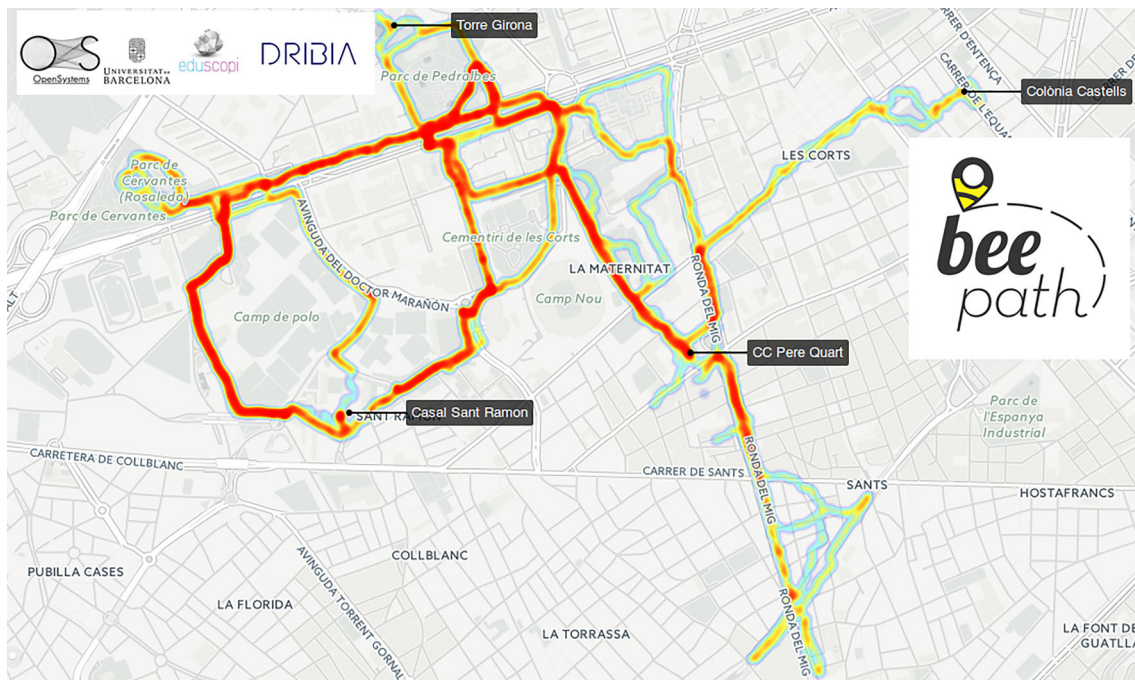
Fig. 3 Map visualization of the recurrent trajectories made by a group of old women from a community center. We show the map being used for the discussions in the community center (Centre Cívic Pere Quart, CC Pere Quart) and being shared with the neighborhood to further promote walkability. Most suitable routes for the about 1h journeys were suggested. Departures and arrivals were made from CC Pere Quart on Tuesdays and from another community center on Thursdays (Casal Sant Ramon). Two additional locations were added in the map as they were key targeted objectives. BeePath is a joint effort of OpenSystems-Universitat de Barcelona, Eduscopi (science education and communication company), and Dribia (data science company), and their logos appeared in these maps

training with three sessions (almost 3 h long each) for teachers and offered by experts on education, the citizen science researchers, and IT experts (four people and one facilitator for coordination with schools and other logistic aspects). During these sessions, teachers used several co-design and co-creation tools to define the experiment in the classroom. Teachers had to bring back to the sessions discussions and perspectives from the class group to finally reach an agreement on the goals and on the logistics of the mobility experiment for all 10 schools. Finally, a scientist went to each school to meet class groups for an hour or two and delivered and discussed key scientific aspects directly to the students.

School participants were therefore actively engaged and contributed to the project in different stages. They decided the scientific question about mobility: "How do we arrive and leave the school?," with the aim to study and learn how is the mobility in schools' vicinity and what obstacles students face in their daily home-to-school (or school-to-home) journey (e.g., narrow side-walks or the absence of pedestrian crossings) [55]. In the different stages of the co-design process, participants developed and refined the experimental protocol for collecting data. They recorded their journey to/from school using a smartphone device with the BeePath App and in a predetermined time window. The students also became testers of the technology developed and interpreted their own school group's mobility data based on their knowledge of the school and the neighborhood and produced visualizations of the trajectories. The students finally presented the results in a public event in front of other school students and municipality representatives. The research done by the students resulted in the delivery of a set of evidence-based recommendations to the municipality representatives, in order to reach a wider urban perspective and thus improve accessibility to schools [75].

