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ORIGINAL ARTICLE

A scoping review provided a framework for new ways of doing research through mobilizing collective intelligence

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Abstract

Objectives: New forms of research involving collective intelligence (CI) of diverse individuals mobilized through crowdsourcing is successfully emerging in various fields. This scoping review aimed to describe these methods across different fields and propose a framework for implementation.

Study Design and Setting: We searched seven electronic databases for reports describing projects that had mobilized CI with crowdsourcing. We used content analysis to develop themes and categories of the methods.

Results: We identified 145 reports. CI was mobilized to generate ideas, conduct evaluations, solve problems, and create intellectual outputs. Most projects (n = 110, 76%) were open to the public without restrictions on participants' expertise. Participants contributed to projects by independent contribution (i.e., no interaction with other participants) (n = 50, 34%), collaboration (n = 41, 28%), competitions (n = 33, 23%), and playing games (n = 16, 11%). In total, 61% of articles (n = 89) reported methods to evaluate participants' contribution and decision-making process: 43% used an independent panel of experts and 18% involved end users. We identified challenges in implementation and sustainability of CI and proposed solutions.

Conclusion: New research methods based on CI through crowdsourcing could transform clinical research. This framework facilitates the implementation of these methods.

Keywords: Clinical research; Collective intelligence; Crowdsourcing; Interdisciplinary collaboration

1. Introduction

New forms of research are needed to tackle the challenges that clinical research is facing [1,2]. Particularly, the methods currently used to identify the research question, choose the study design and outcome, and conduct the study are being questioned [3−6]. In addition, research has shown the need for better methods of public engagement in clinical research to increase research value [7,8].

In other research fields, new ways of doing research based on the concept of collective intelligence (CI) with crowdsourcing have been successfully implemented. With Climate CoLab, an initiative experimenting with new ideas to tackle climate change, more than 90,000 people have developed more than 2,000 research proposals within 7 years since its creation [9].

CI is defined as shared intelligence emerging from a group of people when they work on the same tasks that could result in more innovative outcomes than when individuals work alone [10,11]. CI is a cornerstone of science: researchers are collaborating on a day-to-day basis with

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What is new?

Key findings

- New forms of research involving collective intelligence of diverse individuals mobilized through crowdsourcing is successfully emerging in various fields.
- Collective intelligence and crowdsourcing offer the possibility to mobilize a large and diverse population through enhanced communication and collaboration, which could transform clinical research planning, conduct, and reporting.

What this adds to what is known?

- We provide an in-depth description of methods mobilizing collective intelligence with crowdsourcing in various fields.

What is the implication and what should change now?

- We propose a framework to implement these methods and highlight possible challenges and methodological issues.

other researchers within or outside of their team. However, with crowdsourcing, researchers are experiencing a new kind of CI that inclusively mobilizes people who are not usually involved in research. Crowdsourcing, whereby participants contribute different abilities such as analytical skills, technical knowledge, and creativity, could be applied to harness the CI of diverse stakeholders in clinical research.

To determine whether CI with crowdsourcing could change how research is planned, conducted, and reported, we need an in-depth understanding of how it is being used in different fields. In this study, we aimed to describe methods of mobilizing CI with crowdsourcing in different fields and propose a framework to implement them.

2. Method

We conducted a scoping review drawing on a previously published framework [12,13]. First, we systematically identified original research articles that described projects across different disciplines that had applied methods of CI. Second, we classified the methods described in each article by answering the following questions: what were the reasons for using CI; who participated and what were their motivations; and what was the process of mobilizing CI in terms of organization, communication, evaluation of participants' contributions and decision-making.

2.1. Definition of CI with crowdsourcing

In this study, we defined CI with crowdsourcing as shared intelligence emerging when mobilizing people who are usually not involved in the research process to work on a specific task [11].

2.2. Search strategy and information sources

We searched the English-language articles in the following standard databases: PubMed, Web of Science; Scopus; EBSCO Business Source Premier; EBSCO Academic Source Premier; publication resources of the Center for Collective Intelligence, Massachusetts Institute of Technology (MIT) (search date December 03, 2016); and Google Scholar (January 11, 2017). We also hand-searched databases of funders who support innovation in health research such as PCORI, NIHR, Robert Wood Johnson, Horizon 2020, FP7, and Laboratory for Innovation Science at Harvard (search date December 03, 2018). Search terms were "collective intelligence," crowdsource/crowdsourcing/crowdsourced, "open innovation," "peer production." To increase the precision of the search, search terms were limited to the titles of articles. We also searched Google Scholar for Wikimedia, WikiProject Medicine, and Task Exchange by Cochrane (search date December 03, 2018). The search strategy for each database is presented in Appendix 1. We did not restrict the search by publication date, study design, or study setting.

2.3. Eligibility criteria

Reports were eligible if they reported a project that had applied methods of CI with crowdsourcing as previously defined [11]. We excluded articles without abstracts, conference proceedings, and protocols without results. We also excluded articles about using crowdsourcing to collect data or perform simple tasks such as classifying images or transcribing data because this did not specifically involve intellectual thinking on the part of the crowd. Theoretical articles and studies using mathematical models to simulate different virtual scenarios of CI were also excluded. Reports of literature reviews were retrieved, and the reference lists were screened to identify eligible reports.

2.4. Identification process

One researcher (V.T.N.) screened the titles and abstracts of all retrieved citations and the full text of all relevant citations identified. A second reviewer checked 10% of excluded citations to ensure the quality of the process. Overall, 300 reports were double checked; disagreements were resolved after discussion (Cohen's kappa coefficient = 0.97 [95% confidence interval 0.954–0.986]).

2.5. Data charting process

We applied content analysis to inductively develop themes and categories for each domain. We also relied on the framework from MIT's Center for Collective Intelligence and published work on crowdsourcing to ensure that our themes described essential domains to understand methods of CI [10,14]. First, two researchers (V.T.N and I.B.) read a set of 20 articles to identify themes describing the methods used for each domain. The two researchers then met to reach consensus on the themes to be included in a data extraction form. Second, one researcher (V.T.N.) used this initial set of themes to extract data from another set of 20 articles. The second researcher (I.B.) cross-checked the data collected and the themes to ensure that the themes covered the information needed. Then, two researchers (V.T.N. and L.G.) extracted data from a set of 33% of articles included, with consensus achieved in case of discrepancies (pooled Cohen's kappa coefficient = 0.63 [95% confidence interval 0.42−0.83]), and one researcher (V.T.N.) extracted data from all remaining articles included. Any new themes emerging during data extraction were recorded and discussed with the senior researcher (I.B.), thereby refining and enriching the list of themes.

