CITIZEN SCIENCE:
THEORY AND PRACTICE

Collective Intelligence to Find Solutions to the Challenges Posed by the Sustainable Development Goals

COLLECTION:
CONTRIBUTIONS OF CITIZEN SCIENCE TO THE UN SDGS

METHOD

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ABSTRACT

The implementation of the United Nations (UN) Sustainable Development Goals (SDGs) presents a vast and intricate array of challenges, including the establishment of governance systems that engage all societal actors, particularly nongovernmental entities and youth, in proposing solutions and decision-making. This article investigates the potential of collective intelligence as a tool within citizen science to create solutions for SDG-related challenges and to establish or enhance necessary governance mechanisms. We detail a collective intelligence experiment conducted during the UN Climate Change Conference 2019 (COP25; Madrid, December 2–13), which aimed to generate a prioritised list of actions addressing SDG 6, Water and Sanitation and SDG 13, Climate Action. The experiment involved 1,253 students aged 15 to 17 who proposed, modified, and prioritised 14,517 ideas using an online platform created by Kampal, a spin-off of the University of Zaragoza. We discuss: a) participation protocols following citizen science methodologies; b) the platform description; c) results concerning the participation process, the tool's effectiveness in collectively extracting the best solutions, and the quality of the generated proposals; and d) enhancements and new research directions for using citizen science and collective intelligence to tackle SDG-related challenges in a collaborative and participatory way.

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INTRODUCTION

CHALLENGES IN SUSTAINABLE DEVELOPMENT GOALS IMPLEMENTATION

Implementing the United Nations Sustainable Development Goals (SDGs) presents a multifaceted set of challenges. First, it requires diverse governance frameworks since no single governance style—whether hierarchical, network, or market-based—or any combination thereof, can effectively address all SDG-related challenges (Meuleman and Niestro 2015). Second, governance is no longer exclusive to governments but involves non-state actors working with or even without them (Florini and Pauli 2018).

The 2003 *Commission's Report on European Governance* highlighted the necessity for shared responsibility in achieving a new governance model characterised by openness, participation, accountability, effectiveness, and coherence. The outcome document of the 1992 UN Conference on Environment and Development, Sustainable Development—Agenda 21 encouraged the "active involvement of non-governmental organisations and other groups" (UN 1992, paragraph 1.3).

Shulla et al. (2020) argue, drawing on Sachs (2012), that a networked problem-solving approach involving all actors, especially young people, is necessary rather than a top-down strategy. This approach aligns with SDG 16, which focuses on "Promoting just, peaceful, and inclusive societies."

Despite the undisputed significance of proper governance, including citizen participation, for accomplishing the SDGs, designing effective mechanisms to launch and carry out the required transformations is a complex, multi-scale, and multi-actor process with numerous knowledge gaps (Allen et al. 2023). Furthermore, many initiatives promoting citizen participation fall short, partly because of distrust and frustration arising from the lack of tangible outcomes and accountability.

In this context, along with the continuous development of communication technologies, collective intelligence seems an optimal approach to address these collective challenges. However, its potential remains untapped, particularly in environmental decision-making (Vercammen and Burgman 2019). In fact, there are hardly any references on collective intelligence methodologies to address decision-making and/or proposal development in the context of SDGs. Some cases are found, for example, in the field of sustainable innovation (Erbguth et al. 2022; Wang et al. 2018), geographic knowledge systems (Laurini 2021), or social economy (Miedes-Ugarte, Flores-Ruiz and Wanner 2020).

OBJECTIVE OF THIS PAPER

In this paper, we investigate whether it is possible to use collective intelligence to generate solutions to the challenges associated with the SDGs, and, simultaneously, to create or strengthen the necessary governance mechanisms. We explore the methodology used in a massive online collective intelligence experiment, which includes the use of the Thinkhub platform (https://ic.kampal.com/). We are also interested in deepening our understanding of the effectiveness of collective intelligence under specific situations.

The structure of the article is as follows: First, we provide an introduction to the foundations of collective intelligence, as well as an explanation of its potential to address SDGs and governance issues; second, we describe the experiment methodology; next, we detail the experiment results; and finally, we present the discussion, conclusions, and future work.

BACKGROUND: COLLECTIVE INTELLIGENCE FOUNDATIONS AND ITS POTENTIAL TO ADDRESS SDGS

COLLECTIVE INTELLIGENCE FOUNDATIONS

The concept of collective intelligence has been a polysemic expression since it was coined by Kropotkin in *Mutual Support: A Factor in Evolution*, a work that introduced in biology the importance of cooperation as a factor in survival (Kropotkin 2016). Currently, the notion is also used in other fields such as anthropology, social psychology, literature, management, political studies, and the relationship of human beings with technology. The concept is unstable and polysemic; some examples of its diverse meanings are the following: the capacity for decision-making in democratic spaces (Atlee 2002), a new form of production of knowledge and its value embedded in cyberculture (Lévy 2002; Mazzone 2019), and the properties of highly organised gregarious species to form superorganisms, from bees to human beings (Bert and Wilson 2014; Toca Torres 2014; Wheeler 1926). These meanings have in common that they always slide around the ideas of group, coordination and self-organisation, and a higher cognitive capacity as emergent results of this interaction.

In a similar vein to what Bloom (2000) called group IQ, researchers at Carnegie Mellon University and the Massachusetts Institute of Technology (MIT) operationalized in 2010 the concept of collective intelligence as the better or worse performance of a group of people interacting with each other for the resolution of different tasks (Woolley, Aggarwal, and Malone 2015). This work opened a field to study the capacity that human groups or sociotechnical systems have to act more intelligently than the most intelligent individual in the group would. In an experimental investigation, they assigned the groups they worked with, which had to solve a particular set of tasks, a metric called the c-factor. This metric represents the ability with which they executed different challenges (Woolley et al. 2010). Similar to the g factor of individual IQ (Brand 1996), the c-factor allows the intelligence of a group of people to be measured beyond the specific task assigned and can be used to estimate the ability of that group to solve future tasks.