A total of 427 secondary school students (14–16 years old) and 31 teachers participated in the experiment. Two-hundred-sixty-two out of the 427 students recorded the journey to (or from) school with their own smartphone. All of the details about the co-design and the co-creation phases of the experimental protocol, the data gathering, the data processing, and filtering and the results obtained can be found in Ref. [55]. Figure 4 shares the visualization of the trajectories to arrive or leave the Sant Gabriel School from Viladecans. In this case, 28 unique trajectories were gathered after filtering and processing the collected data. Different scientific analyses were also made by one last-year graduate student in Physics from Universitat de Barcelona as part of his Bachelor's Degree Final Project. Also, we will soon publish scientific results on walkability by means of different statistical analyses typically performed by physicists by means of magnitudes such as the instantaneous velocity and many related statistical features.

2.2.2 Activating public spaces in a neighborhood through mobility

To close this Sect. 2, we provide specific details of our most recent citizen science urban mobility experiment that does not focus on purposed-based mobility and sees pedestrian mobility and public participation as a way to imagine and discuss together possible

Fig. 4 Map visualization of the trajectories from BeePath in schools. Twenty-eight processed home-to-school (or school-to-home) individual trajectories displayed (red) on a map around the Sant Gabriel de Viladecans School (blue), located at the city of Viladecans in the Barcelona metropolitan area. Data are geo-masked following the protocol described in Ref. [55]. Green areas correspond to public parks
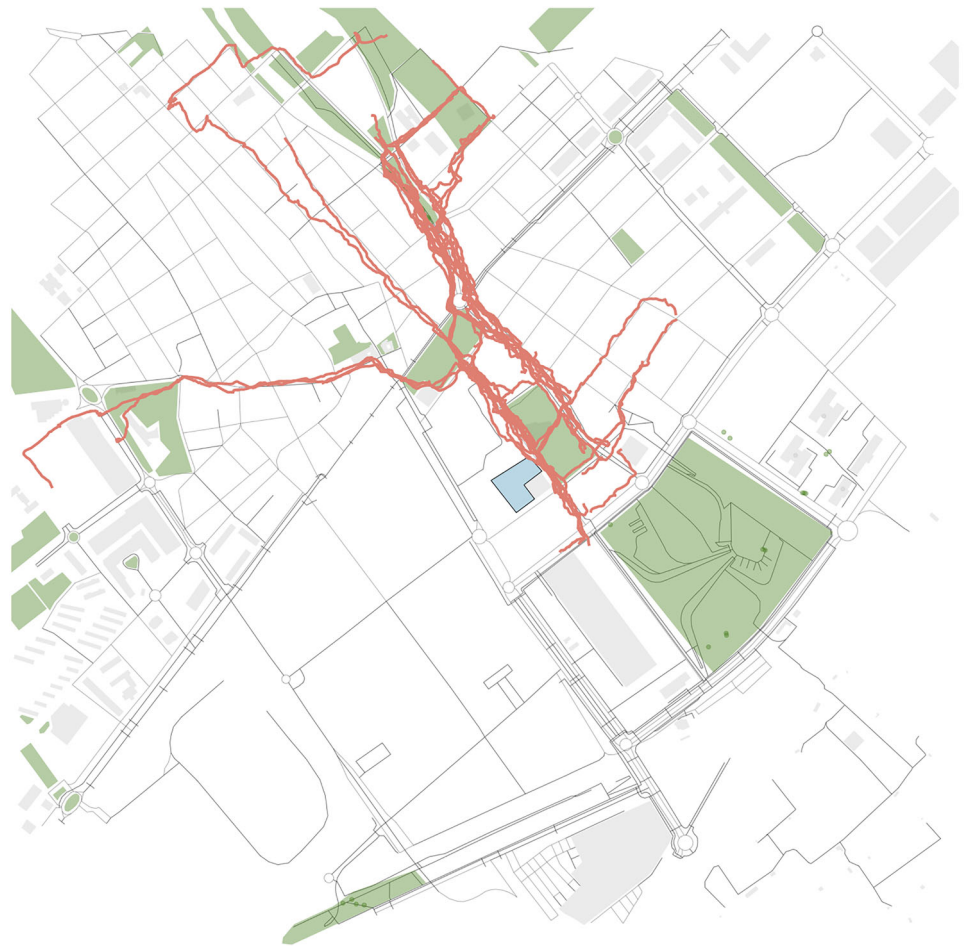
transformations of the existing public space. The experiment was conducted in the "Primer de Maig" neighborhood (3 ha, Granollers, Spain). The experiment was part of the research project "Civic Placemaking: Design, Public Space and Social Cohesion." This project was led by architects and urbanists, and some of us were invited to join the research. The project broadly sought to promote social cohesion and intercultural integration through ephemeral architecture projects that have an impact on public space and rely on the active engagement of citizens [76]. It can be thus considered a collaborative project (see Table 1). Participants took an active role in the data interpretation, and they were drawing conclusions and disseminating the results as part of the public discussion to transform the public space.

