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The FEWSION for Community Resilience (F4R) Process: Building Local Technical and Social Capacity for Critical Supply Chain Resilience

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Local business leaders, policy makers, elected officials, city planners, emergency managers, and private citizens are responsible for, and deeply affected by, the performance of critical supply chains and related infrastructures. At the center of critical supply chains is the food-energy-water nexus (FEW); a nexus that is key to a community's wellbeing, resilience, and sustainability. In the 21st century, managing a local FEW nexus requires accurate data describing the function and structure of a community's supply chains. However, data is not enough; we need data-informed conversation and technical and social capacity building among local stakeholders to utilize the data effectively. There are some resources available at the mesoscale and for food, energy, or water, but many communities lack the data and tools needed to understand connections and bridge the gaps between these scales and systems. As a result, we currently lack the capacity to manage these systems in small and medium sized communities where the vast majority of people, decisions, and problems reside. This study develops and validates a participatory citizen science process for FEW nexus capacity building and data-driven problem solving in small communities at the grassroots level. The FEWSION for Community Resilience (F4R) process applies a Public Participation in Scientific Research (PPSR) framework to map supply chain data for a community's FEW nexus, to identify the social network that manages the nexus, and then to generate a data-informed conversation among stakeholders. F4R was piloted and co-developed with participants over a 2-year study, using a design-based research process to make evidence-based adjustments as needed. Results show that the F4R model was successful at improving volunteers' awareness about nexus and supply chain issues, at creating a network of connections and communication with stakeholders across state, regional, and local organizations, and in facilitating data-informed discussion about improvements to the system. In this paper we describe the design and implementation of F4R and discuss four recommendations for the successful application of the F4R model in other communities: 1) embed opportunities for co-created PPSR, 2) build social capital,

3) integrate active learning strategies with user-friendly digital tools, and 4) adopt existing materials and structure.

Keywords: supply chains, public participation in scientific research, citizen science, food energy water nexus, resilience

INTRODUCTION

In the face of increasing climate uncertainty and potential scarcity of ecosystem services on which people's lives depend, scientists, citizens, commodity providers, and decision makers must better understand and manage the complex interactions between humans and the food-energy-water (FEW) nexus (Scanlon et al., 2017). The FEW nexus is a dynamic, coupled natural-human system that operates on multiple geographic scales, and is managed through private, government, and non-profit providers across many different service areas and jurisdictions (McGrane et al., 2019; Hibbett et al., 2020). The FEW nexus lies at the core of critical lifeline supply chains that support community functions and survival, but also underlies a community's public health, economic development, sustainability, and emergency management (FEMA, 2019; NASEM, 2020).

"Last mile" supply chain connections play a crucial role in food-energy-water systems. The "last mile" of supply chains includes the connections between distributors and consumers, including all retail locations (**Supplementary Figure S1**; Saundry and Ruddell, 2020). Understanding last mile logistics can be critical for decisions that affect the provision of local resources. This includes policies, plans, and actions made by private, public, and non-profit organizations. During catastrophic events like hurricanes, key connections, needs, and logistics are needed to ensure that communities can receive emergency assistance for food, energy, and water resources (Palin, 2018).

It may be difficult for citizens, FEW providers, and decision makers to influence policies and impacts of international supply chains, or even those of other states, but they can focus on making positive impacts, and having authority or influence over decisions for their last mile resources. In order to do so, they must build capacity for managing the FEW nexus at the local level. Building capacity at a local level requires at least two components (McGreavy et al., 2016): 1) technical capacity, which we define as the generation of last mile data to identify, map, and monitor the local FEW nexus (Yung et al., 2019), and 2) social capacity, which we define as the stakeholder engagement, community connections, and social networks generated which simultaneously improve the community's ability to hold data-centered conversations, and translate FEW data into adequate policy (Walker et al., 2002).

Despite the urgent need to understand and manage the nexus, action at the local scale, especially in small cities and rural areas, has lagged due to a lack of technical and social capacity at the community level (Weitz et al., 2017). Capacity issues are compounded at a local level, as existing research projects which identify, map, and manage the FEW nexus currently focus on the national and regional scale (Hibbett et al., 2020). Understanding the local FEW nexus is critical for both scientists and citizens, as most FEW goods and services originate in, and are managed by, rural and small communities (Rushforth and Ruddell, 2016), which are integrally connected to the national FEW network (Kennedy et al., 2007). To develop resilience to short-term disruption and sustainability in the face of long-term climate change, local communities must build capacity to adequately manage their FEW nexus.