In the pursuit of improving and understanding how collective intelligence works, two streams of analysis have emerged (Woolley and Aggarwal 2020). The first one focuses on the individual abilities of participants and their influence on the resulting collective outcomes. The second stream examines how the interaction processes taking place within the activity itself influence the resulting collective outcomes. In these individual problem-solving interactions, the specific traits of the social situation created impact the generation of various responses.

In these situations, striking a balance between the tendency for herd mentality and individual isolation is crucial (Toyokawa et al. 2019). Too much of the former can hinder creativity, while excessive dispersion can limit interaction and prevent reaching a consensus. Channels that enhance social influence among participants raise the average quality of responses but may suppress the most successful possibilities. Bernstein et al. (2018) suggest that intermittent influence is the most effective approach. In general, various behaviours such as creativity, leadership, followership, cooperation, coordination, discussion, agreement-seeking, or overcoming challenges are observed. These behaviours largely depend on the rules and participation methods established by the researchers.

Collective intelligence with large online groups is still a relatively new methodology, with few studies available. However, some researchers have highlighted the significance of group size (Toyokawa et al. 2019). Experiments involving face-to-face interactions typically focus on groups of two to five people, without leveraging the online potential for multi-group coordination (Engel et al. 2014).

In the only large-scale online study we found, conducted by Toyokawa et al. (similar to the experiment we present), there is no moderator or facilitator, and participant interaction is limited. Toyokawa and colleagues distinguish between two behavioural approaches: the herd effect, characterised by a high level of replication and suboptimal response effectiveness, and a phenomenon representing crowd intelligence, an optimal response rate that surpasses the simple sum of unrelated individuals.

COLLECTIVE INTELLIGENCE AND CITIZEN SCIENCE TO ADDRESS SUSTAINABLE DEVELOPMENT GOALS AND GOVERNANCE ISSUES

Technological and sociopolitical strategies need to be developed to promote interrelation, interdependence, and communication in collective action; examples of such strategies are found in citizen science, such as various platforms and networks, shared resources, citizen laboratories, etc. (Pelacho et al. 2021). Collective intelligence, as an emergent result of human interaction, is closely linked to certain methodologies of citizen science (Lukyanenko et al. 2020). This connection is evident in research areas such as astronomy (Cedazo et al. 2020), rare diseases (Radu et al. 2021), and "wicked problems" (Schoder et al. 2014), among others. In citizen science practices, participants can act as information gatherers, analysts, knowledge creators, or decision-makers (Shirk et al. 2012). Consequently, citizen science is recognized as a valuable approach for addressing sustainability challenges and contributing to the implementation of the SDGs (e.g., Fraisl et al. 2020; Shulla et al. 2020; Turbé et al. 2019). Specifically, in terms of governance, Turbé et al. (2019) demonstrate, through the analysis of 503 European environmental projects, how citizen science can contribute to each step of the policy process.

Collective intelligence, through its openness to decisions traditionally reserved for experts and its interaction with science, shows promise for addressing "grand challenges" like those identified in the SDGs (Elia and Margherita 2018), particularly those related to sustainability, which require transformations in production, relationships, and consumption (Atlee 2017). Engaging in collective debate can help translate abstract concepts such as climate change into practical agreements and transformations of everyday actions, integrating learnings and involving the wider population (Piccolo et al. 2018). Moreover, online interconnectivity allows collective intelligence to expand, connecting hundreds or thousands of individuals in what has been termed "the wisdom of the crowd" (Bigham et al. 2018; Lévy 2002; Surowiecki 2005).

Collective intelligence can be understood as a set of practices for collaborative decision-making or proposal development, as well as a product of group decision-making. These practices can serve as a methodology within citizen science and participatory processes, as they enhance the information utilised in decision-making and situate it within a context and relationship with specific knowledge. By defining collective intelligence as a group's ability to address various challenges, it becomes a measure of a community's capacity to implement and address the SDGs (Woolley et al. 2010). Achieving the right balance between group cohesiveness and individual interests, as well as the process's ability to generate original responses, is crucial for implementing localised and concrete solutions related to the SDGs.

METHODOLOGY OF THE EXPERIMENT

Drawing upon the key concepts described in the previous section, we designed an experiment that focused on interaction processes in collective intelligence, the balance between group cohesion and individual interests, and the connection between citizen science and collective intelligence.

The ThinkHub platform facilitates the interaction processes in collective intelligence by providing a virtual environment in which thousands of participants can collaborate, share ideas, and solve problems collectively. Each participant is virtually linked to four other participants, each of them connected to three additional, distinct individuals. It allows users to exchange information and build upon each other's contributions in real time. By providing a controlled environment for observing and analysing these interactions, this platform allows researchers to gain valuable insights into the delicate balance between group cohesion and individual interests in collective intelligence settings, ultimately contributing to a better understanding of how to harness the potential of collective intelligence for problem-solving and decision-making. This platform was developed through a collaborative effort between Kampal and researchers from the Institute for Biocomputing and Complex Systems Physics (BIFI) at the University of Zaragoza.

The experiment took place during the 2019 Climate Summit (COP25), an annual event addressing pressing environmental issues and challenges with representatives from approximately 200 countries. It presented two challenges related to the SDGs, seeking collaborative and collective solutions for five urgent and priority actions concerning SDG 6, Clean Water and Sanitation, which aims to "Ensure availability and sustainable management of water and sanitation for all," and SDG 13, Climate Action, which aims to "Take urgent action to combat climate change and its impacts."

ENGAGEMENT AND EXECUTION

The experiment began on December 4, 2019, with the interactive phases occurring on December 10, 2019. It involved 1,253 students aged 15 to 17 from 68 secondary schools across 13 Spanish autonomous regions. A group of students from Madrid participated in the experiment in person at the COP25 venue.

To prepare for the experiment and to reach potential participants, Ibercivis issued an open call. Additionally, secondary schools from all Spanish autonomous regions were contacted, leveraging existing relationships from previous projects with Ibercivis. Interested teachers could register their classrooms using a distributed form, which collected their personal information for communication purposes during the experiment's organisation. The form contained all relevant information about the current legislation in force in Europe, which is Regulation (EU) 2016/679 (General Data Protection Regulation), and the associated rights. Teachers were required to provide explicit informed consent before submitting their personal information through the form.