2.6. Data items

We extracted the following data from the titles, abstracts, methods, results, and conclusions of retrieved reports.

2.6.1. Publication characteristics

Publication characteristics were title, year of publication, author, type of article (reports of original research, methodological papers), field of study (computer science and technology, biomedicine and other fields including economics, finance and business; environmental science; education; media and communication; psychology and social science), and funding sources.

2.6.2. Methods of CI

To understand the methods of CI, we extracted information for seven domains: (1) reasons for using CI, (2) type of participants and methods of recruitment, (3) motivation, (4) type of participants' contribution, (5) type of interaction between participants, (6) methods to evaluate participants' contribution and decision-making on what ideas or solutions to use, and (7) challenges of CI reported by authors and authors' satisfaction with participants' contributions.

2.7. Critical appraisal

We did not assess bias because neither the Joanna Briggs Institute framework [13] nor the PRISMA checklist for scoping reviews [15] require assessment of risk of bias because scoping reviews aim to provide an overview of the existing evidence regardless of the risk of bias of primary evidence. Furthermore, no validated tool is available for the critical appraisal of research using CI. Nevertheless, we assessed the quality of reporting for the following items: type of participants, sample size, demographic information, motivations for participants, evaluation methods, challenges and limitations.

2.8. Patients and public involvement

Patients and the public were not involved in this scoping review.

2.9. Statistical analysis

We used R v3.4.2 (the R Foundation Statistical Computing, Vienna, Austria) to compute frequencies and percentages for each method. Qualitative data extracted from articles were coded by content analysis and inductively grouped to create categories.

3. Results

3.1. Study identification and general characteristics

We retrieved 3,780 citations from the electronic search and excluded 3,395 based on titles and abstracts. Two further articles were excluded as the full texts could not be found. After reviewing the reference lists of literature reviews retrieved from the search, we identified five more eligible articles. We assessed the full texts of 383 articles, and 145 articles from 145 projects were eligible for data extraction (Fig. 1): 49 from biomedicine, 47 from computer science and technology, and 49 from other fields (Additional File 2). Overall, 89 projects received funding from not-for-profit organizations (i.e., funding from academic institutions, nongovernmental organizations, philanthropic and charity organizations, public funders) [16], 13 from for-profit organizations, and 2 from crowdfunding; 41 articles did not report funding sources.

3.2. Reasons for using CI

From 145 included articles, we identified and classified the following four main reasons for using CI:

- Create intellectual outputs (n = 65 projects, 45%): Participants contribute to the creation of health education materials, clinical trial protocols, prognostic models, software, articles, and policies.
- Generate ideas (n = 38, 26%): Participants contribute to new ideas for research and development. For example, Harvard Medical School launched idea challenges to generate new research questions on type I diabetes [17].

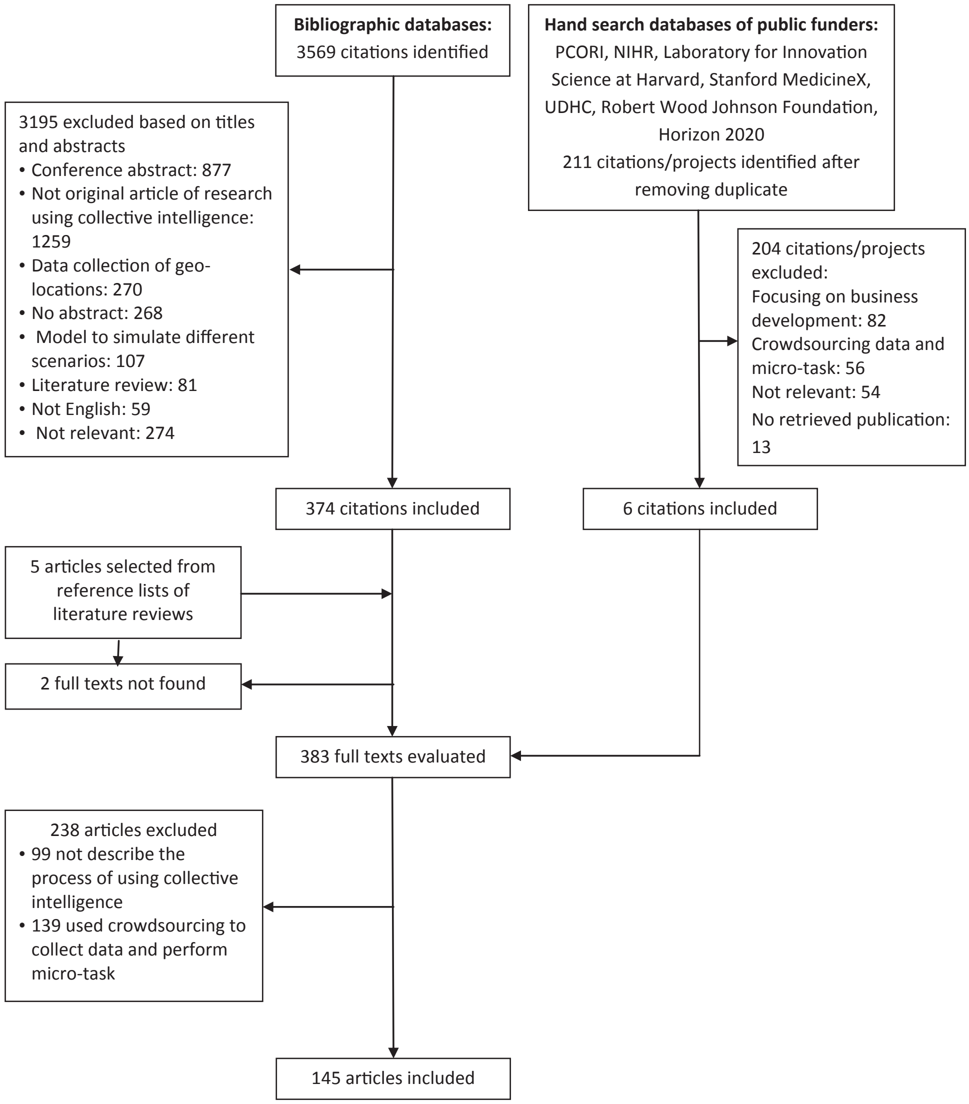

Fig. 1. Study selection process.

