Integrated, Coordinated, Open, and Networked (ICON) Scientific and Societal Relevance

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November 26, 2022

Abstract

This article is composed of three independent commentaries about the state of ICON principles (Goldman et al. 2021) in Science and Society section and discussion on the opportunities and challenges of adopting them. Each commentary focuses on a different topic: Citizen Science; Collaboration across Sciences; and Education Policy. Scientific discoveries, rapid scientific and technological advancements, and solutions benefit society. However, many societal challenges require evolved frameworks and measures to address the 21st-century complex problems. The ICON (Integrated, Coordinated, Open, and Networked) approach to advance science in society formulates the interdisciplinary perspectives and coordinated network that provide solutions to the complex issues in our society. The three independent commentaries embody ICON processes, and further presents challenges and untapped opportunities in these broad areas that can create a better understanding of the impact of science on society.

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Key Points:

- ICON framework builds innovative science with collaborations across disciplines to study complex human-environmental interactions.
- Citizen science should be involved in the planning to the research results discussion phase for a truly successful project.
- A partnership between the underrepresented and the progressively advanced institutions could address educational inequity in society.

Abstract

This article is composed of three independent commentaries about the state of ICON principles (Goldman et al. 2021) in Science and Society section and discussion on the opportunities and challenges of adopting them. Each commentary focuses on a different topic: Citizen Science; Collaboration across Sciences; and Education Policy. Scientific discoveries, rapid scientific and technological advancements, and solutions benefit society. However, many societal challenges require evolved frameworks and measures to address the 21st-century complex problems. The ICON (Integrated, Coordinated, Open, and Networked) approach to advance science in society formulates the interdisciplinary perspectives and coordinated network that provide solutions to the complex issues in our society. The three independent commentaries embody ICON processes, and further presents challenges and untapped opportunities in these broad areas that can create a better understanding of the impact of science on society.

Key words: citizen science, inter- and intra-collaborations, framework, cross-disciplinary, education policy, community engagements

1. Introduction

Why is ICON science important to society?

Science holds a special place in our society. Our society depends on science innovations and technological advancements to meet the growing needs of resilient infrastructures, food and water security, efficient and effective healthcare systems, environmental health, and sustainability. A sizable gap exists between scientists and citizens in communicating a range of science-related issues, including the place of science in our culture and the society (Pew Research Center, 2015). The ICON (Integrated, Coordinated, Open, and Networked) approach to advance science in society can promote cross-disciplinary initiatives, integration, and impactful use of resources and knowledge to close the gaps between science and citizens. We present three broad areas that embody ICON processes in the cross-disciplinary initiatives, various challenges, and untapped opportunities in these broad areas, and discuss how a diverse, equitable, and inclusive environment for all in our society can be orchestrated (Fig. 1).