Each participating school managed the internal logistics required for the experiment. Schools incorporated the experiment into their activities by obtaining necessary permissions from parents or legal guardians. Participation was voluntary and entirely anonymous, with no collection of students' personal data.

EXPERIMENT DESCRIPTION

The experiment begins by outlining a challenge that needs to be collectively resolved. The challenge is presented through the following text:

> *Faced with the great global challenges for the coming years, the UN has succeeded in getting governments around the world to establish a series of common goals to improve the lives of all the inhabitants of the planet. These goals were established in 2015 and have on the horizon the year 2030 to achieve significant progress in each of them. The 2030 Sustainable Development Goals are 17 challenges, each of which has concrete, common and global goals for all countries in the world. Most of the world's governments, many companies, associations, etc. are adopting their agendas, priorities, budgets, etc. to these goals. In this project about 2000 young people build and propose in a collaborative and collective way, the 5 measures that they consider urgent and priority for two of these goals;*
>
> *SDG6: Clean water and sanitation.*
>
> *SDG13: Climate action.*
>
> *For each of them you must propose your 5 measures or proposals.*

Table 1 shows the consecutive phases along the experiment. In Phase 1, which began on December 4, students individually brainstormed and presented their five proposals for each SDG. By Phase 2, on December 10, they could view each other's responses. During Phases 3 and 4, students were able to copy one or all of their peers' proposals, modify their own, or keep them unchanged. Consequently, the level of interaction within the network increased over time, as transformed proposals emerged from observing previously inaccessible contributions. In Phase 5, the platform identified the 10 most copied proposals ("TOP 10"). Participants then had to choose between these proposals or maintain or modify one of their own. In Phase 6, they could no longer edit their submissions but could only replace them with one from the TOP 10. Lastly, Phase 7 revealed the five most copied entries, that is, the "best solutions," for each challenge. As seen in these final three phases, a concentration process unfolds, driving the selection of the best proposals.

HOW RESULTS ARE EVALUATED

To evaluate the collective intelligence generated in the process, we used three indicators, which can be seen in Table 2.

In this paper, we examine the effectiveness and outcomes of collective intelligence, through the analysis of interaction processes and the study of the balance between group cohesion and individual interest. Our experimental design enables us to assess three key dimensions of collective intelligence within a group in a given context.

First, we analyse the balance between individuality and the herd effect to evaluate the potential for generating innovative solutions to the SDGs. The herd effect is characterised by a high degree of participants following and accepting others' responses, while strong individuality suggests that participants are unwilling to accept the ideas of others. Second, we investigate the origin of the responses, determining whether they stem from advanced interactions between participants or individual thought processes. Lastly, we explore the extent to which the online method enables the generation of responses that exhibit high levels of agreement and broad dissemination within the network.

EXPERIMENT RESULTS

In Tables 3 and 4, we present the dynamics of proposal evolution throughout the different phases. These tables summarise the evolution of the three key metrics, defined in the previous section.

In Tables 3 and 4 and Figures 1 and 2, we illustrate the progression of the number of copies and original proposals throughout the phases. Overall, the number of copied proposals is less than half of those created by users, indicating a strong tendency to either maintain initial proposals or modify one's own instead of directly adopting others' ideas.

The initial copies observed in Phase 1 at 10:30 a.m. on day 10 can be attributed to participants independently

PHASE	EDIT	WHAT CAN BE SEEN	COPY	STARTED
Phase 1	Yes	Your own solution (YoS)	No	2019-12-04 20:52:17
Phase 2	Yes	YoS	No	2019-12-10 10:45:17
Phase 3	Yes	YoS	Yes	2019-12-10 10:53:17
Phase 4	Yes	YoS	Yes	2019-12-10 11:01:22
Phase 5	Yes	YoS + Top10	Yes	2019-12-10 11:14:04
Phase 6	No	YoS + Top10	Yes	2019-12-10 11:21:04
Phase 7	No	YoS + BestSolution	Yes	2019-12-10 11:31:04
END	–	–	–	2019-12-10 11:41:04

Table 1 Phase summary.

INDICATOR	DESCRIPTION
Degree of copying versus isolation	The extent to which participants opted to either create unique responses or follow the herd effect by copying the responses of others. It is defined as the number of copied proposals divided by the number of original proposals.
Amendment of response	Collective intelligence entails generating answers through collaborative interaction. It is defined as the number of proposals created in a concrete phase that reach the end of the experiment.
Final degree of agreement	Number of copies for the most shared answers (best 5), which helped us determine the network's degree of clustering, or the final level of consensus among the participants.

Table 2 Indicators for result evaluation.

SDG 6	DEGREE OF COPY/ISOLATION	AMENDMENT OF RESPONSE	FINAL DEGREE OF AGREEMENT
Phase 1	0.09	2860	–
Phase 2	0.145	122	–
Phase 3	0.275	326	–
Phase 4	0.326	331	–
Phase 5	0.359	143	–
Phase 6	0.342	327	–
Phase 7	0.341	78	102

Table 3 Evaluation of the Sustainable Development Goal (SDG) 6 experiment.

SDG 13	DEGREE OF COPY/ISOLATION	AMENDMENT OF RESPONSE	FINAL DEGREE OF AGREEMENT
Phase 1	0.09	2959	–
Phase 2	0.138	137	–
Phase 3	0.252	399	–
Phase 4	0.303	311	–
Phase 5	0.344	94	–
Phase 6	0.330	358	–
Phase 7	0.327	35	110

Table 4 Evaluation of the Sustainable Development Goal (SDG) 13 experiment.

generating proposals with identical textual content. The platform saves these as the same proposal, appearing as if two different users copied them. A significant copying tendency only emerges in Phases 2 and 3, and to a lesser extent in Phase 4 for SDG 13. Ultimately, copy-to-original response ratios of 0.341 and 0.327 are attained for each SDG, respectively. Furthermore, there is a steady increase in original proposals, suggesting that even during more advanced phases, participants still prefer creating their own items over copying those of others.