Box 1 Examples of projects using CI by each reason

Reasons for using CI	Example
Create intellectual outputs	- DREAM challenge is an open science initiative. It leverages CI to use data from clinical trials to create predictive models (e.g., prognostic model of survival rate, prediction model of treatment response) [19,20] - A project used crowdsourcing to mobilize 60 physicians/researchers and 42 patients/advocates to develop a protocol for a cancer trial [21]. This pilot project led to the creation of an online community of doctors and patients to develop protocols of clinical trials called Transparency life sciences [22]
Generate ideas	- Harvard Medical School launched idea challenges to leverage CI from the community to generate new research ideas on type I diabetes [17] - Researchers used a creative contributory contest to ask community members to contribute new ideas for an HIV testing campaign [23]
Conduct evaluation	- CrowdCARE is an initiative that mobilizes the knowledge and skills of the crowd to critically evaluate the evidence from health practice to facilitate evidence synthesis [24]
Solve problems	- DYSCERNE used crowdsourcing to create a network of clinicians in 26 different European countries for the clinical diagnosis of very rare genetic syndromes of multiple congenital anomalies [18] - Foldit and Phylo are online games that allow users to manipulate the structures of proteins to solve problems of the order and structure of nucleotides in proteins to help cure diseases [25,26]

- Conduct evaluations (n = 10, 7%): Participants evaluate the quality of the ideas/work. CI is mobilized to critically appraise research quality.
- Solve problems (n = 25, 17%): Participants solve a practical problem and propose solutions to difficulties given by organizers. For example, CI of experts from 26 different European countries is being mobilized for the clinical diagnosis of very rare genetic syndromes of multiple congenital anomalies [18].

Six articles (4%) described mobilizing CI for both generating ideas and conduct evaluations; one article (1%) aimed to create intellectual outputs and conduct evaluations. Box 1 provides examples for each reason for using CI in biomedicine.

3.3. Type of participants and methods of recruitment

Participants could be classified into three categories (1): open public (n = 110, 76%) (everyone can contribute

Box 2 Main features of types of participants' contributions

Methods of participants' contribution	Examples	Main features
Independent contribution (collection)	- Transparency life science is a platform that mobilizes clinicians and patients in clinical trial protocol development. A clinical trial protocol is divided into several items (i.e., inclusion, exclusion criteria, intervention, sample size). Clinicians, patients, and relatives independently review and contribute to improve the items. Their contribution is aggregated to create a complete protocol that is reviewed again by community members for final approval [21]	- Work is divided into small pieces; participants can work independently - There is a mechanism for aggregating contributions from all participants (e.g., averaging, voting)
Competition	- DREAM challenges (http://dreamchallenges.org/) are competitions in biomedical sciences that use open clinical trial data to answer fundamental questions in biological science and human health. DREAM challenges last from 3 to 6 months. Anyone interested can join DREAM challenges. Teams who have the best-performing models will receive a reward [40] - Researchers in Guangzhou, China, organized a creative competition whereby participants contributed their ideas to develop a campaign to increase the HIV testing rate. Overall, 96 submissions were received after 39 days. A photo gallery was organized to celebrate the top five submissions. Winners were invited to join a panel of experts in the field of sexual health as recognition for their skills and knowledge [23]	- Gives a well-defined problem to solve - Gives clear criteria for evaluation to recognize innovative ideas - Provides a strong communication plan for before, during, and after the competition. Uses different channels to publicize the competition in advance and provide real-time updates - Gives time to participants to understand the problem such as organizing an introduction workshop, providing a data set, and tutorials for training - Provides a forum for participants to exchange ideas and form their teams - Rewards for winners
Play games	- MalariaSpot (http://malariaspot.org/) is a web-based game in which participants detect malaria parasites in digitized blood samples. By playing games, participants recognize which blood images contain parasites and the types of malaria parasites. The results from the games help researchers increase the accuracy of malaria diagnosis [48] - Phylo (http://phylo.cs.mcgill.ca/) and Foldit (http://fold.it/portal/) are Web-based citizen science games allowing participants without a significant background in biology to contribute to the development of protein structures. The games are designed as small tasks with different level of difficulties. By playing the games, participants actually solve a problem in protein structures [25,26]	- Web-based, mobile-based applications accessible to a wide range of participants - Provides tutorials to participants - Creates different levels of complexity - Real-time updates and leader boards are used to increase engagement from participants
Collaboration	- DocCHIRP is a crowdsourcing network of medical doctors that mobilizes the CI of their members to search for solutions to their medical questions [56]	- Work is not able to be divided into independent pieces - Provides a platform for discussion, a way to record ideas from all participants (i.e., Wikis), and a moderator who supports the discussion - Provides tools to navigate ideas contributed by participants (i.e., text analysis) to identify patterns of ideas; automatic team matching

regardless of their background) (2): experts in the field (n = 21, 14%); and (3) defined groups (n = 14, 10%) (a specific population relevant to the research topic, such as students or patients). Participant demographic information (e.g., sex, education, economic status) was reported in only 16 articles (11%). The number of participants contributing to the projects was reported in 59 articles (41%). When reported, the median number of participants who contributed to the projects was 242 [Q1−Q3: 111−535].

The methods used to recruit participants were reported in 50 articles and included creating a Website or mobile phone applications, combined with an open call in social media platforms (60%) [21,27−29], using personal networks and offline communities (22%) [30−32], targeting online communities (PatientsLikeMe, www.reddit.com) (6%) [33−35], contracting with crowdsourcing intermediary platforms (i.e., online platforms connecting organizations wishing to leverage CI with a readily available community) (InnoCentive, Kaggle) (6%) [17,19,36], and recruiting on crowdsourcing marketplaces (Amazon Mechanical Turk) (6%) [37,38].