We there implemented citizen science participatory strategies and sophisticated methods for the data analysis that a physicist working on complex social phenomena would apply [12] (e.g., waiting time distribution, transects lengths, and reorientation angles, or the identification of specific key locations with GPS data clustering). Seventy-two people got involved in 19 groups. They became explorers of the neighborhood, walking and seeking out specific places to perform a set of festive actions. The objective was to study the urban spaces of appropriation in an emergent manner, with a bottom-up approach.

The call for participation was launched through three local neighborhood associations. The engaged participants therefore had different socio-demographic profiles. Groups used tablet devices (one per group) with the Wikiloc App [72] previously installed and registered with Google accounts by the research staff. In this way, participants did not have to provide any personal information that could compromise their anonymity. In addition, running the experiment in groups and starting data gathering from the public associations sites further guarantees the anonymity of the participants (for example, the location of their homes cannot be inferred).

Data collection was divided into two consecutive days. Four groups of teachers did the experiment in the morning, and seven groups of students (Primary school) in the afternoon. During the following day, the rest of the groups (eight) participated in the experiment. The duration of the experiment and data collection was 1 h and 30 min, in which participants explored the neighborhood and completed six festive "missions" (e.g., choosing a place to open a drink and toast as a group, or finding a place to play a song on the speaker and dance). For making possible the experiment, a social worker and a facilitator being part of the research project played a fundamental role to identify and invite specific groups through local organizations' representatives and to organize a final event to discuss about the urban future of the neighborhood.

Table 3 Citizen science in mental health

Context	Digital tool	Participant's profile	N. part	Inter
Name of the project: Games for Mental Health				
Massive event, social spaces	Electronic tablets	Persons with mental health condition and families, and social and healthcare professionals	270	3780
Working group: Twenty participants co-designing a behavioral experiment that uses social dilemmas				
Question: Which is the social role of each actor involved in mental healthcare ecosystem?				
Outcome: Statistical data showing that social workers are the strong ties and that the participants with lived experience need to play a leading role in the mental health ecosystem				
Name of the project: CoAct for Mental Health				
Private/personal	Chatbot	Anyone interested in mental health	> 766	> 16,711
Working group: Sixty-five institutional representatives to frame the research, and 32 co-researchers involved in all research stages, from the project definition to data interpretation and the elaboration of 14 policy recommendations				
Question: What are the key elements of the social support networks in mental health?				
Outcome: Evidence identifying crucial lived experiences within the social support networks and the relevance of specific socio-demographic traits				

For each research project, we report the non-professional researchers working together with professional scientists, the main research question, and its most relevant outcome of the mental health investigations. Columns refer to the context in which the experiments were organized, the digital tool being used to collect behavioral data, the profile of the participants in the digital platforms, the number of participants involved, and the number of decisions collected in each of the experiments. Chatbot number of participants and number of interactions are taken on December 22, 2023, but these numbers are growing everyday

The collected high-resolution pedestrian mobility data helped us to capture movement flows within the neighborhood and to identify those sites chosen by participants to perform the actions (and their duration). Actions chosen had urban relevance. Data are planned to be released during 2024 jointly with a scientific publication. The municipality is currently using the results as an additional source of information to undergo the urban transformation of this rather small but complex neighborhood [76].

3 Mental health

As already mentioned in the introduction, Jusup and co-authors [1] define social physics "as a collection of active research topics aiming to resolve societal problems to which scientists with formal training in physics have contributed and continue to contribute substantially." Societal problems are key drivers in funding schemes from research agencies. Societal problems are intricate, wicked, and intrinsically involve uncertainty, complexity, and divergence of perspectives [77]. Societal problems require the joint effort of a wide range of actors and stakeholders [77].

A recent report [78] by the European Research Executive Agency has proposed a mission-oriented research framework where "bold missions can provide new syntheses that are today impossible and thus will hopefully achieve the breakthroughs that are urgently needed to solve some of the most pressing issues facing our citizens." The same report states that "citizens can possibly be mobilized to become active participants in missions, for example, by cleaning plastics from beaches or by providing real-time monitoring data as enabling technologies develop and become more universally present in society." Citizen science and social physics may therefore together meaningfully contribute to a societal issue and initiate a research differently.

We here take one specific societal problem: mental health and the related care provision. The World Health Organization (WHO) understands mental health as a "state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community." WHO advocates for urgent change in mental healthcare shifting from a biomedical approach to a recovery model based on principles that include self-determination, resources beyond professional care, and a community approach. WHO also states that "recovery-oriented care is not about treatment of symptoms but about empowering people to have control of their own lives" and that "we must intensify our collective actions to reform mental health systems toward comprehensive community-based networks of support" [79].

