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Perspective

# Co-Designing Information Interventions in Global Environmental Health and Engineering with Marginalized Communities

Lee E. Voth-Gaeddert,* Douglas Momberg, Bongiwe Nkambule, Daniel Salcedo Serrano, Peter Rohloff, Rihlat Said-Mohamed, and Alastair van Heerden

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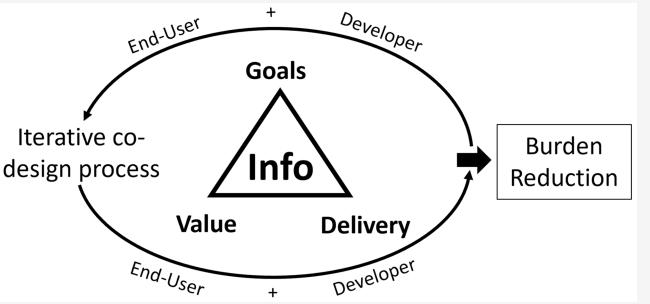
**ABSTRACT:** Improving access to environmental health and engineering related information among marginalized communities via traditional and advanced methods of collection, analysis, and dissemination is imperative to achieving the Sustainable Development Goals. While infrastructure and equipment are important for achieving equity in global environmental health—e.g., improving water access or reducing malnutrition—these resources are only part of the larger complex system that enables optimal use and accountability for all stakeholders. In this perspective, we synthesize various areas of work on information interventions in global environmental health, providing examples from the water, sanitation, and hygiene and food system sectors. First, we propose a typology for the "goals of the information" and the "process of delivery". Second, we discuss the actual and perceived value of information and how this varies over time for the end-user. Finally, we provide an overview of the primary steps for co-developing an information intervention along with available tools. Given the continued democratization of digital platforms, we hypothesize a substantial need for decentralized support and guidelines for marginalized communities to build their own hyper-local platforms to solve local problems. We close by providing recommendations for focusing on underutilized information interventions and specific needs within global environmental health and engineering.






## INTRODUCTION

Global environmental health and engineering interventions aimed at improving the lives of marginalized communities can provide significant benefits to the end-user and community (e.g., illness reduction, cost savings, etc.). Traditionally, a majority of environmental health engineering interventions among marginalized communities have been focused on delivering a physical product. For example, for water, sanitation, and hygiene (WASH), physical interventions include water treatment technologies,[1] improved toilets, and the provision of soap while for food systems, physical product interventions include nutrition recovery programs (delivery of nutrient supplementation), subsistence farming practices (seed provision), and food safety approaches (food storage equipment). However, given the advancements in areas such as behavioral economics, digital technologies, and capacity development, information and data are becoming increasingly popular tools as standalone environmental health engineering interventions.[2] Previous peer-reviewed and gray literature provides important insight into suboptimal or failed global environmental health interventions as well as the reasons for the failure.[3,4] Common core features in failed interventions may relate to the type of stakeholders involved (or not involved), poor or nonexistent feedback loops and accountability systems across stakeholder groups, or limited understanding of the human-information interface, among others.[5,6] Pai provides an excellent collection of reasons for failure within global health.[3] Furthermore, an unbalanced power dynamic may also be present among the funders, implementors, and the "recipients" during an intervention. Hence, there has been a recent, significant, and critical shift to user-centered design, co-design, or community-based participatory design approaches.[25,27]

While forms of marginalization across communities can occur through various modalities—e.g., race, ethnicity, economic—here we utilize the term "marginalized community" to refer to communities in lower-income settings that have traditionally been either excluded from accessing basic resources (health care, clean water, adequate sanitation, nutritious food, etc.) or that have little power in dictating the types of services they receive. In addition, the term