Citizen science methods have been widely used as a means of increasing resilience within socio-ecological systems by building both technical and social capacity at a local level (Bonney et al., 2009; Buytaert et al., 2014; McGreavy et al., 2016). One method of citizen science increasingly used to engage citizens in the scientific and policy process is Public Participation in Scientific Research (PPSR). PPSR designs address the social, political, and economic goals of community stakeholders as well as those of scientists (Shirk et al., 2012). PPSR methods have been effectively applied in communities to generate data which will enhance resilience (Newman et al., 2017) and reduce vulnerability by improving a community's capacity to manage resources (Miller-Rushing and Bonney, 2012). Despite the ability of PPSR approaches to build community capacity, these methods have not been widely adopted in the context of FEW systems and critical supply chains [Yung et al. (2019)].

Considering the applicability of PPSR approaches to obtain local FEW nexus data and influence policy, we designed a 2-year PPSR project, *FEWSION for Community Resilience* (F4R), to supplement the mesoscale data collected by our NSF-funded initiative, FEWSION. This effort was designed in tandem with FEWSION to develop a cadre of engaged citizen volunteers and civic agencies to study vulnerabilities and resiliencies of local FEW systems in a rural, geographically-isolated city in the Southwest United States. We designed a suite of interrelated interventions that addressed training for volunteer citizens to collect and validate data on local FEW systems, use data analysis and visualization tools to identify local FEW vulnerabilities and resilience, and generate community-based conversations that would influence city-level policy.

In this paper we describe the design and implementation of the F4R model, and explore two research questions regarding the validity of this model for improving two aspects of community capacity that are crucial for building resilience: 1) to what extent did the F4R model generate sufficient last mile data to satisfy scientific requirements (technical capacity)?; and 2) to what extent did the F4R model build the community's ability and willingness to use data to manage FEW systems at the local level (social capacity)?

Background

In 2011, the World Economic Forum outlined the concept of a food-energy-water nexus (World Economic Forum Water Initiative, 2012); a complex network of synergies and tradeoffs that occur between these three critical resources. FEW nexus concepts encompass both the social and natural components of resource systems, including the flow of resources and their use, availability, and distribution across societies (Bizikova et al., 2013). Since 2011, the concept of the FEW nexus has been integrated into resource management policies across the world and is promoted as an advancement from traditional–often siloed–means of governing resource use (Biggs, 2015).

Effective management of the FEW nexus requires research into the dynamics and data gaps of this complex system (Ringler et al., 2013; Rushforth and Ruddell, 2018; Lant et al., 2019). Many current research projects analyzing the technical elements of the nexus, such as those funded by the National Science Foundation (NSF, 2016; Jones et al., 2017), have adopted interdisciplinary and transdisciplinary approaches to explore how the nexus functions and responds to disruptions (King and Jaafar, 2015; Rodriguez et al., 2019), to map the current resource flows (Jones et al., 2017), and map interconnections between resources (Daher and Mohtar, 2015). This research is thus framed towards addressing critical knowledge gaps regarding how the FEW nexus operates (Weitz et al., 2017; Lant et al., 2019), and is then being used to develop frameworks and concepts which can be applied to improve the management of the FEW nexus (Biggs, 2015). Despite current efforts, technical and social capacity issues remain salient as there are significant gaps in FEW nexus data regarding its response to disruptions, climate change, and urbanization (Weitz et al., 2017). Recent work has helped to fill and visualize an important data gap by generating mesoscale FEW data (Rushforth and Ruddell, 2018; Lant et al., 2019). The mesoscale of FEWSION's datasets is the finest level of detail on the system that currently can be obtained using publicly available aggregated statistics. FEWSION visualizations of mesoscale data show patterns of dependence and independence of FEW supply chains. For example, **Supplementary Figure S2** shows all commodity inflows for a western United States county. Users can select specific commodities as well as analytics to better understand the footprint, vulnerabilities, strengths, and dependencies for their county and state FEW systems.

Significant scalar issues pertain to both the technical and social capacity issues in FEW research and management (Hibbett et al., 2020). The majority of FEW research is focused at a global (D'Odorico et al., 2018), national (Lant et al., 2019), or large-city scale (Rushforth and Ruddell, 2016). Small towns, neighborhoods, and rural areas comprise the local scale of "last-mile" data, where the majority of FEW resources are produced, distributed and managed, and where people live and work. The "last mile" concept provides the supply chain link between the global/meso and the local scale in the FEW nexus, connecting regional distribution centers to neighborhoods, consumers, and retailers (Kennedy et al., 2007). Yet small communities typically lack understanding of the large scale FEW nexus as well as sufficient technical and social capacity to manage their FEW nexus and supply chains at this critical last mile scale (Piontak and Schulman, 2014; Hibbett et al., 2020). These local gaps are compounded by traditional resource management structures that favor top-down approaches to environmental governance (Bulkeley and Mol, 2003; Sperling and Berke, 2017).