Below, we will share two experiences where the participation of people with lived experience in mental health is enhanced and in which the partnership with a civil society organization becomes totally relevant. These two experiences are summarized in Table 3. The next subsections will first explain the related digital tools to collect data and the methodologies involved, and some of them are straightforwardly related to social physics. We will later emphasize those aspects related to the participatory dynamics and the specificities of the research topic.

Fig. 5 Electronic tablet of Games for Mental Health. The text of tablet says that not all participants are ready and that the next game is about to start. The Citizen Social Lab digital platform is running through a local server connected to electronic tablets with a Wi-Fi connection. Participants played in groups of six in an outdoor public space during the 2016 World Mental Health Day-related event in Lleida (Spain)

3.1 Digital tools: crowdsourced data collection on mental health and human behavior

Mental health research reported here looks for behavioral traits, organizing a set of experiments to collect data related to these traits. The participants contribute using digital devices through which they can express themselves. Their interaction with digital devices may only take few minutes, but it is still possible to get a benefit as a participant. The interactions trigger self-reflection about their own actions during the experiment. Specific personalized reports or updated information about the research progress was also offered. It is also possible to build mobile-based digital tools that allow for brief but repeated interactions during a longer period of time (several months) as we will also describe below.

3.1.1 Social dilemmas in digital platforms

Some of us have recently developed Games for Mental Health (Jocs per la Salut Mental, in Catalan) [29]. The project (2015–2018) was a joint collaboration with the civil society organization called Catalonia Mental Health Federation (Salut Mental Catalunya, in Catalan). The Federation is currently composed of 79 associations of families and users of mental healthcare services.

As a point of departure, Games for Mental Health took social dilemmas and games which have been extensively explored by the social physics community [5, 11]. The broad aim of the social physics community is to better understand social interactions and human cooperation in a stylized manner within the mental health ecosystem conformed by persons with mental health condition, their families jointly with social and healthcare professionals.

Behavioral experiments have traditionally been conducted in laboratories generally placed in universities and research centers [4]. Individuals usually do not know who they are paired with. They take decisions through a computer, in front of a screen that provides the instructions to perform the experiment. Also, online experiments have become increasingly popular during the last years, particularly through Amazon Mechanical Turk. Online experiments allow to recruit very large samples (thousands of subjects) worldwide, and several authors claim that online experiments show similar results to physical laboratory experiments [4].

However, neither the physical laboratories nor the online experiments seemed to us the best way to involve the mental healthcare provision community. We opted to run in-the-field (or in-the-wild) experiments [47, 80]. We relied on our own previous experiences in running several public experiments [47, 48] on human behavior [44, 46, 49, 50]. This option is required to use a flexible digital platform to run the experiment in more natural conditions, where social interactions of the mental health ecosystem are generally taking place as they are the spaces of the mental healthcare community. Non-permanent and pop-up infrastructure [47] with electronic tablets, a laptop that acted as a local server and a router to set up a local Wi-Fi network, allowed us to run behavioral experiments easily and in a flexible manner. Figure 5 illustrates these settings with one participant holding an electronic tablet during an experiment in the World Mental Health Day 2016. A specific platform was developed under the name of Citizen Social Lab [48]. The source code developed by one of our collaborators is available at GitHub [81].

3.1.2 A chatbot to maintain a long-term interaction

An alternative approach to the event-oriented platforms described in the previous section is to build a chatbot within a popular messaging App. Main motivation is to set up a long-term interaction with the participant. The periodic interactions of the participants from within their different private spaces give the researchers access to a much more natural context [29]. We have recently developed