Figure 3 captures the experiment at 12:20 a.m., just before entering Phase 6. Each node symbolises a student, and a link between two nodes indicates that the corresponding students shared a proposal. The figure reveals that numerous participants are either isolated or connected to only one other node, suggesting that they have either made a single copy or had their proposal copied once.

As shown in Tables 3 and 4 (column 2), the majority of the final proposals originated in Phase 1. This suggests that participants were more inclined to retain their own items rather than adopt those proposed by others, displaying a certain stubbornness in defending their proposals. Together with the low copying rate, this highlights a pattern of interaction in which most users preferred not to alter their items or select others' items.

The final indication of this low-interaction pattern is the frequency of the most popular items, seen in the third column of Tables 3 and 4. The number of people copying any of the top 5 final answers is 102 and 110, respectively,

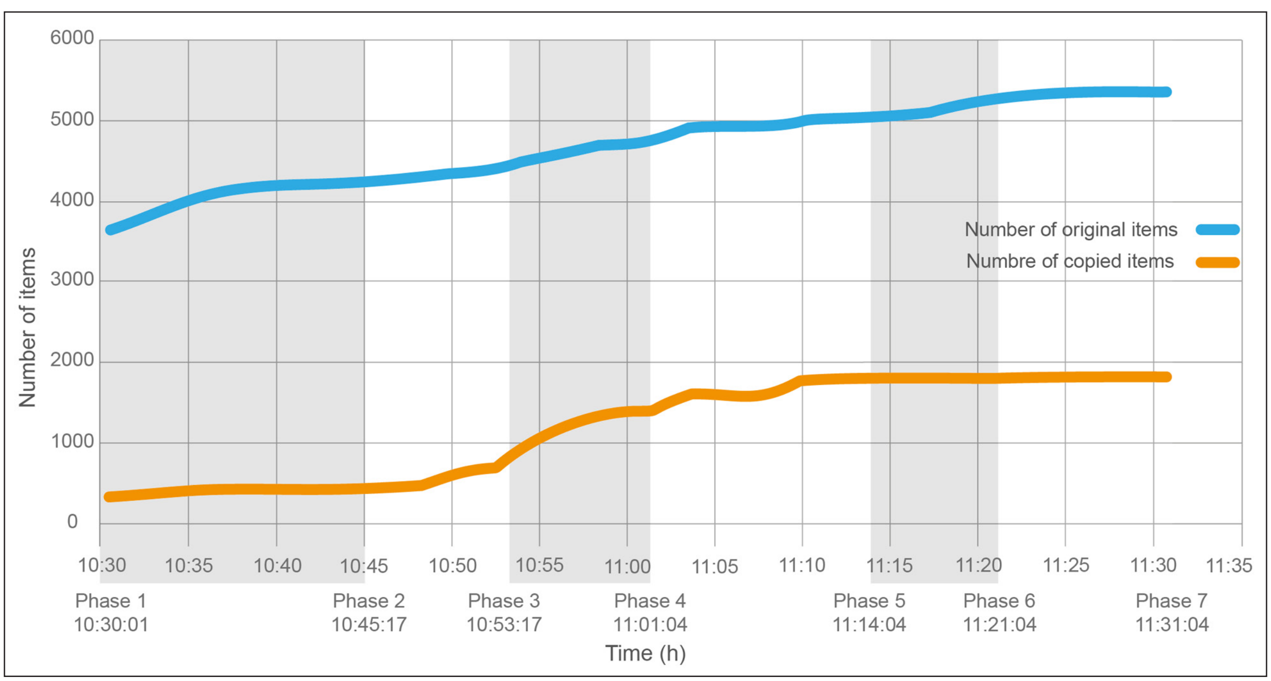

Figure 1 Number of original and copy items for Sustainable Development Goal (SDG) 6, Clean Water and Sanitation. The graph shows the evolution of the system since 10:30 a.m. on December 10th.

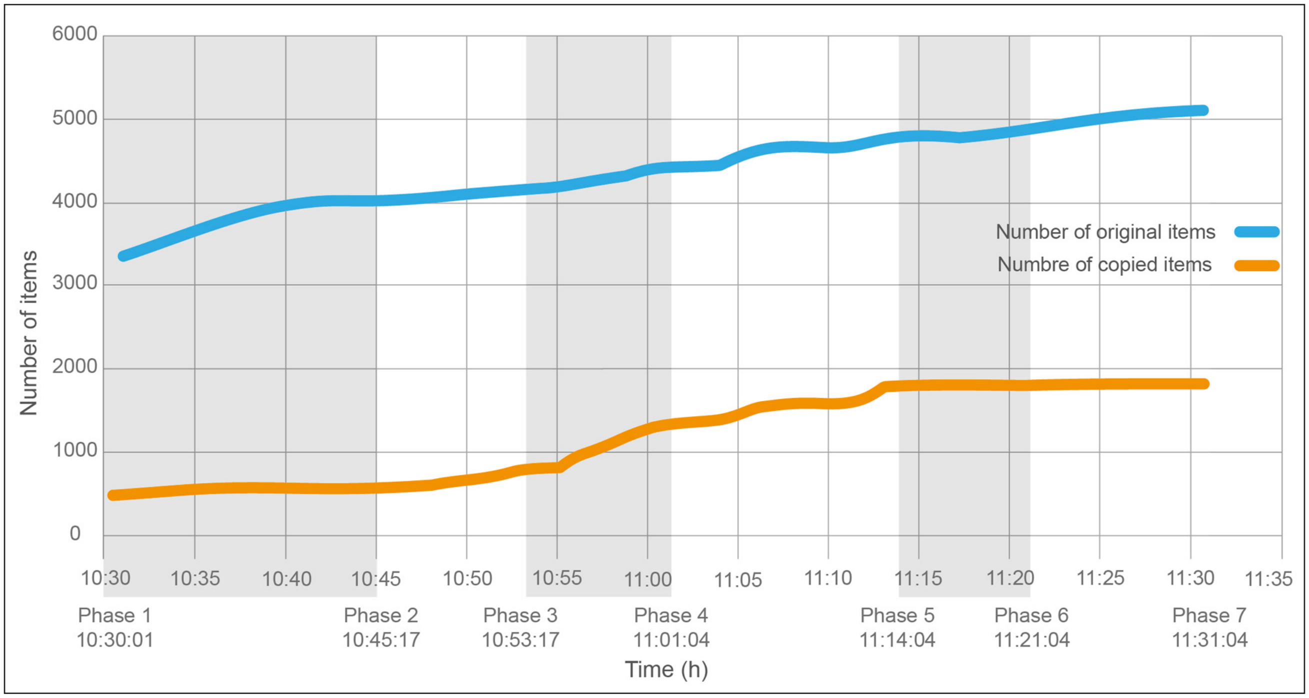

Figure 2 Number of original and copy items for Sustainablel Development Goal (SDG) 13, Climate Action. The graph shows the evolution of the system since 10:30 a.m. on December 10th.