Capacity to manage FEW systems at a local scale is hindered by a research agenda that is dominated by global or national scale studies, high-level policy, PhD-expert laboratory science, a lack of stakeholder engagement and prioritization of abstract technical knowledge (Sperling and Berke, 2017; Dai and Wu, 2018; Yung et al., 2019). Adopting only a technocratic lens to understand the FEW nexus overlooks the social dimensions of resource use, access, and distribution across the nexus (Biggs, 2015; Benson et al., 2017; Markolf et al., 2018). Policy makers need to understand both the technical and social dimensions of the FEW nexus to adequately manage threats (Markolf et al., 2018; Yung et al., 2019).

Thus, there is a pressing need to improve two capacity issues prevalent for the FEW nexus and local supply chains: 1) improve local technical capacity by generating "last mile" local FEW data, and 2) engage local stakeholders to improve their social capacity to adequately manage the FEW nexus (Hibbett et al., 2020). Gaps in local supply chain data and local supply chain management capacity cannot be filled without the input and involvement of community members, including staff and officials of local government agencies and non-profits, FEW providers and private sector leaders, and diverse groups of citizens. By addressing these gaps and engaging in data-driven discussions, community members can identify actions and decisions that meet the needs of the community and improve resilience of the local FEW nexus. The F4R model was developed to generate last-mile data, and through this process, build social capacity to manage local FEW resources with data-centered conversations which facilitate evidence-based policy making.

A CITIZEN-LED APPROACH FOR CAPACITY BUILDING

Building community resilience for the effective management of the local FEW nexus requires both technical and social capacity; a community needs to understand their existing resources, and have the capacity to design and implement responsive policies (McGreavy et al., 2016). Our definitions of technical and social capacity are situated within this framework of community resilience in socio-ecological systems (McGreavy et al., 2016), where systems require adaptive capacity in order to respond to change (Chapin et al., 2009). In our use, a community's technical capacity refers to the ability of a community to understand, map, and monitor their local FEW nexus. Folke et al. (2002) argue that, in order to build responsive policies to build community resilience in systems, a community must visualize their resources as complex systems and generate sufficient scientific knowledge which can be translated into policy.

Boyd and Folke (2012) argue that responsive policies must also be based upon multiple perspectives and forms of knowledge, thus requiring the engagement of diverse stakeholders in the policy making process (Hart and Aram, 2010). We define this requirement for diverse perspectives as a community's social capacity; the ability of stakeholders to engage in decision making and share information about complex issues (McGreavy et al., 2016). In our use, a community's social capacity can be explored through the social networks which develop for FEW management, and the ability of stakeholders to hold data-centred conversations about FEW related issues.

McGreavy et al. (2016) outline how citizen-led approaches to scientific research can contribute to both the technical and social capacity of a community. Firstly, specific types of citizen led approaches, such as citizen science, can build a community's technical capacity by generating local scale data (Dickinson et al., 2012), and has been widely used to supplement larger scale data sets to improve marine conservation (Cigliano et al., 2015) and sustainable water management (Buytaert et al., 2014; Buytaert et al., 2016). Other forms of citizen-led approaches, such as community based participatory research (CBPR), also offer expansions in a community's technical capacity by running training workshops which provide tools for community members to conduct data analysis (Unertl et al., 2016), create research projects (Jernigan, 2015), and to conduct policy advocacy based on these findings (Israel et al., 2010).

Secondly, the process of citizen-led approaches can build a community's social capacity by creating new social networks which facilitate information sharing and provide spaces for deliberative decision making across a wide range of stakeholders (McKinley and Fletcher, 2012). In their study of adaptive governance of vernal pools in Maine, United States, McGreavy et al. (2016) outlined that citizen science could contribute to both aspects of community resilience by "producing necessary scientific knowledge in ways that simultaneously built networks among diverse actors and institutions." Mooney-Somers and Maher (2009) analysis of the Indigenous Resiliency Project, e.g., demonstrates how CBPR approaches, which prioritize community voices in the research process, helped establish relationships between community organizations and researchers. These new citizen-scientist relationships have both helped researchers to better reflect community priorities in their research programs, and have helped community members to actively participate in, and have influence over, a range of health initiatives in their area (Mooney-Somers and Maher, 2009).