Fig. 6 CoActuem per la Salut Mental chatbot. The mobile of one participant has just received a micro-story from a person with lived experience in mental health. The chatbot is asking a concrete question, and the participant needs to select one of the possible answers
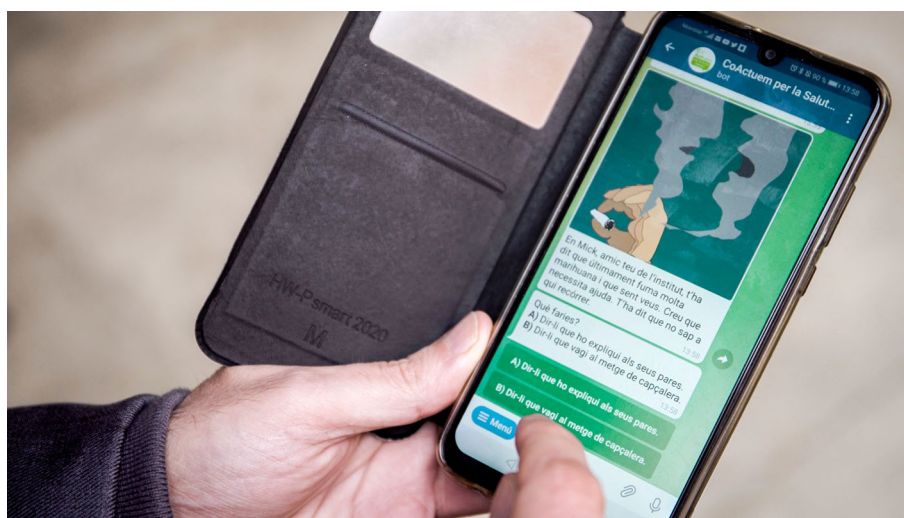
the chatbot CoActuem per la Salut Mental [82] (CoAct for Mental Health, in English) in Telegram. The chatbot is part of the subproject of the Horizon 2020 project titled CoAct [83] (2020–2022). The Federation was also part of the consortia.

The chatbot [84, 85] meets high standards of data privacy and is therefore especially apt for exploring any stigmatized social topic, not only mental health. The automated data collection results in well-structured digital data and can be adapted to research questions and scientific methods, especially in the field of social physics, comprising network theory, game theory, epidemics, or opinion dynamics [1–6].

Anyone, with or without a mental health problem, can subscribe to the CoActuem Telegram chatbot. The chatbot automatically sends messages and particularly questions to mutually unconnected participants. The participants receive the contents with a flexible rhythm (e.g., daily) and can decide on the timing of their answering themselves. Figure 6 shows the chatbot and the messages that a participant receives in its own mobile device.

The first dialog that the participant subscribed to the chatbot receives welcomes them and asks for providing informed consent. The second dialog serves as capacitation building and gives examples of what later will be the two types of dialogs the participants are asked to answer. The participants are also asked to complete an extensive socio-demographic survey, comprising 32 questions.

After these interactions, the participant periodically receives a dialog which includes a micro-story experienced and put into words by persons with lived experience in mental health (see co-creative sessions below, reported in Sect. 3.2.2). One type of micro-story, "share experiences," asks the participants whether they lived the shared experience, too, and whether someone in their surrounding lived it. The other type, "find solutions," asks the participants to decide between two different reactions to the presented micro-story, also written down by persons with lived experience in mental health. All in all, participants can react to up to 222 micro-stories and receive a total of more than 300 dialogs. The source code is available at GitHub [84] and is also documented in Zenodo [85].

The interaction via buttons facilitates the later analysis considerably. All sent contents and data collected from the participants are stored in a database in a way that is easily accessible during its runtime. After having collected the participants' answers and for scientific research, the unstructured data are converted into several tables that grant quick access to the data analysts. One possible analysis is to build a network of micro-stories of type "share experiences." A link can be built based on whether a pair of participants answers in the same manner for different micro-stories. It is then possible to build a network. The nodes can be taking information from the socio-demographic survey (e.g., gender self-reported identity). We exemplify these possibilities in Fig. 7 where we select a group of participants and build a multiplex network with the two answers from each participant to a set of micro-stories of type "share experiences."

3.2 Participation: lived experiences in mental health

WHO is emphasizing that to transform mental healthcare provision, it is necessary to enhance the participation of people with lived experience in mental health [79]. There are also other several official recommendations to ensure participation of persons with mental health problems and their families, at all levels, including research, design, and implementation of services and programs [86, 87].

A citizen science project in this context can therefore provide new tools and strategies to valorize inside a scientific research the knowledge from the people with lived experience. This expertise is mostly held at an individual level, and it is barely socialized due to social stigma or the limited number of spaces available to put knowledge in common. The scientific research in this community-based frame is still limited, and there is a lack of data to provide evidence on the benefits and challenges behind the community-based mental care provision [29].