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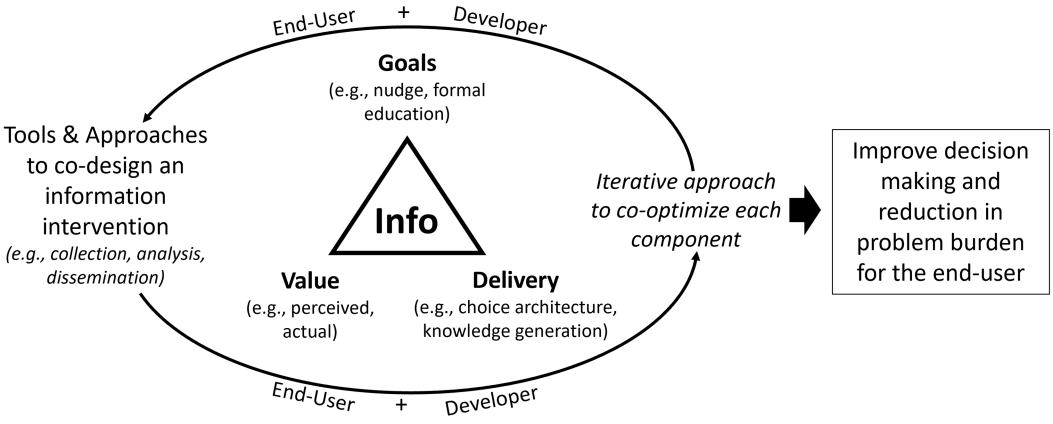


**Figure 1.** Integrated framework for "co-designing" and "co-optimizing" information interventions in global environmental health engineering with the end-users to improve ability to reduce burden.

"community" here refers to stakeholders within a specific geographic proximity often defined by a municipal service area, while it is important to note that with information interventions, a community network can span broad geographic, even global, areas. This is important as reception and interpretation of information is based on a shared understanding, emphasizing the need for user-centered and empathy driven design approaches, which are discussed further below. However, care must be taken to not completely "responsibilize" marginalized communities for environmental health problems that affect them.[7] Finally, we use the term "end-user" to refer to individual community members, leaders, or service providers who make decisions with the information intervention. We suggest this is a more inclusive term, compared to "beneficiary", as this has taken on a more "passive" or "recipient" style connotation, while "end-users" are often actively involved in co-developing solutions.

Interventions in global environmental health and engineering can be categorized in several ways. Here we focus on interventions that exclusively, or as part of a larger package, use information, providing illustrative examples from the WASH and food systems sectors. We define an "information intervention" as any intervention where information or data is provided in some format to an end-user to support in the alleviation of a target set of problems. However, it is important to note that all end-users live and participate in a constant flow of information, making choices based on 1) available information actively and passively delivered and 2) their current physical location or environment. The use of information as a core component of an intervention or product aimed at improving livelihoods during a dedicated project or program is common, be it the private sector, local governments, or the international development sector. General examples of targeted information include the rise of ride sharing platforms that utilize GPS-enabled mobile phones to connect nearby riders and drivers (providing information on demand and supply). An equivalent example pertaining to food systems includes government funded weather sensors and models that provide farmers with granular weather projections to inform farming practices.[8] In the international development sector, demographic and health surveys allow local and international organizations to better target resource allocation.[9]

In this manuscript, our aim is to present a synthesis of information interventions based on literature and practice across South Africa, Guatemala, and the United States facilitated by the coauthors of this manuscript. It is important to note that even within a small community there are many types of "end-users" (e.g., for water systems there are households, water operators, community leaders, water boards, etc.) that each require a tailored assessment or co-design process to ensure the information fits within the user's mental model and current community-based processes, procedures, and responsibilities. Our focus in this paper will be on the individual within a community. Core questions that informed formal and informal discussions among stakeholders leading to this initial framework included:

- What is the desired goal of delivering the information, the outcome of achieving that goal, and the process to deliver the information?
- What is the relative value of the information for the end user and how does the perceived and actual value of information differ?
- What are the core areas and tools to utilize in co-designing an information intervention?

The paper is divided into three sections, captured in Figure 1: Section 1. The Goal and Delivery of Information, Section 2. The Perceived and Actual Value of Information and Section 3. Approaches and Tools to Leveraging Information as an Intervention. In Figure 1, the goal, delivery, and value of the information intervention must be co-designed and co-optimized iteratively between the user and developer to achieve the desired state or action of the end-user to enable them to reduce their burden. Below, we provide further detail for each component of this framework. To improve the use of information in global environmental health engineering, we must focus on empowering the end-user along their journey toward solving the critical problems they face.