3.4. Motivation

In total, 108 articles (74%) reported the incentives or intrinsic factors used to motivate participants to take part in the projects. Financial incentives were the most common (n = 42, 39%) [27,36,39,40], followed by recognition from the network (n = 8, 7%) [18,41] and access to data (n = 2, 2%) [42,43].

Intrinsic motivation could sometimes have a role; for example, participation in a project could arise from individuals' sense of belonging to a network (n = 17, 16%) [23,44], personal interest in the topic and gaining new knowledge (n = 17, 16%) [45,46], fun (n = 12, 11%) [25,47,48], and altruism (n = 4, 4%) [31,49]. Six articles (6%) reported a combination of both incentives and intrinsic motivation.

3.5. How participants contributed to the projects

We identified four methods by which participants contributed to projects: independent contribution (collection) (i.e., participants work independently to complete small pieces of work) (n = 50 projects, 34%) [21,32,34]; competition (i.e., participants submit their work independently, only good solutions are selected and rewarded) (n = 33, 23%) [23,27,36]; the use of a game to collect independent contributions from participants while creating fun and enjoyment (n = 16, 11%) [25,47,48]; and collaboration (i.e., participants work interdependently and collaboratively to complete tasks together) (n = 41, 28%) [50,51]. One project (1%) combined competition with independent contribution [52]. Participants joined the competition to

Box 3 Challenges during the process of CI and proposed solutions

Challenges	Proposed solutions
Challenges in recruitment	
Attracting a large number of participants and keeping them motivated	Combine extrinsic motivation (i.e., financial rewards, recognition) with intrinsic motivation. There are different ways to trigger intrinsic motivation (i.e., using games to make taking part in tasks enjoyable for participants [48], encouraging participants to develop their knowledge, providing tutorials and giving participants opportunities to practice and develop new skills [27])
Challenges in communication	
Feeling of disappointment when participant's ideas are not implemented, feeling of being exploited	Communicate clearly to participants the goals of organization, how the ideas will be used to contribute to the organization and community, and the implementation plan
Lack of platform for idea sharing	Create an online platform for participants to share ideas. Combined with automatic text analysis to provide real-time feedback, create a classification to keep track of all ideas and eliminate redundancy
Dominant voices in the discussion	Provide options for being anonymous in the discussion and a moderator to manage the platform, resolve conflicts, flag dominant voices, and arrange categories of ideas without intervening in the discussion
Challenges in sustainability	
Difficulties in integrating ideas of participants in a business model	Communicate clearly the goals of the organization, what the organization is looking for
Time and resources required for screening and selecting ideas of participants	Assign a dedicated staff (a moderator) to manage the classification of ideas, which can accelerate the evaluation process
Lack of policy for data sharing	Predefine terms of participation and communicate with participants for agreement on data sharing

generate ideas and then the community was involved in evaluating the ideas independently. Four projects (3%) combined competition with collaboration: the project first organized a competition and then held a workshop at which the leading teams collaborated to create better solutions [33,53−55]. Box 2 provides examples of each type of contribution in biomedical projects.

3.6. Interactions between participants and organizers

A total of 64 articles (44%) described no interaction among participants or between participants and organizers (stand-alone). For 54 projects (37%), participants could receive feedback from other participants and for 20 (14%), from organizers. Other methods for interaction between participants and organizers included online focus group discussion (n = 7, 5%).

3.7. Evaluation of participants' contribution and decision-making process

Although 98 (68%) articles claimed that authors were satisfied with participants' contributions, only 89 (61%) reported methods to evaluate the contribution and decision-making for selecting the best contributions. We identified two main categories: evaluation and decision by an independent panel (n = 63, 43%) and evaluation and decision by end users (target customers, community members) (n = 26, 18%). For example, Harvard Medical School launched an idea competition on diabetes and used a panel of 142 faculty members to review the 150 submissions and select the best one [17]. In Dell's IdeaStorm, community members gave points to each idea [44]; the evaluation was based on average points from all participants.

3.8. Challenges of mobilizing CI

Among 145 articles reviewed, only 13 mentioned the challenges encountered when using CI. Most of the challenges concerned two main issues: (1) implementation of CI projects and (2) sustainability (Box 3).

Regarding challenges in implementation, two articles discussed difficulties in recruitment and participant retention [56,57]. Two articles described challenges in communicating with participants, including lack of a platform for exchanging ideas among participants, dominant voices in the discussion, unclear communication from organizers