Benefits of these citizen-scientist relationships are plentiful; improving both technical and social capacity by generating data, raising community awareness of issues, encouraging critical thinking, and helping policy makers and citizens engage with uncertainties (Bodin, 2017; Yung et al., 2019).

Public Participation in Scientific Research

Citizen-science approaches use a variety of forms, techniques, and practices (Arnstein, 1969; Bonney et al., 2009). PPSR has been demarcated as a separate field within citizen science methodologies (Bonney et al., 2009). Shirk et al. (2012) define PPSR as "intentional collaborations in which members of the public engage in the process of research to generate new science-based knowledge." PPSR models encompass a range of citizen and scientist partnerships, from top-down data collection to citizen-led initiatives to address the political, social, or economic goals of a community (Shirk et al., 2012; **Supplementary Table S1**).

In line with the previously outlined examples of citizen science for community resilience (McGreavy et al., 2016), models of PPSR that are collaborative or co-created with citizens have the potential to build both technical and social capacity. These citizen engagement approaches enable researchers and citizens to engage in interdisciplinary research methodologies to explore the social dimensions of socio-ecological systems, a key component of the FEW nexus which is often overlooked (Biggs, 2015). Studies which incorporate PPSR methodologies have noted benefits for participants (Haywood, 2014), community capacity (Newman et al., 2017), and scientific research (Shirk et al., 2012). By engaging citizens in the scientific process, researchers gain access to more data, which can be applied to improve modelling (Landstrom et al., 2011) or provide fine-resolution data for existing data sets. At an individual participant level, PPSR researchers have reported gains in scientific literacy (McCallie et al., 2009), and changes in behaviors of participants which included increased stewardship and political engagement (Evans et al., 2005; Bonney et al., 2009).

Co-created and collaborative approaches similarly offer benefits in terms of social capacity (Israel et al., 2010). Projects focused on issues of environmental and personal health have demonstrated multiple benefits for both researchers and communities, many of which have had a direct impact on policy-level decisions (Grossberndt and Liu, 2016). By coupling local data with increased social capacity and increased individual awareness of environmental issues and changed behaviors, a co-created PPSR process provides a powerful tool to establish better policies to manage complex environmental problems (Bonney et al., 2009; Shirk et al., 2012). Thus, PPSR approaches have the ability to improve the technical and social capacity of communities to manage the complexity of FEW systems (Armitage et al., 2009; Shirk et al., 2012).

In this paper, we build upon the insights outlined above to examine the ability of a PPSR methodology for generating community capacity. We pose two research questions:

- RQ1) to what extent did the F4R model generate sufficient last mile data to satisfy scientific requirements (technical capacity)?
- RQ2) to what extent did the F4R model build the community's ability and willingness to use data to manage FEW systems at the local level (social capacity)?

METHODOLOGY

In this section, we explain the F4R model and our research framework. We then describe relevant details of project implementation, participants, and demographics. Finally, we outline our data collection and analysis processes.

Design of the FEWSION for Community Resilience (F4R) Model

In 2017, the NSF funded a supplement to FEWSION to form two cohorts of PPSR for iterative development of a process for local FEW data collection and capacity building. The cohorts were tasked with collaborating with researchers to identify and filter relevant content, data and questions for overall food, energy, and water supply chains. The initial design utilized mesoscale FEWSION data and a generic supply chain model (Saundry and Ruddell, 2020; **Supplementary Figure S1**), and embedded a process to of data collection and discussion of similarities and differences in supply chain structures, especially between food, energy, and water systems, different commodities, and local and corporate businesses. The result of this effort is FEWSION for Community Resilience (F4R). To form Cohort 1, initial engagement structures included a recruitment cycle during which the project team and collaborating organizations reached out through news, social media, and email lists to engage interested citizens. Activities for Cohort 1 included two 1.5˚days learning workshops followed by group meetings every 2 weeks, culminating with a community open house. Volunteers were asked to commit to 50 h of in-person time as well as time to complete background research, community outreach, and interviews.

Based on feedback from Cohort 1, in the following year Cohort 2 comprised three 1˚day learning workshops, whole-group meetings every 2˚weeks, plus less formal weekly meetings to address individual and small group needs. The overall time commitment was reduced to approximately 40 h of in-person time plus up to 40 h of additional time for data collection and community engagement.

The F4R model for both cohorts used a PPSR process to develop local FEW nexus technical and social capacity in participants. This was a co-created PPSR design, one that is jointly designed by the community and scientists, and in which citizens are involved in all aspects of the research process, from identifying questions to communicating findings. Thus, citizens, FEW stakeholders, and decision makers are directly involved and helping to guide the research process (**Supplementary Table S2**).