**Section 1: The Goal and Delivery of Information.** Two of the three attributes or characteristics of the information intervention presented in Figure 1 include the goal and delivery process of the information. Individuals interact with information via various forms of digital, analog, and human interfaces. Fundamentally, this occurs within a complex system of interacting components. These components of the complex systems may include hardware technologies, software systems and information, human behaviors and social networks, as well as all larger systems that incorporate these components (e.g., economic, food and water systems, transportation systems, health systems). In this paper, the boundary conditions for our


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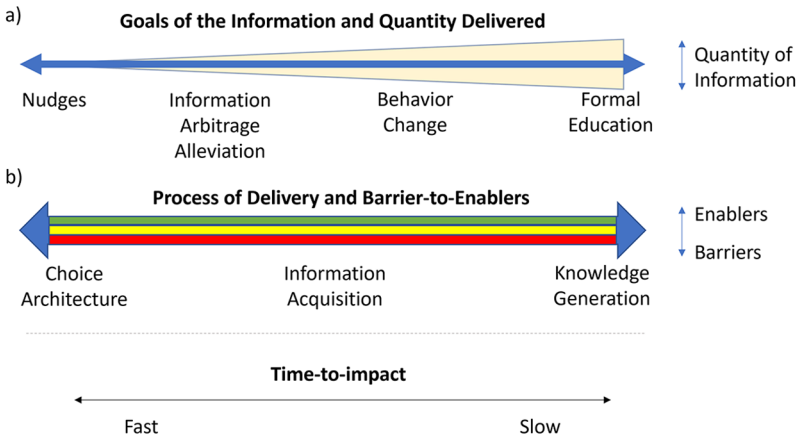


**Figure 2.** Spectrum of the a) goal of the information and quantity delivered and b) process of delivery and barriers-to-enablers.

**Section 1 Box: Selected Examples**

**Nudge (Goal)**: Blackwell and colleagues evaluated the effect of placing arrows on the floor between the toilet and sink in bathrooms at their university and found that a significantly higher proportion of students washed their hands after using the bathroom when arrows were present[14].

**Choice Architecture (Delivery)**: The arrows on the ground and the layout of the bathroom in our previous example, are the choice architecture while the nudge is handwashing.

**Information Arbitrage Alleviation (Goal)**: E.g.,1) A household knowing the quality of their water may prompt immediate action for remediation and possible adjustment in their source water. E.g.,2) A parent with available capital is provided information on which nutrition supplement to use and where to acquire it, they can take immediate action to improve the nutrition status of their child.

**Information Acquisition (Delivery)**: E.g.,1) The mechanism in which the household acquires or receives their water quality information (e.g., self-tested or a government program). E.g.,2) The mechanism in which the parent receives information on nutrition supplements (e.g., telehealth visit).

**Knowledge Generation (Delivery)**: Parents may have an improved level of knowledge regarding nutrition for their second or third child given repeated chances to transform information into knowledge during the initial years of life of their first child.

focus include the larger water, sanitation, and food systems and how households in marginalized communities interact with these systems at various human-information interfaces. First, the different types of goals for the information generated and disseminated in a larger system can be placed along a spectrum. This spectrum ranges from simple "nudges" to complex formal education. Second, the spectrum of these goals for information also aligns with the spectrum of the delivery processes. The delivery process spectrum ranges from choice architecture to knowledge generation. Finally, there are boundaries of quantity, barriers, and enablers to these two spectra that improve or hinder access to the information and subsequent outcomes. Each of these attributes must be considered within the local context when in the iterative, co-design process.