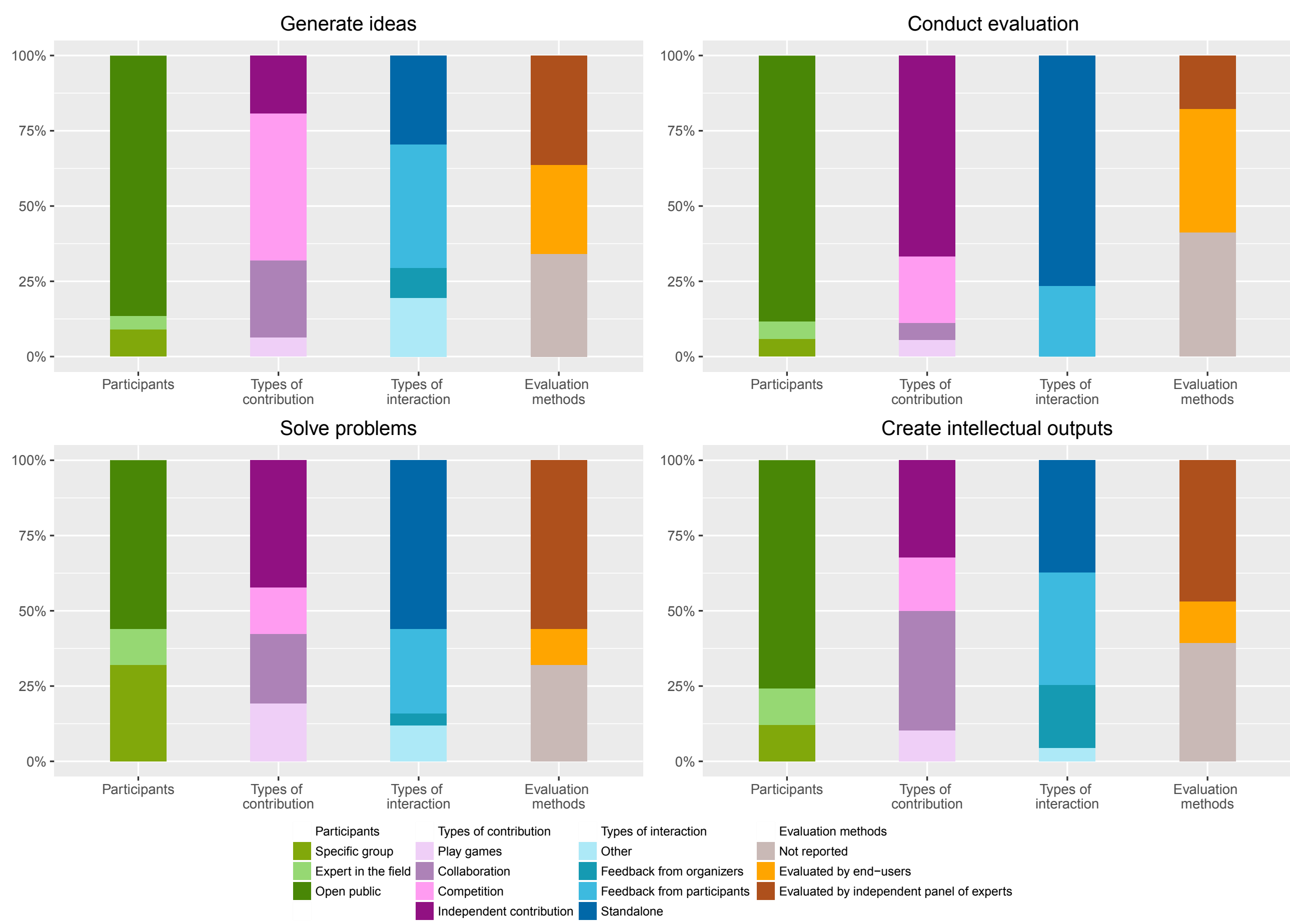

Fig. 2. Differences in methods of mobilizing CI by reasons for using CI. CI, collective intelligence.

causing mistrust and a feeling of being exploited, and unclear idea expression from participants, which slowed the idea selection [44,58]. Two articles emphasized the importance of making the research questions understandable to participants and provided participants with adequate information to address the problems posed [27,59]. One article discussed the issues of selecting inappropriate comparison standards when evaluating participant contributions [60].

Seven articles highlighted the challenges in sustaining the integration of CI in traditional business models, including resources and changes in the organization's culture when integrating new ideas from participants [44,54]; increased workload for organizers to prepare tasks for participants, screen and select the best solutions [56,61]; and the need for policies on data sharing and how participants could access data contributed by other participants [56,62].

3.9. A framework to mobilize CI

Fig. 2 presents types of participants, how participants contributed to projects, interactions among participants, and the evaluation of participants' contributions and decision-making according to the different reasons for using CI. To generate evaluation and solve problems, independent contributions were used often, with mostly no interaction among participants. In contrast, competition was often used to generate ideas, and participants were able to exchange ideas and receive feedback from each other. To create intellectual products, participants collaborated with each other and were able to receive feedback from other participants and organizers to improve their products.

Considering all the information recorded, in Fig. 3, we propose a framework of the process of mobilizing CI. The framework describes seven steps in the process and the classification of methods for each step.

4. Discussion

This scoping review provides an in-depth description of methods mobilizing CI with crowdsourcing and proposes a framework to implement these methods in research.

In this review, we defined CI with crowdsourcing as shared intelligence that emerges when people who are usually not involved in research are mobilized to work on a specific task. Some literature considers crowdsourcing used to collect data and perform simple tasks as a kind of CI [10,63]. However, in this study, we focused on research harnessing CI whereby participants contribute their intellectual abilities.

CI relies on the principles of the wisdom of the crowd and "swarm" intelligence. The wisdom of the crowd theory states that decisions resulting from the aggregation of information from a large crowd of independent individuals are often better than those from any single member of the group [64]. Wisdom of the crowd is particularly relevant to evaluation and decision-making. Swarm intelligence emerges when the interaction of independent individuals produces better problem-solving abilities than a single individual [65,66]. Swarm intelligence is used to generate ideas, solve problems, and create intellectual products.

By applying principles of CI and by using an online interface to crowdsource to a large population, clinical research might be accelerated and enriched by innovation. CI can be applied to support different stages of clinical research (e.g., identify research questions, design

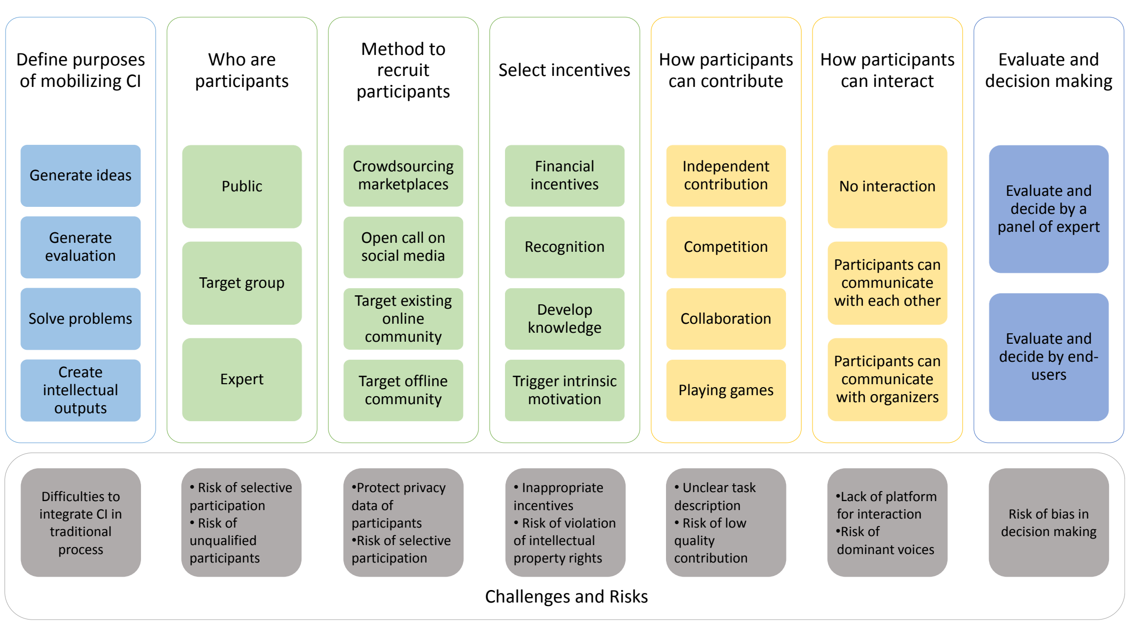

Fig. 3. Framework of process of mobilizing CI. CI, collective intelligence.