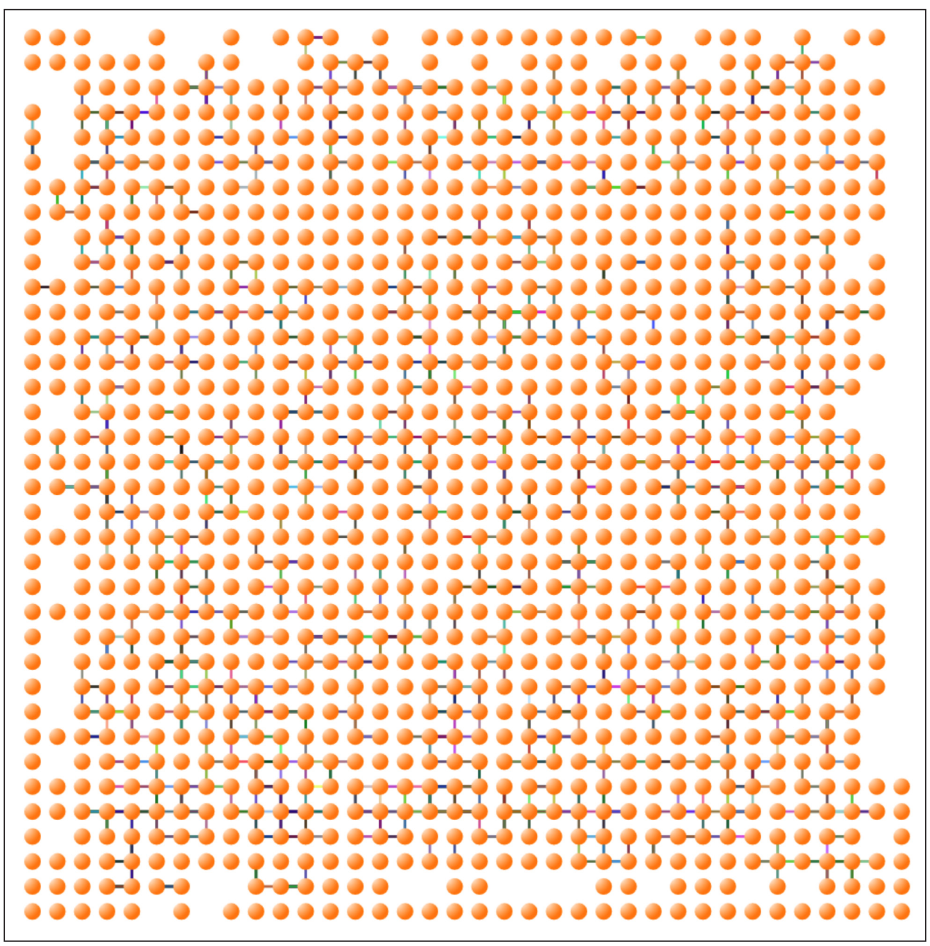

Figure 3 Experiment copy network.

POSITION	PROPOSAL TEXT	# OF COPIES
1	Create more wells for the common good, well covered but also very useful, so that people would have more water to wash themselves and also for their consumption	23
2	Stricter laws banning polluting products such as agricultural chemicals, pesticides, wet wipes...	22
3	Increase of desalination plants, with this objective we will be able to make water that is not so clean much more useful, above all for the use	20
4	Avoiding deforestation	19
5	To make people aware of how important clean water is in their lives, without it they could not live and since people waste it, if we can raise awareness among those people who rely on wasting it and not putting it to very good use, this could be a great progress for humanity.	18

Table 5 Most copied proposals for Sustainable Development Goal (SDG) 6, Clean Water and Sanitation.

POSITION	PROPOSAL TEXT	# OF COPIES
1	Save energy	29
2	The diet? Low CO_2	21
2	Acts against forest loss	21
3	Recycle	20
4	Reduce plastic consumption	19

Table 6 Most copied items for Sustainable Development Goal (SDG) 13, Climate Action.

accounting for just under a tenth of the participants. This reveals that no distinct discourse clusters or positions championed by large portions of the network were established. Tables 5 and 6 present the text of the 5 most copied answers at the experiment's conclusion.

Raw data of the experiment is published on Zenodo under Creative Commons Attribution 4.0 International licence, DOI https://doi.org/10.5281/zenodo.7673917.

DISCUSSION

As global challenges, the SDGs require tools and methodologies that enable mass participation, while recognizing the value of each individual's contribution. To achieve this, it is essential to develop networked, participatory, or community-based governance styles that capitalise on both situated knowledge and the "wisdom of the crowd" (Bigham et al. 2018; Han, Ozturk and Nickerson 2020; Lévy 2002; Surowiecki 2005).

OBSERVED INTERACTION PROCESSES

Our experiment demonstrates the viability and usefulness of collective intelligence and open decision-making processes in tackling "grand challenges" (Elia and Margherita 2018). Utilising the ThinkHub platform, we observed extensive online collaboration involving numerous participants, which generated collective intelligence dynamics and led to the successful creation and prioritisation of solutions.

However, our results reveal that the interaction among participants was not as high as initially anticipated. There was relative isolation, low sharing frequency, and a reluctance to alter or transform initial responses. Participants' opinions remained mostly unchanged throughout the experiment's phases. Additionally, in the case of SDG 13, the development of the final responses did not achieve the desired level of elaboration.