Figure 2 depicts the aligned spectra of a) the goal and quantity of information (nudge to formal education) and b) the delivery process (choice architecture to knowledge generation). Along the spectrum of the goal of the information we highlight several examples, however, this is not an exhaustive list. On the left are nudges, defined as "*any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, intervention must be easy and cheap to avoid. Nudges are not mandates.*".[10] On the right side of the spectrum is formal education, which would include basic and higher education along with certificates and licenses (e.g., water operator/engineering training). In the middle are information interventions targeting behavior change including examples such as community led total sanitation (CLTS)[11] and breastfeeding promotion.[12] The reader is encouraged to review Michie et al. 2015 for an extensive review of the behavior change literature.[13] The final attribute of the goals of the information spectrum is information arbitrage alleviation, which we feel is the least well studied in global environmental health engineering. This is where the end-user would act on the information in a constructive way if they had access to it. The information has immediate value, given a specific time and mechanism of delivery. Importantly, these goals are directly linked with hypothesized outcomes, here focused on contaminant exposure reduction and improved food security. Selective examples of goals and their outcomes are provided in the Section 1 Box. When information interventions are being co-designed, various goals along this spectrum are often integrated (intentionally or unintentionally), which can help improve the likelihood of a successful intervention dependent on the desired outcome. It is also important to recognize that


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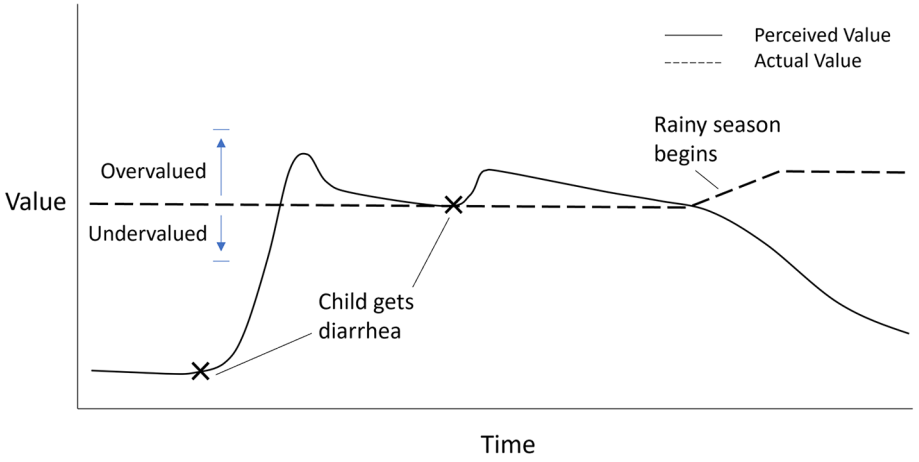


**Figure 3.** Hypothesized fluctuations of the actual and perceived value of information to a parent regarding diarrhea therapies for their child.

for both spectra in Figure 2, there is a "time-to-impact" factor that generally runs from short to long, going from left to right along the spectrum. This is the time between receiving the information and when the desired goal is achieved by the end-user. Development of knowledge via formal education takes time, where the improvement of a choice architecture that facilitates a healthy nudge can have an immediate impact, provided the hypothesized outcome is achieved. However, the process of delivery is also critical for a successful information intervention.

In Figure 2, the second spectrum focuses on the process of delivery of the information intervention and ranges from the choice architecture to information acquisition to knowledge generation. The choice architecture is defined as the way in which choices are presented to the end-user that influences their decision[10] (e.g., the bathroom setting and arrows[14]). Moving to the right along the spectrum is information acquisition, with information retaining its classic definition of "facts provided or learned about something or someone" (Oxford English Dictionary). While information is present within the other two examples of the process of delivery, the choice architecture relies on subconscious habits and reactions, while knowledge generation requires the transformation of information into knowledge via several mechanisms. Therefore, information acquisition occurs often via mechanisms tailored to the immediate use of this information (e.g., a text message on the low-level of water in a household storage tank). Finally, on the right side of the spectrum is knowledge generation. Knowledge generation requires the end-user to leverage information to build a more holistic understanding of the topic. These three "processes of delivery" represent different points along the spectrum that enable the corresponding goal of the information to be achieved.