Fig. 7 Network construction of a sample of participants in the chatbot. Each node represents a participant (women in blue, men in red, and other answers in yellow). In each layer, links can be built if two participants have provided the same answer to the same micro-story. Top layer corresponds to the question of whether they have had the same experience, and the most crowded layer corresponds to the question of whether anybody around them have had the same experience
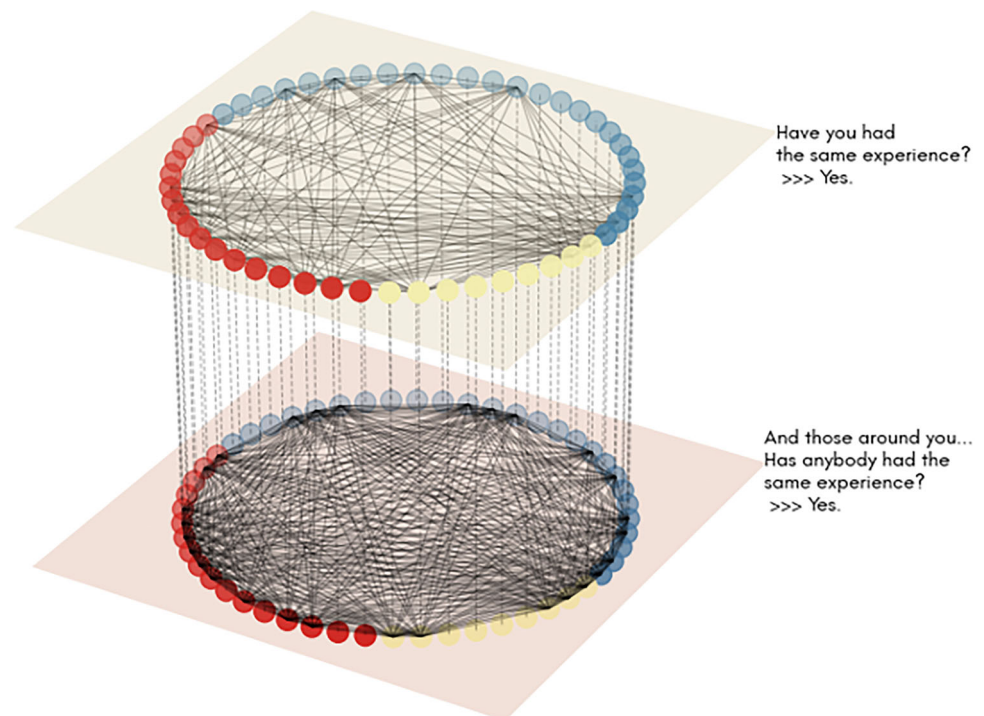
3.2.1 Behavioral traits within the mental healthcare community

With the support of the Federation, a working group was created to co-design the experiments (a co-created project, see Table 1). The working group was formed by a range of 20 people with diverse experiences and expertise: two psychiatrists (all men), two mental health nurses (one man and one woman), four family members (two women and two men), eight persons with mental health conditions (four men and four women, with different mental health problems), two social workers (one man and one woman, working as professional caregivers), and two women from the Federation technical office (with full knowledge of the whole Catalan network of associations and being responsible for organizing public events) [29].

Three hands-on workshops of about 3 h each were organized with the aim to frame and co-design the research. The first session framed the experimental settings. The session introduced social dilemmas in the form of games and then openly discussed about their meaning, interpretation, and value in the context of mental healthcare provision. The second session served to together decide which were the most relevant behavioral traits (cooperation, trust, reciprocity, and sense of collectivity) and the most interesting games (Prisoner's Dilemma, Trust Game, and Collective Risk Dilemma). This was done in an interactive manner and with co-design strategies to collect all perspectives and formulate the main research questions. The last session tested the research methods and protocols related to see the experiments also as an experiential activity that enables participants to self-reflect about their position within the mental healthcare community and in the mental health ecosystem. The sessions were carefully organized in collaboration with the Federation. A facilitator (expert in co-design processes) and two professional researchers were moderating these sessions.

As carefully described in Ref. [29], we first ran the Games for Mental Health (120 participants) as one of the activities in a massive event at a regional level during the week of the World Mental Health Day. Participants belonged to the mental health associative movement, including people with mental health conditions and their families, and social and healthcare professionals from the sector. We also embedded the experiment in three social spaces. In these settings, 150 more people played the games, thus reaching out a total number of participants of 270 individuals. This number of participants is below the number of experimental subjects gathered in Mechanical Turk behavioral experiments, but the numbers resulted are comparable to those gathered in physical laboratories that have studied mental conditions in clinical settings [29].

Results obtained from the public experiments with the active and conscious participation people with lived experience in mental health, non-professional caregivers (e.g., family members), and professional caregivers (e.g., social workers) were published in a scientific journal [51], and the experimental data were also released [88]. Results showed that caregivers are the strong ties in the community as they showed high levels of cooperation and optimism. Also, participants with lived experience also showed to play a leading role in the ecosystem because they were putting larger efforts toward reaching a collective goal in a specific game. The study also emphasized the need to take complex systems science perspective when looking at the community involved in mental healthcare provision. A press conference was also jointly organized by the Universitat de Barcelona and the Federation. An easy-to-read document with policy recommendations was also released jointly with the press release of the scientific paper [89].