A deeper investigation is required to understand the questions arising during the solution-generation process, and how they are influenced by the specific configuration of the tool and methodology. Additionally, we believe it would be useful to examine the interactions between participants in a collective intelligence process, and identify variables that impact the process and the outcome in terms of individualization, herd effect, the level of collective work in creating final answers, and the degree of agreement.

OBSERVED BALANCE BETWEEN GROUP COHESION AND INDIVIDUAL INTEREST

The experimental design itself presents a conflict between enhancing individual contributions and disseminating collective responses. When a participant alters their response to improve it, they create a new idea that must start from scratch and compete with already established proposals. Interestingly, most final answers were generated in the initial phases, showing a certain stubbornness to modify and improve one's own responses. This outcome allows us to pinpoint two distinct variables necessary for collective intelligence among large groups, further elaborating on Toyokawa et al.'s (2019) distinction between herd and isolated behaviour. These variables include the generation of collective responses through interaction and the diffusion of these responses within groups, thus creating subsets of participants supporting a specific idea (Figure 4).

We can regard these two approaches to idea generation as orthogonal. For instance, when individually conceived responses are spread across the network or when each individual generates their response from interaction, leading to fewer instances of copying but responses created in later phases. However, these variables are interconnected and positively impact one another.

PROPOSED PROCESS IMPROVEMENTS

In order to address the challenges faced in the experiment and enhance the collective intelligence methodology for tackling SDG-related issues, we propose the following measures. First, proposals could be streamlined by enforcing copying, periodically removing low-diffusion proposals, and strengthening the idea selection system. Providing participants with information on the number of copies each item has may further incentivize choosing popular ones, promoting centralization. Gamification techniques could boost participation. Additionally, controlling or eliminating "trolls" or users who submit unrelated proposals can prevent distortion of the process.

Second, it would be worth exploring other features to increase interaction during the experiment. Identifying questions and issues that more directly affect participants and even generating positions that force a choice between alternatives could be beneficial.

Improving the process may be achieved by separating the construction of collective solutions from their dissemination and discussion. For instance, an initial stage could involve producing the main answers (e.g., reaching best 5 answers through various dynamics) where answers must be mutually exclusive or at least require preference. In a subsequent stage, participants could choose an answer and provide a short supporting argument, which could then be copied, transformed, or maintained. This approach enables participants to change their position based on arguments, which may or may not spread across the network, fostering genuine discursive poles (Conde 2009). Interactions can be further developed between arguments by refining, merging, or selecting those that fail to convince. Thus, the dynamics would revolve around both answers and arguments, fostering interaction and collective intelligence.

Furthermore, broadening participation offers diverse decision-making processes and facilitates the transfer and approximation of abstract concepts (Piccolo et al. 2018), particularly those related to environmental and climate change issues. Problems and solutions can be made more concrete and connected to everyday actions.

CONCLUSIONS

Our study demonstrates that using collective intelligence has the potential to generate and prioritise innovative solutions to challenges associated with the SDGs, while simultaneously creating and strengthening necessary governance mechanisms. The active involvement of participants, including students, teachers, and institutions,

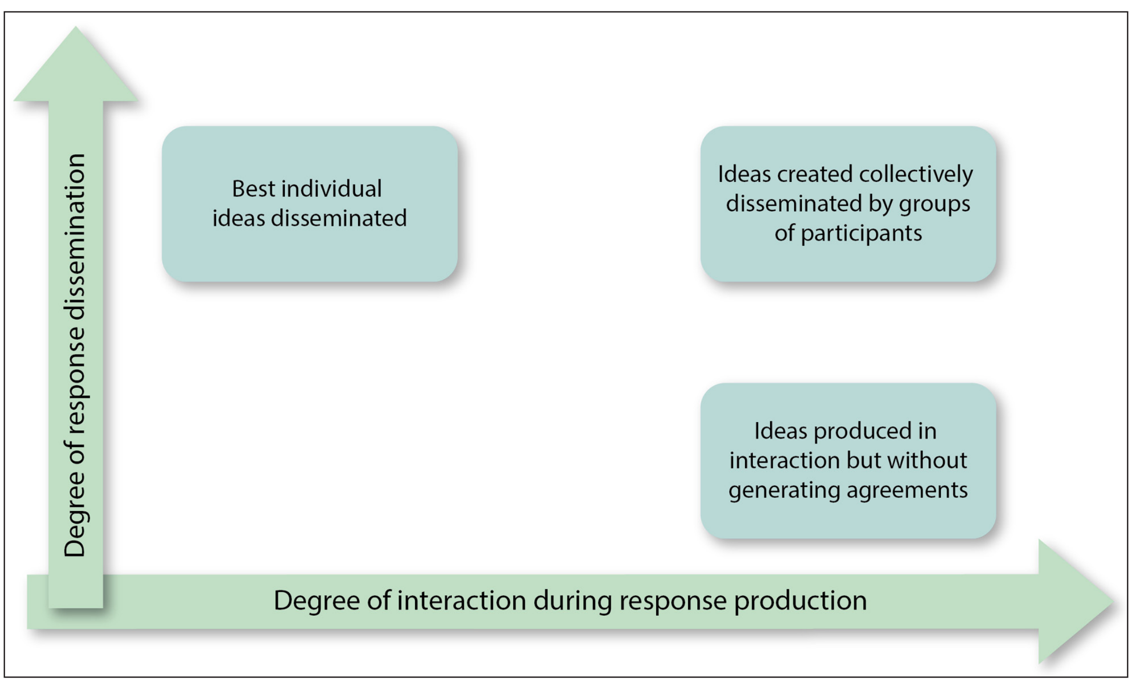

Figure 4 Dimensions in the responses of a massive collective intelligence experiment.

supports the notion that harnessing diverse perspectives can lead to more effective problem-solving.

Additionally, by incorporating various functionalities and methodologies, such as interactive platforms, gamification techniques, and fostering open debate, we can further enhance the collective intelligence process. The improvement of interaction dynamics and the incorporation of argument-based discussions can lead to a more robust decision-making process that better addresses the complexities of SDG-related challenges.