Finally, there are boundaries of quantity, barriers, and enablers that facilitate or hinder the transfer of information due to issues of quantity and quality. Boundaries of quantity refer to the breadth of the type of information that is being shared. While this boundary naturally gets broader as one moves from left to right on both spectra, the co-designers still have control over the breadth of the boundary at a given point along the spectrum. As a general example, the type of information exchanged on social media platform X, formally known as Twitter, has very few boundaries, while the type of information exchanged on Airbnb has very specific boundaries. These boundaries are directly related to the goal and process of information dissemination. Barriers and enablers of the dissemination of information will vary significantly along the spectra in Figure 2 as well as be dependent on the characteristics of the larger ecosystem present (e.g., geographic implications, language barriers, technological maturity, social power dynamics, etc.). For example, malnutrition recovery programs may be available in a geographic setting, but information and in-person exchanges may not be available in indigenous languages creating a barrier for information dissemination.[15,16] Being aware of the influence of these cross-cutting factors based on the portion of the spectrum used for the intervention can help be a positive catalyst for the information intervention. The end-users and developers must ensure they review, identify, and agree upon the goals and delivery processes as well as account for these cross-cutting factors as they co-optimize the information intervention. Section 3 provides details on tools for addressing these cross-cutting factors, while Section 2 provides details on the third core attribute all stakeholders must address, the value of information.

**Section 2: The Perceived and Actual Value of Information.** To build a successful information intervention, it is important to understand the perceived and actual value of information for the end-user. All information has value, although certain pieces of information may have a value of zero for some end-users. Within economics, the approach to understand this value is called the economic valuation of information or information economics.[17−20] However, this value can fluctuate based on the setting. Furthermore, there may be a discrepancy in the perceived and actual economic value of the information, and therefore understanding what drives perceived value is critical. Several factors can be used to help us understand aspects of this discrepancy. For the information, factors may include the "virality" of the information, the credibility of the information source, and the accuracy of the information (e.g., misinformation). For the end-user, factors may include education, cultural and social norms, and demographic characteristics. If the developer or stakeholder of an information intervention is not the end-user, employing a user-centered design approach can provide an empathy-driven understanding of the end-user and their information needs, which is critical for providing valuable


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**Section 2 Box: Selected Examples**

**Actual Value of Information**: E.g.,1) As a service provider example, Rutayisire and Kuria from Pit Vidura presented on the hypothesized fluctuation of the willingness-to-pay for desludging services of a household pit latrine in Kigali, Rwanda, which suggests that understanding these fluctuations can help improve timing of the information dissemination about available desludging services to households.[22] E.g.,2) For child health, parents are hypothesized to value information on therapies for diarrhea, during and directly after a child in their household has a bout of diarrhea, compared to outside these event windows (see Figure 3). Brown and colleagues evaluated the value of health risk information regarding water quality information among households in Cambodia identifying core characteristics of households that placed a higher value on the information.[40]

**Perceived Value of Information**: Berger provides several public health examples including, how initial anti-drug use commercials in the 1980s and 1990s in the US actually increased the likelihood of drug use among teenagers. The hypothesis is that commercials made drug use public and highlighted that other teenagers were using drugs (see Tide® pod example).[23]

information to them that will achieve the goals and outcomes highlighted in Section 1.

The economic valuation of information is an area of study used to better understand the actual value of information for a person, community, or, mostly commonly, a company.[20] This value is subject to fluctuations (appreciation and depreciation), given a variety of factors. Patrick Meier and others have highlighted the hypothesized exponential decay of the value of information in emergency response settings.[21] As time progresses, information obtained early in the response becomes less useful (and therefore less valuable) in dictating actions in the response. The opposite trend may occur when there is an information gap, and the demand (and therefore value) for filling this gap continues to increase over time. A more complicated situation occurs in non-emergency settings where the value of information may increase or decrease given recent events (directly or indirectly to the individual or organization). However, the confounding issue is that the actual value and perceived value of information can fluctuate in different ways as actual value is often based on its theoretical commodification while the perceived value is often based on the general concept of willingness-to-pay or, more importantly, ability-to-pay (see the Section 2 Box).[22] As the actual value becomes more apparent to the designer (potentially based on barriers to access or scarcity), the perceived value by the end-user must also be considered. Both values are a product of factors related to the information and characteristics of the end-user. This warrants the use of user-centered or community-based co-design approaches to align and maximize value (Figure 3).