Box 4 Potential risks of mobilizing CI

Internal validity

Because most of the projects are open to the public, participants might not have adequate skills and knowledge to contribute meaningfully to research. This might have severe consequences if the contribution of unqualified participants influences decision-making, especially when it leads to changes in health care practices. Some projects added an extra step to assess the ability of participants. For example, the SPRINT data challenge had a qualification round to ensure that participants had certain skills to tackle the research problem [67]. This issue emphasizes the importance of an independent evaluation panel for objective assessment to adequately evaluate participants' contribution

External validity

Clear guidance is lacking on how many participants are needed to obtain relevant results. In our sample, the number of participants who actually contributed to the projects varied considerably, from 37 to 6200. This raised questions about the external validity of the contributions of participants and whether ideas or solutions generated and voted for by participants would be applicable to the community

Risks related to privacy and personal data

There are certain risks for participants when joining CI projects. When registering to be a member on intermediary platforms, participants might have to disclose their knowledge, but the platforms can use this knowledge without proper acknowledgment [69]. Similarly, ethical questions have been raised about online communities when data contributed voluntarily by patients has been sold for financial interests without informing patients [70]

Intellectual property

Participants in projects funded by academic institutions were not required to transfer exclusive copyright to organizers, and their contributions could be publicly accessible [17], whereas in projects funded by for-profit organizations, participants were obligated to transfer the copyright to organizers in exchange for monetary rewards. The latter case might imply some ethical risks. Organizations offered monetary rewards for only the highest ranked submissions, but in some cases, claimed ownership of all of submissions, which might cause a sense of mistrust in participants [71]. Hence, organizations should ensure the transparency of the terms of intellectual property

interventions, develop research protocols, analyze data, and appraise research quality). Examples include a Harvard Medical School challenge to leverage the wisdom of crowd to identify pioneering ideas for type I diabetes research [17]. Similarly, the New England Journal of Medicine launched the SPRINT data challenge to give data scientists across the world the opportunity to access and analyze clinical trial data [67]. Cochrane crowd and CrowdCARE are initiatives that use the power of the crowd to reduce the research burden and accelerate the process of evidence synthesis [24,68].

To our knowledge, this scoping review is the first study to systematically describe the methods of mobilizing CI with crowdsourcing in published research across different fields. Our results show that some essential information is missing from reports of research involving CI. Half of the articles did not report the number of participants contributing to the project, and demographic information on participants was reported in just 10% of articles. This hinders verification of claims made about the diversity of participants and regarding the irrelevance to the problem. There are several potential risks of bias related to CI that we discuss in Box 4.

The literature on CI might entail risk of reporting bias. Overall, 68% (98/145) of articles stated positive outcomes from mobilizing CI, but only 9% reported difficulties encountered. In all, 28% (40/145) did not report sources of funding. Most retrieved publications were funded by not-for-profit organizations (61%), indicating that projects using methods of CI funded by for-profit-organizations might be underreported. Hence, funders and researchers must be encouraged to publish their research to contribute to the knowledge base and thereby assist methodological improvement.

Our scoping review has some limitations. First, we restricted our search to keywords in titles to reduce the number of irrelevant articles, so we might have missed some reports that contained keywords elsewhere in the text. However, our aim was to provide a description of different methods of mobilizing CI rather than exhaustively review all relevant articles or report multiple repetitions of the same methods. Second, we focused on published literature, and some projects involving CI may not result in a classical scientific publication. Third, because no validated tool for critical appraisal was available, we were not able to assess the quality of research reports involving CI.

5. Conclusion

In conclusion, we describe methods to mobilize CI across different disciplines and a framework to implement these methods. For researchers who want to apply CI, this framework could be useful to select appropriate methods. Nevertheless, more research is needed to further understand the conditions that enable and constrain the success of CI.

CRediT authorship contribution statement

Van Thu Nguyen: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft. **Mehdi Benchoufi:** Conceptualization, Methodology, Formal analysis, Writing - review & editing. **Bridget Young:** Conceptualization, Writing - original draft, Methodology, Formal analysis. **Lina Ghosn:** Data curation. **Philippe Ravaud:** Conceptualization, Methodology, Formal analysis, Writing - review & editing. **Isabelle Boutron:** Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft.