3.2.2 The social support networks in mental health

Social physics and complex systems science can also find interest in the so-called social support networks in mental health. These networks are a broad construct of social resources that an individual perceives [91]. They also refer to mutual assistance, guidance, and validation about life experiences and decisions [92]. However, there are not much data to further understand how social support networks work in the context of mental health. This lack of empirical data is hindering the transforming mental healthcare provision toward an enhancement community-based health services.

With the high ambition of maximizing the collaboration with citizens, a group of 32 co-researchers (either persons with mental health issues or their family members) was gathered in the earliest stage of the project. The project can be considered a co-created project with a very high level of involvement of the co-researchers (see Table 1). They were part of the research team as they were considered competent experts in-the-field, based on their daily lived experiences. This hand-in-hand contribution was parallel to another effort in creating a community that we gave the name of knowledge coalition. It was formed by 65 institutional representatives from public administrations, civil society organizations, educational organizations, and academia working on mental health. In this project, the role of the facilitator (in some steps of the project, there were two persons facilitating and curating the communities) was essential to balance the power relations among the large number of persons involved. The research team was completed with four professional scientists in which the role of the project coordinator was necessary.

The first step made was to together frame the research. Collaborative documents and definitions were also prepared, to establish a common definition of social support network and a shared basis on the research approach being taken. Then, co-researchers were invited to write personal stories about their lived experiences of social support, accompanied by a professional writer and a professional graphic artist who illustrated the stories. The process of writing micro-stories was not a straightforward task, and a Research Diary was produced to give support to co-researchers. The Research Diary [85] was meant to be used as physical supporting material after, during, and between the sessions to favor individual and self-reflective processes. The resulting micro-stories were then shared to anyone subscribed in the CoActuem per la Salut Mental chatbot as described in Sect. 3.1.2. In this way, we wanted to explore whether participants in the chatbot and people around them have lived similar experiences.

We together hypothesized that the chatbot serves us as a first proxy to explore the roles of everyone and the experiences that can help to better identify key aspects of social support networks (see also Fig. 7). This is still an ongoing work with the co-researchers and the knowledge coalition. However, it has already served to support with evidences, a set of 14 policy recommendations delivered to local public authorities (Barcelona City Council and commissioner for the National Mental Health Plan at a regional level). The document under the form of a policy brief was discussed during an assembly (November 2023) with knowledge coalition members and co-researchers [93, 94]. The event was also open to anyone who has participated in the chatbot or that was simply interested in mental health.

Both the co-researchers and the knowledge coalition have been involved for a quite long-term period (2–3 years) and for a wide variety of tasks within a research which is indeed not fully ended. Figure 8 describes the co-researchers' contributions so far under the form of a journey. The same dynamics can be used to any other citizen science project facing a societal problem where a group of co-researchers can contribute with their lived experiences. We are still under the process of writing several related scientific publications which some of them will be co-authored by some co-researchers.

4 Discussion and conclusion

We have aimed to call attention to some citizen science practices and encourage social physics community to adopt them and expand them. We believe that citizen science offers ways to circumvent the current obstacles to the further advancement of social physics and by extension, the broader field of computational social science [95, 96]. Experts have observed inadequate data sharing paradigms to consolidate scientific outcomes and the absence of clear mechanisms to perform ethical research [68, 95, 97]. Running an ethical research is not only related to privacy issues and regulation compliance, but It also refers to a further consideration of socio-economic inequalities and vulnerabilities as part of the research agenda, to the inclusion of concerned citizens collectives and eventually those in a vulnerable position in research activities, or to an increment of the citizens' sense of ownership on their own digital data [68, 98].

Along these lines, citizen science practices can become a very relevant approach. In citizen science, participants take an active role in the research definition, the research question, the results interpretation, or the transformation of the scientific results into valuable knowledge [83]. If we talk about social phenomena, both the motivation and the value of the co-produced knowledge are deeply involved in participants' everyday life, and the results can in turn influence policies and actions to promote social change [28, 29, 99]. In a broader level, benefits also cover a wide list of aspects that surpass scientific interest and include innovative STEM or STEAM education [43, 100], democratic values enhancement [101], social inclusion promotion [102, 103], or evidence-based policy making [29, 99, 104, 105]. Furthermore, citizen science practices can be key in the problem identification and agenda setting in scientific research related to societal problems [1] or become a key element in sustainability transitions [104, 105]. And, both globally and locally, citizen science projects can bring to the table non-traditional data sources to contribute to the United Nations Sustainable Development Goals [106].