The perceived value of information is directly dependent on the individual or organization that receives the information. However, the value can be influenced by increasing demand by providing additional types of information. For example, as people's understanding of the consequences of diarrhea improves, the perceived value of both pathogen exposure prevention and diarrhea therapies should theoretically increase. Many marketing books claim to have identified the secret ingredients for information to "go viral" (i.e., an advertisement). This would refer to information that is valuable to both receiving and share. Berger 2016 summarizes their research by identifying six unifying attributes of valuable information which include social currency (sharing things to make ourselves look good), triggers (top of mind, tip of tongue), emotion (we share when we care), public (build clout), practical value (share news that others can use), and stories (embed an idea in story).[23] In addition to these attributes, the credibility of the source of the information can play a role in the perceived value. Unfortunately, these factors can be exploited intentionally or unintentionally via mis- or dis-information and has been a central focus in the World Health Organizations work on "infodemics".[24] Therefore, care should be taken to ensure that not only is the information being transferred accurate but access to the delivery process is limited to prudent stakeholders.

In addition, understanding the characteristics of the end-user and the larger community is important to understanding the value of the information intervention. To help optimize and increase this value, a user-centered or agile design approach[25,26] or a community-based participatory research approach[27] can aid in identifying these core characteristics of the end-user of the information. This can contribute to an improved hyper-local focus and enable the ranking of desired information and critical problems the end-user or communities have as their priorities. Finally, the value of information can be influenced by the cost or time of the information collection. For Figure 3, information associated with diarrhea treatment methods is readily available and low cost to collect (i.e., a simple Internet search), while predicting when the rainy season will begin (increasing exposure risks to diarrheal pathogens) takes more time and money to generate and disseminate. In water systems, knowing current pathogen contamination levels can help trigger immediate remediation steps by the water operator, but collecting this data overtime can help water committees improve their overall operation and maintenance strategies. As highlighted in Figure 1, value is a core attribute to incorporate into the iterative co-design process of information interventions. Furthermore, understanding the tools and approaches necessary to design and deliver an information intervention is critical even when the information is deemed highly valuable; Section 3 provides an overview of these resources.

**Section 3: Approaches and Tools to Leveraging Information as an Intervention.** In order to leverage information as an intervention, several approaches can be helpful. First, understanding the complex system through which the information will flow is critical. If the intervention is targeting households, this is largely based on the social network of the communities and end-users but is influenced by factors such as technology and digital literacy, economic status, education, etc. If the intervention is targeting a set of organizational stakeholders, existing relationships and working agreements may influence the existing information management systems (formal or informal). Systems thinking techniques such as causal loop diagrams and system dynamics



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models[28,29] can help stakeholders understand the feedback loops that govern potential proliferation of information in the larger system. In addition, network analyses can help map social and power networks within the communities while all of these techniques help the stakeholders and designers understand the leverage points in the system.[30,31] Next, three areas common in typical information projects include data or information collection (acquire value), analysis (increase value), and dissemination (provide value back to end-users) and are most often used in combination to deliver the information intervention. In addition, various tools can be applied across the three areas that can help achieve the goals established in each step. Figure 4 provides a synthesized framework for these attributes.

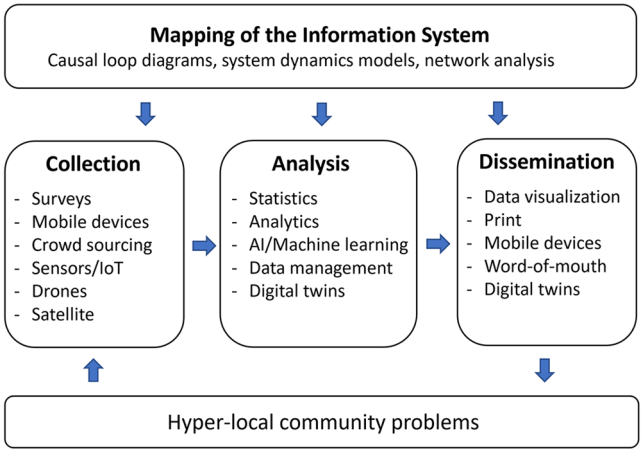


**Figure 4.** Synthesized framework on mapping, steps, and tools for understanding and building information intervention. Adapted from 32.