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Supplementary data

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References

[1] Bhatt A. Quality of clinical trials: a moving target. Perspect Clin Res 2011;2(4):124−8.
[2] Reynolds T. Clinical trials: can technology solve the problem of low recruitment? BMJ 2011;342:d3662.
[3] Rupp T, Zuckerman D. Quality of life, overall survival, and costs of cancer drugs approved based on surrogate endpoints. JAMA Intern Med 2017;177(2):276−7.
[4] Macleod MR, Michie S, Roberts I, Dirnagl U, Chalmers I, Ioannidis JP, et al. Biomedical research: increasing value, reducing waste. Lancet 2014;383(9912):101−4.
[5] Yordanov Y, Dechartres A, Porcher R, Boutron I, Altman DG, Ravaud P. Avoidable waste of research related to inadequate methods in clinical trials. BMJ 2015;350:h809.
[6] Kasenda B, von Elm E, You J, Blumle A, Tomonaga Y, Saccilotto R, et al. Prevalence, characteristics, and publication of discontinued randomized trials. JAMA 2014;311:1045−51.
[7] Boote J, Baird W, Beecroft C. Public involvement at the design stage of primary health research: a narrative review of case examples. Health Policy 2010;95(1):10−23.
[8] Price A, Liew SM, Kirkpatrick J, Price J, Lopreto T, Nelken Y. Mind the gap in clinical trials: a participatory action analysis with citizen collaborators. J Eval Clin Pract 2017;23:178−84.
[9] Chunara R, Smolinski MS, Brownstein JS. Why we need crowdsourced data in infectious disease surveillance. Curr Infect Dis Rep 2013;15(4):316−9.
[10] Malone TW, Laubacher R, Dellarocas C. The collective intelligence genome. MIT Sloan Manag Rev 2010;51(3):21.
[11] Sieg JH, Bücheler T, Pfeifer R, Füchslin R. Crowdsourcing, open innovation and collective intelligence in the scientific method: a research agenda and operational framework. In: Artificial Life XII − Twelfth International Conference on the Synthesis and Simulation of Living Systems. Denmark: Odense; 2010:679−86.
[12] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol Theor Pract 2005;8(1):19−32.
[13] Peters MDJ, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. Guidance for conducting systematic scoping reviews. Int J Evid Based Healthc 2015;13(3):141−6.
[14] Créquit P, Mansouri G, Benchoufi M, Vivot A, Ravaud P. Mapping of crowdsourcing in health: systematic review. J Med Internet Res 2018;20(5):e187.
[15] Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 2018;169:467−73.
[16] Salamon LM, Helmut KA. The International Classification of Nonprofit Organizations: ICNPO-Revision 1, 1996. Working Papers of the Johns Hopkins Comparative Nonprofit Sector Project, no 19. Baltimore: The Johns Hopkins Institute for Policy Studies; 1996.
[17] Guinan EVA, Boudreau KJ, Lakhani KR. Experiments in open innovation at harvard medical School. MIT Sloan Manag Rev 2013;54(3):45−52.
[18] Douzgou S, Pollalis YA, Vozikis A, Patrinos GP, Clayton-Smith J. Collaborative crowdsourcing for the diagnosis of rare genetic syndromes: the DYSCERNE experience. Public Health Genomics 2016;19(1):19−24.
[19] Brinkmann BH, Wagenaar J, Abbot D, Adkins P, Bosshard SC, Chen M, et al. Crowdsourcing reproducible seizure forecasting in human and canine epilepsy. Brain 2016;139:1713−22.
[20] Ewing AD, Houlahan KE, Hu Y, Ellrott K, Caloian C, Yamaguchi TN, et al. Combining tumor genome simulation with crowdsourcing to benchmark somatic single-nucleotide-variant detection. Nat Methods 2015;12(7):623−30.
[21] Leiter A, Sablinski T, Diefenbach M, Foster M, Greenberg A, Holland J, et al. Use of crowdsourcing for cancer clinical trial development. J Natl Cancer Inst 2014;106(10). dju258.
[22] Transparency life sciences. About us: Transparency life sciences 2018. Available at https://www.transparencyls.com/about-us/. Accessed December 3, 2018.
[23] Zhang Y, Kim JA, Liu F, Tso LS, Tang W, Wei C, et al. Creative contributory contests to spur innovation in sexual health: 2 cases and a guide for implementation. Sex Transm Dis 2015;42(11):625−8.
[24] Crowdcare about crowdcare 2018. Available at https://crowdcare.unimelb.edu.au/about.html. Accessed December 3, 2018.
[25] Cooper S, Khatib F, Treuille A, Barbero J, Lee J, Beenen M, et al. Predicting protein structures with a multiplayer online game. Nature 2010;466:756−60.
[26] Kawrykow A, Roumanis G, Kam A, Kwak D, Leung C, Wu C, et al. Phylo: a citizen science approach for improving multiple sequence alignment. PLoS One 2012;7:e31362.
[27] Allen GI, Amoroso N, Anghel C, Balagurusamy V, Bare CJ, Beaton D, et al. Crowdsourced estimation of cognitive decline and resilience in Alzheimer's disease. Alzheimers Dement 2016;12(6):645−53.
[28] Kajmakoska B, Koeck AM, Willfort R. Computer-based solutions for open innovation processes. Acta Technica Corvin Bull Eng 2011;4(3):41−8.
[29] Bullinger AC, Rass M, Adamczyk S, Moeslein KM, Sohn S. Open innovation in health care: analysis of an open health platform. Health Policy 2012;105(2/3):165−75.
[30] Tanno LK, Calderon MA, Goldberg BJ, Gayraud J, Bircher AJ, Casale T, et al. Constructing a classification of hypersensitivity/allergic diseases for ICD-11 by crowdsourcing the allergist community. Allergy 2015;70(6):609−15.
[31] Bailey C, King K, Dromey B, Wynne C. Fear of falling and older adult peer production of audio-visual discussion material. Educ Gerontol 2010;36(9):781−97.
[32] Kurvers RH, Krause J, Argenziano G, Zalaudek I, Wolf M. Detection accuracy of collective intelligence assessments for skin cancer diagnosis. JAMA Dermatol 2015;151(12):1346−53.
[33] Thawrani V, Londhe ND, Singh R. Crowdsourcing of medical data. IETE Tech Rev 2014;31(3):249−53.
[34] Bevelander KE, Kaipainen K, Swain R, Dohle S, Bongard JC, Hines PDH, et al. Crowdsourcing novel childhood predictors of adult obesity. PLoS One 2014;9:1−14.
[35] Burnett S, Furlong M, Melvin PG, Singiser R. Games that enlist collective intelligence to solve complex scientific problems. J Microbiol Biol Educ 2016;17(1):133−6.
[36] Davis JR, Richard EE, Keeton KE. Open innovation at NASA. Res Technol Manag 2015;58(3):52−8.