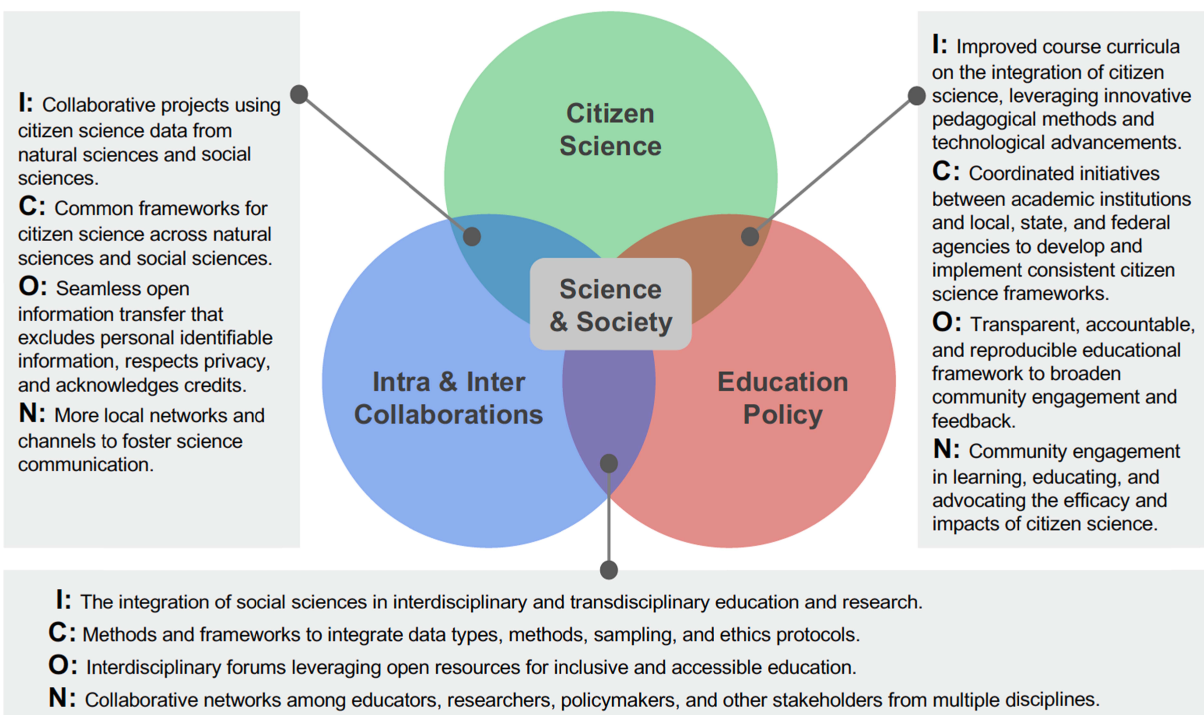

Figure 1: A framework of three broad areas that represent science and society and how they embody ICON principles in the cross-disciplinary initiatives and the people-centric approach to foster science and improve the connections between science and society.

2. Citizen Science

Citizen science is an opportunity to incorporate society into science research directly and can be profoundly successful in bridging the gap between the two, but only if it is done in a meaningful way. To have a truly successful project that includes citizen science, the volunteers should be involved in all the stages of the research, from the planning phase to the discussion of the results, as this is more likely to include aspects that are important to the community and thus lead to more engaged volunteers (Starkey et al., 2017; Pandya et al., 2012).

2.1. Integration

Currently, the utilization of citizen science in various disciplines is not well defined, and each discipline has its own approach, creating difficulties integrating the two. How often citizen science is utilized varies across disciplines, with some that frequently have many studies with a large scope, while others use this rarely in studies and only for very specific purposes. While some disciplines have utilized citizen science more than others, focusing on integration techniques that have been successful in these cases can provide a framework for fields that are just beginning to incorporate citizen science into research.

2.2. Coordination

Scientists are generally not trained in incorporating citizen science effectively (Buytaert et al., 2014). This divide can be seen even more clearly in social science and humanities, where there are no standardized procedures to incorporate citizens into the research (Albert et al., 2021, Heinisch et al., 2021). Because of the divides between disciplines and an overall lack of experience utilizing citizen science, even in the individual disciplines, there is no true coordination to create standards for effective use of citizen science. The lack of coordination presents an opportunity for professional organizations across disciplines to define what characterizes citizen science, develop protocols for implementing it in research, and provide opportunities for training (Lorke et al., 2019). Access to hybrid training platforms, including the online citizen science, in the formal and informal environment plays an important role in providing the training opportunities across disciplines for a new model of doing science.

2.3. Open access

With the current lack of consistent protocols around citizen science, it is uncertain if regular updates and results are shared fully with participants and if they are conveyed in a meaningful, understandable way. Without transparency, participants can be left wondering what they volunteered for and how the research will affect their lives or improve their environment. The open access to the full research process, including regular meetings to share data, project updates, and solicit feedback, ensures a full understanding of the project. The researchers gain existing knowledge from the community, and increased research transparency builds a better rapport between researchers and volunteers. The open access to the data and results of the project from an appropriate repository can also provide learning outside the project. Suppose the volunteers can still access the data after the project's conclusion. In that case, they can more readily identify changes in the environment around them, potentially bringing about vital future projects that researchers would not have recognized and removed from the community.

2.4. Network

The lack of protocols around citizen science can lead to missed opportunities, as it can be unclear how to utilize qualitative or quantitative data, or how to incorporate volunteers beyond simple data collection. There are also issues of experiment complexity, level of volunteer training, procedure unification for consistent sampling, and involvement of multiple stakeholders, all of which can present difficulty for integration of citizen participation in scientific research (Buytaert et al. 2014). Different stakeholders have varied preferences, abilities, and access to how and when to get involved during the research process. Proper communication established early on could help understand and adjust alternative participation methods. Volunteers should be shown that their experience is valued and that they themselves are valued by using existing qualitative data from the community. Further, by considering limitations that may prohibit full participation, researchers can indicate appreciation of the volunteers themselves. For instance, to increase access and equitable opportunity for participation, direct and indirect costs to participants should be considered (Weeser et al., 2018; Pandya, 2012) during the design phase, even if these seem minimal to the researchers. By removing as many barriers as possible from full participation, researchers may be more likely to involve and keep volunteers long term. This can build rapport between researchers and the community members and lead to higher quality data, as retained volunteers are more experienced and data collection is more consistent. The strengthened relationship between the scientific community and their engagement with the general population can lead to better understanding and confidence in the research and the results obtained. Communities with a strengthened scientific knowledge base and trust in scientific studies may become more informed and involved in science policy that affects them and the surrounding regions.