Lastly, the integration of collective intelligence in educational settings not only contributes to the generation of solutions but also encourages the development of critical thinking and collaborative skills among students. This, in turn, contributes to the overall effectiveness of governance mechanisms within educational institutions.

Overall, our findings suggest that employing collective intelligence as a tool for addressing the SDGs holds promise for generating solutions and strengthening governance mechanisms, ultimately paving the way for more sustainable and equitable global development.

However, this article does not delve into two potential lines, which could be recommended for future research. Firstly, the influence of participants' sociodemographic characteristics on their perspectives of the SDGs could be explored. By examining factors such as age, gender, and educational background, it would be possible to identify differentiated responses or behaviours within the collective intelligence process. This is crucial for generating inclusive solutions that consider the needs of various communities, including minority groups that might be otherwise excluded from the decision-making process. Secondly, a semantic analysis could be conducted to assess the quality and complexity of the responses in relation to the SDG objectives. By examining a sample of responses stratified by phase or degree of diffusion and employing intercoding techniques among multiple researchers, we could determine whether there is an improvement in response quality over time or among the most shared ideas. This analysis could provide valuable insights into the effectiveness of the collective intelligence process in addressing the complex challenges associated with the SDGs.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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REFERENCES

Allen, C, Malekpour, S and **Mintrom, M.** 2023. Cross-scale, cross-level and multi-actor governance of transformations toward the Sustainable Development Goals: A review of common challenges and solutions. *Sustainable Development sd.2495*. DOI: https://doi.org/10.1002/sd.2495

Atlee, T. 2002. *The Tao of Democracy: Using Co-Intelligence to Create a World that Works for All*. BookSurge Publishing.

Atlee, T. 2017. Public wisdom: the key to sustainability. In: Hartz-Karp, J and Marinova, D (eds.), *Methods for Sustainability Research*. Cheltenham, UK: Edward Elgar Publishing. pp. 292–306. DOI: https://doi.org/10.4337/9781786432735.00031

Bernstein, E, Shore, J and **Lazer, D.** 2018. How intermittent breaks in interaction improve. *Proceedings of the National Academy of Sciences of the United States*, 35: 8734–8739. DOI: https://doi.org/10.1073/pnas.1802407115

Bert, H and **Wilson, EO.** 2014. *El superorganismo: Belleza y elegancia de las asombrosas sociedades de insectos*. Madrid: Katz.

Bigham, JP, Bernstein, MS and **Adar, E.** 2018. Human-computer interaction and collective intelligence. In: Malone, TW and Bernstein, MS (eds.), *Handbook of Collective Intelligence*. The MIT Press. pp. 57–83. DOI: https://doi.org/10.1184/R1/6470123.v1

Bloom, H. 2000. *Global Brain: The Evolution of Mass Mind from the Big Bang to the 21st Century*. John Wiley & Sons Inc.

Brand, C. 1996. *The g Factor*. Chichester, UK: Wiley.

Cedazo, R, Gonzalez, E, Serra-Ricart, M and **Brunete, A.** 2020. Improving the results of citizen science projects through reputation systems: The case of Wolf's Number Experiment. *IEEE Access*, 8: 186026–186038. DOI: https://doi.org/10.1109/ACCESS.2020.3030006

Conde, F. 2009. *Análisis sociológico del Sistema de discursos*. Madrid: CIS.

Elia, G and **Margherita, A.** 2018. Can we solve wicked problems? A conceptual framework and a collective intelligence system to support problem analysis and solution design for complex social issues. *Technological Forecasting and Social Change*, 133. DOI: https://doi.org/10.1016/j.techfore.2018.03.010

Engel, D, Woolley, AW, Jing, LX, Chabris, CF and **Malone, TW.** 2014. Reading the mind in the eyes or reading between the lines? Theory of mind predicts collective intelligence equally well online and face-to-face. *PloS ONE*, 9(12): e115212. DOI: https://doi.org/10.1371/journal.pone.0115212

Erbguth, J, Schorling, M and **Morin, JH.** 2022. Co-creating innovation for sustainability. *Gruppe. Interaktion. Organisation. Zeitschrift für Angewandte Organisationspsychologie (GIO)*, 53(1): 83–97. DOI: https://doi.org/10.1007/s11612-022-00619-8

European Commission. 2003. *Report from the Commission on European Governance*. Luxembourg: Office for Official Publications of the European Communities. https://ec.europa.eu/governance/docs/comm_rapport_en.pdf [Last accessed 3 02 2023].

Florini, A and **Pauli, M.** 2018. Collaborative governance for the Sustainable Development Goals. *Asia & the Pacific Policy Studies*, 5: 583–598. DOI: https://doi.org/10.1002/app5.252

Fraisl, D, Campbell, J, See, L, Wehn, U, Wardlaw, J, Gold, M., Moorthy, I, Arias, R, Piera, J, Oliver, JL, Masó, J, Penkerand, M and **Fritz, S.** 2020. Mapping citizen science contributions to the UN sustainable development goals. *Sustainability Science*, 15(6): 1735–1751. DOI: https://doi.org/10.1007/s11625-020-00833-7

Han, Y, Ozturk, P and **Nickerson, JV.** 2020. Leveraging the Wisdom of the Crowd to Address Societal Challenges: Revisiting the Knowledge Reuse for Innovation Process through Analytics. *Journal of the Association for Information Systems*, 21(5): 1128–1152. DOI: https://doi.org/10.17705/1jais.00632

Kropotkin, P. 2016. *El apoyo mutuo: un factor en la evolución*. Logroño, Spain: Pepitas de calabaza.

Laurini, R. 2021. A primer of knowledge management for smart city governance. *Land Use Policy*, 111. DOI: https://doi.org/10.1016/j.landusepol.2020.104832

Lévy, P. 2002. *L'intelligenza collettiva. Per un'antropologia del cyberspazio*. Milano: Feltrinelli.