Mapping existing information flows along with the networks that carry this information is critical to 1) developing a unified mental model among stakeholders (e.g., group model building exercises), 2) understanding leverage points within the system, and 3) optimizing the information (type, frequency, duration—see Section 1) and location within the system in which it will be disseminated. Our current stakeholder focus is on households, and therefore the following techniques would have these stakeholders at the "center" of the models. Systems thinking, systems engineering, and network analysis all provide helpful methods to better understand the complex system and relationships which exist. Causal loop diagrams, and their modeling counterpart system dynamics models, are an excellent tool to map stakeholders, factors that influence rates of change, and the positive and negative feedback loops which exist in these systems.[33] In addition, multiple systems and subsystems can be mapped; however, understanding boundary conditions of the system can be difficult. Sawyer and colleagues used a causal loop diagram approach to map the dynamics of the complex food environment focused on dietary intake among individuals.[34] Network analyses have also been used extensively to understand social networks and the power dynamics present within communities and larger stakeholder systems. Network analysis usually consists more narrowly of nodes and edges which represent the individual units of study (e.g., household, stakeholder) and their direct and indirect relationship with others.[35,36] For example, Buchthal and colleagues utilized network analysis to identify opportunities for building nutrition partnerships within diverse low-income communities.[37] Finally, there are other available and effective tools that can be used to help map information systems including information flow diagrams and WHO's institutional mapping tool.[38,39] Mapping is an important first step in not only building consensus around understanding the current system but also monitoring during the intervention.

As the information intervention and the delivery mechanisms are being co-developed via a user-centered or community-led approach, the processes can be broken into three primary areas; information/data collection, data integration and analysis, and information dissemination. Information and data collection refer to any type of gathering of data or information used to inform what will be disseminated back to the end-user. Examples of tools for data collection include analog surveys, crowd sourced data (including citizen science), sensors and the Internet-of-things, mobile devices, drones, and satellite data. Any mechanism, tool, or device that generates signals can be used to help infer various phenomena or pieces of information. This is where "value" is initially acquired. Next is data integration and analysis, which can be as simple as aggregating end-user data or as complex as integrating multiple third-party sources with end-user data and performing analytics to generate new or improved insights. The aim in this step is to increase the value of the information and data collected in the prior step. Examples of tools for data integration and analysis include basic statistics and analytic approaches, artificial intelligence and machine learning approaches, data management tools, digital twins, and facilitating these processes in workflows and pipelines. The final area of work is information dissemination. This includes understanding the timing of delivery, the mechanisms of delivery, and the format of delivery that creates the most value for the end-user. Examples of tools for information dissemination include approaches for data visualization (consumable format), print, mobile devices (smart and basic), word-of-mouth, and digital twins. However, given the discussion in Section 2 on fluctuating values of information, care should be taken to disseminate the information at a strategic time where the perceived value is high. In addition, most information interventions require the co-designers to understand all three areas, at least in part, to ensure information is locally and culturally adapted to definitions of value and effectiveness of the larger engaged community. Finally, across all tools, important approaches and biases must be consistently and robustly addressed and implemented, including data privacy and security, racial and ethnic biases, cognitive biases, and other factors leading to increasing digital divides. Viswanathan et al. 2023 provide an excellent, in-depth review of core components for these areas reiterating the importance of community-led, inclusive approaches. As the end-user and developer iterate on the three core attributes of goals, delivery processes, and value, they also must be cognizant of the digital/analogue and social mechanisms in which this information will be collected, analyzed, and disseminated.

## CONCLUSION AND RECOMMENDATIONS

In this article we aimed to provide a framework to help stakeholders in global environmental health and engineering improve their approach to co-identifying and co-developing information interventions with marginalized communities (see Figure 1). First, understanding the types of information interventions is important and includes the spectrum of the


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goals of the information (nudge to formal education) and the spectrum of the delivery process (choice architecture to knowledge generation). Second, the value of information fluctuates significantly over time and varies based on if it is the perceived value or actual value. While it may not be necessary to know the specific value, understanding general trends can help facilitate uptake. Finally, we provide an overview of the different possible areas of an information intervention and the variety of tools that could be used for each area.

To apply this framework, stakeholders (e.g., INGOs, governments, social enterprises, local community leaders, etc.) should review their current portfolios of information and product-based interventions, map their current information interventions to this framework, and identify gaps to increase investment including (i) areas of focus (section 1), (ii) protocols for optimizing messaging (section 2), and (iii) tools for executing interventions (Section 3). Below, we provide specific recommendations for further work in applying this framework to the WASH and nutrition sectors.