3. Collaborations across sciences

Social sciences offer inherent opportunities in scientific research and policymaking to solve critical societal challenges. The natural sciences paradigmatic orientation that natural sciences are the key to protect nature from human influences lacks the leverage of social sciences to solve our most complex problems such as the most complex coupled socio-environmental problems exacerbated by climate change. As a result, social sciences tend to be viewed as a discipline that only provides outreach and education to natural science, interdisciplinary or transdisciplinary research rather than a synergistic piece to advance our understanding of complex socio-environmental problems. We present the challenges in ICON principles and the potential solutions to overcome those challenges in the following subsections.

3.1. Integration

There are several challenges in fully embracing the integration of social sciences with natural science research to tackle our most pressing environmental problems. The primary challenge is the lack of a unifying framework for understanding the reciprocal nature of human-environmental interactions. Ostrom's social-ecological systems framework is one of many frameworks that bridge the divide between social and environmental systems using a governance lens to understanding human-environmental relationships (Ostrom 2007, 2009; McGinnis and Ostrom 2014). Additionally, the integration is also limited due to the differences in lexicons between sciences, which create barriers to communication. Natural scientists may not weigh the qualitative data as heavily as they do with quantitative data as it is seen as "subjective" without acknowledging the bias within quantitative data sets. Even when social science is utilized in the research process, the expertise and experiences of social science professionals are often not leveraged to solve critical problems. This may impact the research quality, such as the ethics protocols, sampling, research designs, methodologies, and insufficient data analysis associated with tackling the driving research questions.

3.2. Coordination

Social scientists are not well-connected with natural scientists in the research process. When an aspect of social sciences is considered in interdisciplinary or transdisciplinary research, it is mainly treated as a parallel effort. The lack of coordination prevents integration due to the differences in the methodologies to generate different types of data and results in the same spatial and temporal dimensions as the natural sciences. For instance, rapport and trust take time to build, essential to obtaining reliable qualitative data. Therefore, social science is often ad-hoc to a research grant instead of an integral piece used to advance solving coupled socio-environmental challenges.

3.3. Open

Differences in data types and methodologies often limit the open use of data across natural and social science. Several programs exist within the United States to foster coordination and break down methodological and disciplinary gaps between social sciences and natural sciences to tackle complex socio-environmental problems. The SESMAD project is one example that bridge case study examples of complex human-environmental interactions (SESMAD, 2014). Some other examples would be the National Socio-Environmental Synthesis Center and the National Science

Foundation's Dynamics of Integrated Socio-Environmental System (DISES) program. One limitation to continuing these efforts is the lack of a widely used data platform for sharing qualitative social sciences datasets that address contextual relevance, privacy, and ethical concerns. The successful open dissemination of the qualitative data addressing these concerns may create new scientific models that bridge the divide among the disciplines to address the most pressing problems of our times.

3.4. Network

Networking in research requires significant time, patience, and energy to generate data, collect samples, and contribute to the other phases of the research lifecycle. Engaging different stakeholders to data within the collaborative efforts also require authorship ethics and extensive communication across groups to build trust and rapport. Sometimes these efforts limit the rapid generation of mutually beneficial research that benefits the interconnected communities. When the study is completed, the challenge of investing significant time and resources to publish results remains. It can be challenging to obtain peer-review congruent with the topic and diverse methodologies used within integrated social and natural science research. The professional societies have an essential role in launching journals or publishing platforms that can address the challenge of seeking the required peer-review and timely publication of collaborative research works.

4. Education Policy

An effective education policy requires commitment from all stakeholders – including federal agencies, state and local governments, academia, the private and the public sector to create an equitable, inclusive, and welcoming path for all sections of society. It is critically important that our education goals and policies reflect on the various Science, Technology, Engineering, and Mathematics (STEM) education indicators and the factors that have led to that performance in STEM skill sets and workforce (Science and Engineering Indicators 2020; OECD 2021; PISA Results 2018).

4.1. Integration

The 21st-century digital era and pandemic have raised serious questions about access to education. Today, our schools and educational enterprises need the framework of policies and collaborations that prioritizes easy access to digital infrastructure to all, including remote sections of society, and integrate the science learning approach across the spatial and temporal scales. Computer machines and devices are indispensable tools of educational technology nowadays. The ICON approach to educational tools and technology allows leverage to integrate the interactive components of the technology to deliver greater access, flexibility, and efficiency in education.

The digital tools and algorithms are becoming more intelligent and, at times, outperforming the experts. The latest technological advancements, such as artificial intelligence and data science, can be integrated into the educational resources and interaction with students that meet the need of theory and laboratory in science education.