Fig. 8 The co-researchers journey in CoAct for Mental Health. We collect the direct experience of six co-researchers that participated in all phases of the research on social support networks in mental health. We here cut in two slices the long journey made between 2020 and 2022. The pdf file is available in Zenodo [90]. Graphic document was made by Verity Harrison

We have here focused in our own experience in two particular topics which can be linked to the approaches and methods that social physics typically uses [1]. Learnings from the shared experiences being presented in this paper are many. We would like to stress the importance of building new digital tools which need to be versatile and adaptive to participants' needs, concerns, and constraints. This generally leads to the use of electronic tablets and mobile devices which are more accessible and closer to daily-life activities of the participants. Sometimes, it is however more effective to customize existing digital tools rather than building new ones. Customization may involve new features and uses, but most importantly, it allows to run in-the-field human behavior experiments in more natural conditions. These efforts allow to collect data avoiding the intermediation of tech companies or to get data that are much more aligned to concerned groups of citizens. In both cases, these data can be complementary to existing data. The data can allow to narrow down the research question and more effectively address very specific issues.

Also, participatory dynamics needs to be carefully organized. For this reason, the role of the facilitator is very important. For contributory projects, the tasks of the facilitator might be more focused on engaging participants, in making the project more understandable or in better communicating scientific content. The establishment of collaborations with non-academic organizations favors participation (city councils, public schools, neighbor, or several kinds of civil society organizations), and mapping most relevant stakeholders related to the social issue under investigations is strongly advisable before starting a new citizen science project. In fact, inviting them to frame the research helps to make knowledge to be co-produced more socially robust. For a higher level of engagement (collaborative and co-created projects), the facilitator should also make sure that the voice of the participants is being heard and influencing the project. Most concerned participants are experts in-the-field on the social issue. They can become co-researchers of the project, and the relationship with academic researchers needs to become more horizontal. Co-creation and co-design techniques (with workshops or assemblies) and the production of specific materials to facilitate discussion and raise agreements can therefore become very helpful. Finally, participants expect that their effort has a clear societal impact. This requires that the project establishes relationships and communication channels with policymakers and representatives from civil society organizations and thus make become actionable the knowledge co-produced. All in all, citizen science projects require a larger research team, with soft skills, with the capacity to blend and combine disciplines and expertises, and, most importantly, the research team needs to be flexible and responsive to participants' initial expectations.

To run the experiments reported, one can take windows of opportunity in massive events such as a science festival or the public events during the World Mental Health Day. It is however also important to approach to several contexts much closer to daily social

interactions, even if it is for few minutes or for a much longer period of time. In any case, it is particularly relevant to establish a long-lasting relationship with specific groups that have a clear motivation (young students or a group of old women). These collaborations are valuable to construct communities around the research (such as the knowledge coalition described in CoAct for Mental Health), but it is even more important to incorporate as co-researchers persons with lived experience as they already have invaluable knowledge in their hands. Further reflections of a citizen science for social physics can highly benefit from ongoing discussion around the so-called citizen social science or social citizen science [28, 29]. Citizen social science enhances the social dimension in citizen science and can be understood as participatory research co-designed and directly driven by citizen groups sharing a social concern [29].

Several other topics that social physics investigates can also be part of these ongoing efforts. Many techniques from social physics can be further developed or even reformulated when considering citizen science data. For instance, GPS collected data can help to build completely new stochastic models with special interest in human micro-mobility [55]. Social interactions can also be characterized with the definition of specific traits that quantifies ties among individuals within the mental healthcare ecosystem [51]. The sample of participants in citizen science projects might be more limited (hundreds of participants) compared to other efforts coming from social physics, complex systems, and computational social science. However, the smaller size of the datasets is compensated with the fact that citizen science can gather richer data or at least more meaningful data. The collected data can be more oriented to specific research questions. In the case of pedestrian mobility, the location data are from specific socio-demographic profiles and belong to already identified purposed-based mobility or narrow down the analysis to a concrete neighborhood. In the cases related to mental healthcare, it is possible to run behavioral experiments to characterize the social interactions in terms of traits such as cooperation or trust and reinterpret these traits to better understand the mental health ecosystem. Or, alternatively, it is indeed possible to map out and better understand key elements in social support networks based on lived experiences narrated under the form of micro-stories with complex networks, clustering analysis, and machine learning algorithms. Also, social physics and complex systems communities have the tools and methods to go deeper in behavioral patterns of the participants in citizen science projects [107, 108]. Or alternatively, it is possible to increase, in the future, the participatory and engagement components in similar experiments on human behavior and human interactions to those already very successfully reported in prestigious journals [109, 111].

Overall, the adoption of a citizen science for social physics increases research legitimacy and the potential to transform scientific knowledge into specific actions and policies. Crowdsourced citizen science practices around complex social phenomena extend the research effort to the general public. A deep involvement of co-researchers and knowledge coalition members in scientific research can promote an evidence-based culture beyond the academic context and can open new deliberative spaces to a wide variety of groups and organizations in our societies. This joint effort has the potential to nurture richer public debates around many crucial societal challenges.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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