Lukyanenko, R, Wiggins, A and **Rosser, HK.** 2020. Citizen Science: An Information Quality Research Frontier. *Information Systems Frontiers*, 22: 961–983. DOI: https://doi.org/10.1007/s10796-019-09915-z

Mazzone, S. 2019. Saber social, inteligencia colectiva, cibercultura y enseñanza: una hipótesis postestructuralista. *Tabanque: Revista pedagógica*, 32: 71–79. DOI: https://doi.org/10.24197/trp.0.2019.71-79

Meuleman, L and **Niestro, I.** 2015. Common But Differentiated Governance: A Metagovernance Approach to Make the SDGs Work. *Sustainability*, 7: 12295–321. DOI: https://doi.org/10.3390/su70912295

Miedes-Ugarte, B, Flores-Ruiz, D and **Wanner, P.** 2020. Managing Tourist Destinations According to the Principles of the Social Economy: The Case of the *Les Oiseaux de Passage* Cooperative Platform. *Sustainability*, 12(12): 4837. DOI: https://doi.org/10.3390/su12124837

Pelacho, M, Rodríguez, H, Broncano, F, Kubus, R, Sanz, F, Gavete, B and **Lafuente, A.** 2021. Science as a Commons: Improving the Governance of Knowledge Through Citizen Science. In: Vohland, K, et al. (eds.), *The Science of Citizen Science*. Cham: Springer. DOI: https://doi.org/10.1007/978-3-030-58278-4_4

Piccolo, LSG, De Liddo, A, Burel, G, Fernández, M and **Alani, H.** 2018. Collective intelligence for promoting changes in behaviour: a case study on energy conservation. *AI & Society*, 33(1): 15–25. DOI: https://doi.org/10.1007/s00146-017-0710-y

Radu, R, Hernández-Ortega, S, Borrega, O, Palmeri, A, Athanasiou, D, Brooke, N, Chapí, I, Le Corvec, A, Guglieri, M, Perera-Lluna, A, Garrido-Aguirre, J, Ryll, B and **Nafria Escalera, B.** 2021. Global collaborative social network (Share4Rare) to promote citizen science in rare disease research: platform development study. *JMIR Formative Research*, 5(3): e22695. DOI: https://doi.org/10.2196/22695

Sachs, J. 2012. From Millennium Development Goals to Sustainable Development Goals. *The Lancet*, 379(9832): 2206–2211. DOI: https://doi.org/10.1016/S0140-6736(12)60685-0

Schoder, D, Putzke, J, Metaxas, PT, Gloor, PA and **Fischbach, K.** 2014. Information Systems for "Wicked Problems" Research at the Intersection of Social Media and Collective Intelligence. *Wirtschaftsinformatik*, 56: 3–11. DOI: https://doi.org/10.1007/s11576-013-0395-x

Shirk, JL, Ballard, HL, Wilderman, CC, Phillips, T, Wiggins, A, Jordan, A, McCallie, E, Minarchek, M, Lewenstein, BL, Krasny, ME and **Bonney, R.** 2012. Public participation in scientific research: a framework for deliberate design.

Ecology and Society, 17(2): 29. DOI: https://doi.org/10.5751/ES-04705-170229

Shulla, K, Leal Filho, W, Sommer, JH, Lange Salvia, A and **Borgemeister, C.** 2020. Channels of collaboration for citizen science and the sustainable development goals. *Journal of Cleaner Production*, 264. DOI: https://doi.org/10.1016/j.jclepro.2020.121735

Surowiecki, J. 2005. *The wisdom of crowds*. New York: Anchor.

Toca Torres, CE. 2014. Inteligencia colectiva: enfoque para el análisis de redes. (Swarm intelligence: approach to the analysis of networks). *Estudios Gerenciales*, 30(132): 259–266. DOI: https://doi.org/10.1016/j.estger.2014.01.014

Toyokawa, W, Whalen, A and **Laland, KN.** 2019. Social learning strategies regulate the wisdom and madness of interactive crowds. *Nature Human Behaviour*, 3: 183–193. DOI: https://doi.org/10.1038/s41562-018-0518-x

Turbé, A, Barba, J, Pelacho, M, Mugdal, S, Robinson, LD, Serrano-Sanz, F, Sanz, F, Tsinaraki, C, Rubio, JM and **Schade, S.** 2019. Understanding the Citizen Science Landscape for European Environmental Policy: An Assessment and Recommendations. *Citizen Science: Theory and Practice*, 4(1): 34. DOI: https://doi.org/10.5334/cstp.239

United Nations. 1992. United Nations Conference on Environment & Development. Sustainable Development, AGENDA 21. Available at: https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf (Last accessed 27 02 2023).

Vercammen, A and **Burgman, M.** 2019. Untapped potential of collective intelligence in conservation and environmental decision making. *Conservation Biology*, 33(6): 1247–1255. DOI: https://doi.org/10.1111/cobi.13335

Wang, G, Hu, Y, Tian, X, Geng, J, Hu, G and **Zhang, M.** 2018. An Integrated Open Approach to Capturing Systematic Knowledge for Manufacturing Process Innovation Based on Collective Intelligence. *Applied Sciences*, 8(3): 340. DOI: https://doi.org/10.3390/app8030340

Wheeler, WM. 1926. Emergent evolution and the social. *Science*, 64(1662): 433–440. DOI: https://doi.org/10.1126/science.64.1662.433

Woolley, AW and **Aggarwal, I.** 2020. *Collective intelligence and group learning*. In: Argote, L and Levine, JM (eds.), *The Oxford Handbook of Group and Organizational Learning*. Oxford Library of Psychology. Oxford: Oxford University Press. pp. 491–504. DOI: https://doi.org/10.1093/oxfordhb/9780190263362.013.46

Woolley, AW, Aggarwal, I and **Malone, TW.** 2015. Collective Intelligence and Group Performance. *Psychological Science*, 24(6): 420–424. DOI: https://doi.org/10.1177/0963721415599543

Woolley, AW, Chabris, CF, Pentland, A, Hashmi, N, and **Malone, TW.** 2010. Evidence for a collective intelligence factor in the performance of human groups. *Science (New York, N.Y.)*, 330(6004): 686–688. DOI: https://doi.org/10.1126/science.1193147

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