4.2. Coordination

We need to build science innovation that is coordinated and generates interoperable data across the disciplines to understand complex problems and sustainable solutions. We can benefit from the strengthened and collaborative partnership between technological enterprises and the education sector in the 21st century. The investment in training schools and educational technology, better science labs at our educational institutions, and community engagement in learning, educating, and advocating can help build a stronger education system. It is also important to reflect on what has become redundant today and what will become a necessity in the future in our interconnected global world. Universities and colleges can help engage 21st-century students in science by supporting teaching innovation in science education that builds a stronger pipeline to STEM-related jobs and benefits society. Currently, the data comparisons and trends of STEM indicators used by local, state, and federal policymakers, businesses, universities, and many others to inform their decisions clearly show the under-representation of minorities and women in STEM (NAEP Science Assessments, OECD PISA Results 2018, Science and Engineering Indicators 2020). It is essential to welcome and engage the underrepresented minority groups and women in STEM disciplines to ensure effective coordination of consistent protocols and methods across systems. Including the indigenous populations in the coordinated approach will include knowledge that spans hundreds of years, closing the gaps in how scientists and citizens view the impact of science on society. A policy shift to prioritize and coordinate workplace well-being and child-care support for young parents on our academic campuses' will retain the workplace talent and boost productivity and support for innovation in a 21st-century sustainable society (Litchfield et al., 2016). Including these concepts in scientific study and planning will produce more robust scientific practices and strengthen the nexus of science, society, and the economy.

4.3. Open

The open science approach creates 21st-century science and global policies that help develop new initiatives and equip the scientific community with tools to bring change. The ICON open science philosophy based on the FAIR (findable, accessible, interoperable, and reusable) principles foster inclusion, equity, access, and sharing across the disciplines. Today, we need a cultural shift where science is easily shared and incentivized to engage communities in our global policies. Some currently existing open-source initiatives such as NumFOCUS, GitHub, and Slack promote open practices in research, education, data, codes and provide the necessary tools and resources to solve complex problems. The open science approach allows for broader community feedback that engages the community in educational programs that have a lasting impact. The FAIR principles in open science must be guided by the people-centric approach in good data management and preservation. We also need a cultural shift from producing science hidden behind the paywalls to sharing science with open access that will shift the pace of scientific progress. The transparent, accountable, and reproducible science framework can help save billions of dollars by accelerating discovery communication. Open science could support a perpetual network of science institutions, educators, students, and the community to engage society in discussions and activities that assist one in understanding the impact of science on society.

4.4. Network

The ICON principles consider "Networked" in the context of shared efforts to create mutually beneficial research for the scientific and stakeholder community. For an educational policy, it has become essential to develop educational partnerships and networks for the progress and prosperity of nations as the global economy brings nations closer together. We can learn from each other's education model or science policies as a nation in this interconnected global world. The United States two-year community college model is one example that offers untapped opportunities to provide affordable access to workforce education, grants certifications and diplomas, and a bridge to higher education degree programs. Community colleges offer a forum for the impactful use of our resources as they address the educational needs of many students of all ages, education levels, and socio-economic backgrounds. Unfortunately, community college education suffers from adequate support to help raise public science knowledge. One solution to boost the impact of science in our society would be partnerships between the underrepresented minority-serving institutions (MSI) and the progressively advanced institutions. The partnerships can involve hosting STEM seminars presented by graduate students or early-career scientists at community colleges or underrepresented MSI. The undergraduate summer student internships for community college or MSI students mentored and sponsored by scientists or faculty at progressively advanced institutions hold an essential aspect of science - encouraging young minds to be inspired and learn from the best in the field.

5. Conclusion and Outlook of Science and Society

Science contributes to the advancement of society while societal needs drive science priorities; however, there are often disconnects between the two. A framework like ICON can help bridge these gaps. Integration of a wide range of inputs, coordination with a variety of stakeholders and developers, an open research framework fostering inclusiveness and transparency, and a tightly knit network that engages all involved in the research will result in a more seamless integration of science and society, paving the way for effective and efficient solutions of several critical challenges we are facing today.

6. Acknowledgements

We are grateful to the ICON leadership for their valuable comments and suggestions in the original version of this manuscript. MS served as an Assistant professor in the Department of Engineering, Physics, and Technology at Bronx Community College of the City University of New York at the time of drafting the early version of this manuscript. She is currently on a Visiting Research Scholar appointment in the Department of Physics at Stevens Institute of Technology. Her visiting affiliation does not associate with any funding support for this work.

7. Authors contribution

MS authored section 4, EA authored section 2, CF authored section 3, and TR created Figure 1. All authors worked on sections 1 and 5 and collectively reviewed the final version of the manuscript. MS is the section champion of the Science and Society section and led the manuscript writing in the ICON Special Collection.

8. Conflict of Interest

Authors declare no conflict of interest with respect to the results of this publication.

9. Data Availability Statement

No datasets were generated or analyzed in this study.

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