[37] Kristan J, Suffoletto B. Using online crowdsourcing to understand young adult attitudes toward expert-authored messages aimed at reducing hazardous alcohol consumption and to collect peer-authored messages. Transl Behav Med 2015;5(1):45−52.
[38] Wu C, Scott Hultman C, Diegidio P, Hermiz S, Garimella R, Crutchfield TM, et al. What do our patients truly want? Conjoint analysis of an aesthetic plastic surgery practice using internet crowd-sourcing. Aesthet Surg J 2017;37:119−21.
[39] Küffner R, Zach N, Norel R, Hawe J, Schoenfeld D, Wang L, et al. Crowdsourced analysis of clinical trial data to predict amyotrophic lateral sclerosis progression. Nat Biotechnol 2015;33(1):51−7.
[40] Guinney J, Wang T, Laajala TD, Winner KK, Bare JC, Neto EC, et al. Prediction of overall survival for patients with metastatic castration-resistant prostate cancer: development of a prognostic model through a crowdsourced challenge with open clinical trial data. Lancet Oncol 2017;18:132−42.
[41] Silvertown J. Crowdsourcing the identification of organisms: a case-study of iSpot. Zookeys 2015;480:125−46.
[42] Bow HC, Dattilo JR, Jonas AM, Lehmann CU. A crowdsourcing model for creating preclinical medical education study tools. Acad Med 2013;88:772−6.
[43] Boydstun AE, Feezell JT, Glazier RA, Jurka TP, Pietryka MT. Colleague crowdsourcing: a method for fostering national student engagement and large-N data collection. PS Polit Sci Polit 2014; 47(4):829−34.
[44] Di Gangi PM, Wasko M. Steal my idea! Organizational adoption of user innovations from a user innovation community: a case study of Dell IdeaStorm. Decis Support Syst 2009;48(1):303−12.
[45] Kostakis V, Drechsler W. Commons-based peer production and artistic expression: Two cases from Greece. New Media Soc 2015; 17(5):740−54.
[46] Ponti M. Peer production for collaboration between academics and practitioners. J Librarian Inf Sci 2013;45(1):23−37.
[47] Good BM, Loguercio S, Griffith OL, Nanis M, Wu C, Su AI. The cure: design and evaluation of a crowdsourcing game for gene selection for breast cancer survival prediction. JMIR Serious Games 2014; 2(2):e7.
[48] Luengo-Oroz MA, Arranz A, Frean J. Crowdsourcing malaria parasite quantification: an online game for analyzing images of infected thick blood smears. J Med Internet Res 2012;14(6):207−19.
[49] Brooks SC, Simmons G, Worthington H, Bobrow BJ, Morrison LJ. The PulsePoint Respond mobile device application to crowdsource basic life support for patients with out-of-hospital cardiac arrest: challenges for optimal implementation. Resuscitation 2016;98:20−6.
[50] Hildebrand M, Ahumada C, Watson S. Crowdoutaids: crowdsourcing youth perspectives for action. Reprod Health Matters 2013;21(41): 57−68.
[51] Sun L, Xiang W, Chen S, Yang Z. Collaborative sketching in crowd-sourcing design: a new method for idea generation. Int J Technol Des Educ 2015;25(3):409−27.
[52] Wu H, Corney J, Grant M. An evaluation methodology for crowd-sourced design. Adv Eng Inform 2015;29(4):775−86.
[53] Arganda-Carreras I, Turaga SC, Berger DR, Cireşan D, Giusti A, Gambardella LM, et al. Crowdsourcing the creation of image segmentation algorithms for connectomics. Front Neuroanat 2015; 9:1−13.
[54] Schweitzer FM, Buchinger W, Gassmann O, Obrist M. Crowdsourcing leveraging innovation through online idea competitions. Res Technol Manag 2012;55(3):32−8.
[55] Sieberts SK, Zhu F, Garcia-Garcia J, Stahl E, Pratap A, Pandey G, et al. Crowdsourced assessment of common genetic contribution to predicting anti-TNF treatment response in rheumatoid arthritis. Nat Commun 2016;7:12460.
[56] Sims MH, Bigham J, Kautz H, Halterman MW. Crowdsourcing medical expertise in near real time. J Hosp Med 2014;9(7):451−6.
[57] Cabiddu F, Castriotta M, Di Guardo MC, Floreddu P. Open innovation and crowdsourcing communities design: a cross case analysis. In: Baskerville R, De Marco M, Spagnoletti P, editors. Designing Organizational Systems. Lecture Notes in Information Systems and Organisation, vol 1. Berlin, Heidelberg: Springer; 2013:143−55.
[58] Djelassi S, Decoopman I. Customers' participation in product development through crowdsourcing: issues and implications. Ind Market Manag 2013;42(5):683−92.
[59] Sabou M, Scharl A, Fols M. Crowdsourced knowledge acquisition: towards hybrid-genre workflows. Int J Semantic Web Inf Syst 2013;9(3):14−41.
[60] Meyer P, Siwo G, Zeevi D, Sharon E, Norel R, Segal E, et al. Inferring gene expression from ribosomal promoter sequences, a crowd-sourcing approach. Genome Res 2013;23(11):1928−37.
[61] Aitamurto T. Crowdsourcing as a knowledge-search method in digital journalism: ruptured ideals and blended responsibility. Digit Journalism 2016;4(2):280−97.
[62] Lundberg N, Koch S, Hagglund M, Bolin P, Davoody N, Eltes J, et al. My care pathways - creating open innovation in healthcare. Stud Health Technol Inform 2013;192:687−91.
[63] Lesser E, Pulver B, Ransom D, Rawn S. Collective intelligence: capitalizing on the crowd. New York: IBM Institute for Business Development; 2012.
[64] Surowiecki J. The wisdom of crowds. New York: Anchor Books; 2005.
[65] Liu Y, Passino KM. Swarm intelligence: literature overview. Columbus, OH: Department of Electrical Engineering, The Ohio State University; 2000.
[66] Salminen J. Collective intelligence on a crowdsourcing site: GBI working paper 2013. Available at https://sites.google.com/site/gbialternative1/working-papers.
[67] Burns NS, Miller PW. Learning what we didn't know — the SPRINT data analysis challenge. N Engl J Med 2017;376(23):2205−7.
[68] Cochrane. Cochrane Crowd 2018. Available at http://crowd.cochrane.org/index.html. Accessed December 3, 2018.
[69] Acar OA, van den Ende J. Understanding fear of opportunism in global prize-based science contests: evidence for gender and age differences. PLoS One 2015;10.
[70] Van Dijck J, Poell T. Understanding the promises and premises of online health platforms. Big Data Soc 2016;3(1).
[71] de Beer J, McCarthy IP, Soliman A, Treen E. Click here to agree: managing intellectual property when crowdsourcing solutions. Bus Horiz 2017;60(2):207−17.