1 Within the area of goals and delivery processes, there has been recent significant progress in nudges and behavior change approaches (and associated cross-cutting factors); however, limited data exists (e.g., research, field trials) on the effect of information arbitrage alleviation and information access on marginalized communities in regards to WASH and pathogen exposures. Investment in research and development of information arbitrage alleviation approaches can potentially have a significantly high return-on-investment at scale.

2 Within the area of valuation of information, various economic methods exist for estimating the value of information and has been demonstrated for water quality;[40] however, the current complexity and difficulty to facilitate these methods and the lack of understanding about how detailed an estimate of both actual and perceived information is needed, limits the WASH sector in effectively targeting information to households who lack sufficient access to sanitation services or have higher consistent exposure risks due to location or occupation. Further research and protocol development should be conducted to improve tools for identifying the value of a planned or developing information intervention.

3 Within the area of tools and approaches, there has been a recent increase in focus on systems thinking methods, generally in the WASH sector,[28] and these tools can be adapted to develop simple tools and protocols for local organizations in conducting mapping exercises of information flows in communities. Furthermore, advancements in digital technologies will continue to change how people receive and interact with information and the WASH and nutrition sector must be able to rapidly prototype new solutions as advancements progress.

4 Finally, this framework can be utilized by a wide range of stakeholders. Critically, as digital development technologies become more user-friendly and decentralized, hyper-localization of ICT platforms will become more prevalent as the developor may also be the end-user (as opposed to scaling up/monopolization of a single platform as demonstrated by Silicon Valley). Therefore, an increased focus should be given to supporting and preparing marginalized communities in developing their own digital technologies (ICT platforms). This includes supporting local development of privacy, safety, and security protocols defined by and attuned to local communities.

## AUTHOR INFORMATION


### Corresponding Author

**Lee E. Voth-Gaeddert** − *Biodesign Center for Health Through Microbiomes, Arizona State University, Tempe, Arizona 85281, United States; SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Soweto 1862, South Africa; Center for Indigenous Health Research, Wuqu' Kawoq | Maya Health Alliance, Tecpan 04006, Guatemala;* orcid.org/0000-0002-9541-1958; Email: Lee.Gaeddert@asu.edu

### Authors

**Douglas Momberg** − *SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Soweto 1862, South Africa; Department of Archaeology, Biological Anthropology, University of Cambridge, Cambridge CB2 3DZ, U.K.*

**Bongiwe Nkambule** − *SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Soweto 1862, South Africa*

**Daniel Salcedo Serrano** − *Biodesign Center for Health Through Microbiomes, Arizona State University, Tempe, Arizona 85281, United States*

**Peter Rohloff** − *Center for Indigenous Health Research, Wuqu' Kawoq | Maya Health Alliance, Tecpan 04006, Guatemala; Division of Global Health Equity, Brigham and Women's Hospital, Boston, Massachusetts 02115, United States*

**Rihlat Said-Mohamed** − *SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Soweto 1862, South Africa; Department of Archaeology, Biological Anthropology, University of Cambridge, Cambridge CB2 3DZ, U.K.*

**Alastair van Heerden** − *SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Soweto 1862, South Africa; Center for Community Based Research, Human Sciences Research Council, Pietermaritzburg 3201, South Africa*

Complete contact information is available at: https://pubs.acs.org/10.1021/acsestwater.4c00015


### Author Contributions

CRediT: **Lee Emerson Voth-Gaeddert** conceptualization, validation, writing-original draft, writing-review & editing; **Douglas Momberg** conceptualization, validation, writing-review & editing; **Bongiwe Nkambule** conceptualization,



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validation, writing-review & editing; **Daniel Salcedo** conceptualization, validation, writing-review & editing; **Peter Rohloff** conceptualization, validation, writing-review & editing; **Rihlat Said-Mohamed** conceptualization, validation, writing-review & editing; **Alastair van Heerden** conceptualization, validation, writing-review & editing.

### Notes

The authors declare no competing financial interest.

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