The F4R design aimed to generate benefits for both academic researchers and the local community. By including citizens in the scientific process of collecting and analyzing FEW nexus data, academic researchers (NSF/USDA, 2016) gained access to fine resolution data for identifying, mapping, and modeling the community-level FEW nexus. In return, the local municipality (citizens, organizations, and policy makers) would increase technical capacity to understand, obtain, and apply FEW nexus data to solve problems at multiple scales, and increase social capacity to ensure resilient, secure, and sustainable management of local FEW systems. Whilst the central aim of the project was data driven, we hypothesized that employing a PPSR process would provide benefits to the community beyond their technical capacity, such as stronger social networks of engaged volunteers and FEW stakeholders who could facilitate data-centered conversations and evidence-based policy making. **Supplementary Figure S3** outlines the F4R co-created PPSR design.

Implementation

Our project was piloted in a small, geographically-isolated city in the United States Southwest that contains one of three state universities. The municipality has a population of approximately 76,000 residents, and a fluctuating demographic of seasonal secondary homeowners from a major urban area to the south. It is the hub of a region of about 150,000 residents, with many rural Native American communities and small agricultural and mining towns. Like most small cities, the pilot site is a center of policy decisions and commerce that depends upon and loosely interacts with the surrounding rural communities. It is also representative of many communities in the Southwest that are vulnerable to drought and lack infrastructure and capacity to manage FEW policy decisions. Due to the community's small size, we theorized that it should be possible for a group of citizen scientists to successfully collect and analyze local FEW data (increase technical capacity), and engage local key FEW stakeholders such as government agencies and FEW distribution and supply chain managers for decision making (increase social capacity). These attributes, along with its convenient co-location with the research team, made it an ideal pilot location.

The project was piloted in two iterations, from October 2017 through May 2018 (Cohort 1), and October 2018 through June 2019 (Cohort 2). Each iteration was led by a team including the lead educator, the national FEW data scientists, and education researchers. In parallel with F4R, the lead data scientists designed and implemented a graduate-level course at the university.

Education Research Methodology

To inform the design and educational strategies of the PPSR model, and to examine the extent to which F4R built technical and social capacity at the local scale, we employed the methodology of design-based research (DBR). A DBR lens enables researchers to study learning processes as they are enacted, taking into account the complex interrelationships among the ideal design, its implementation, the contexts of a design, and its impact on participants (Brown, 1992; Eric et al., 2003). The DBR methodology is well-suited to the development of innovative learning interventions with its emphasis on collaboration between researchers, and educators, flexible and responsive data collection and analysis, and rapid prototyping and feedback to designers.

Supplementary Figure S4 illustrates how the DBR methodology was structured to examine the PPSR model. The scientists and educators who developed F4R held both articulated and tacit theories about what knowledge and abilities the PPSR volunteers would need to obtain local-scale FEW data—what kinds of intervention would be needed to ensure project outcomes. In this pilot study, DBR methodology enabled researchers, FEW data scientists, and the educational facilitator to rapidly prototype and adjust training and respond to participants' experiences, knowledge, interests, and motivation, thus maintaining engagement while meeting project goals.

We used a mixed-methods research design. Quantitative methods probed volunteer knowledge, motivation and perceived efficacy using scales from the Cornell DEVISE instruments (Phillips et al., 2014). There were too few participants in each cohort to conduct parametric analyses; categorical changes were used instead. Qualitative methods included researchers' observations and field notes of project events, participant-created artifacts, pre-and post-participation open response questionnaires, and one-on-one interviews post-program. Community perspectives were gathered through interviews and analysis of artifacts from community forums. Management and analysis of qualitative data was supported with the NVivo qualitative analysis software. The use of multiple methods and data sources, practice of triangulation, and discussion of findings with both staff and participants increase trustworthiness and applicability of findings (Lincoln and Guba, 1985).

Participants

Recruitment

Recruitment methods included newspaper, email, and social media announcements, and a digital application process. Participants self-identified through this outreach effort, which was based on their ability to connect with digital resources, attend in person sessions, and to allocate a significant time commitment to the project.

Cohort 1 Participants

Citizen volunteers for Cohort 1 included ten individuals, one of whom dropped out. Volunteers ranged in age from 27 to 65, with a median age of 48.

Cohort 2 Participants

Eleven volunteers were initially recruited for Cohort 2. Four dropped out and two joined midway through the project, resulting in participation of nine citizens. Volunteers ranged in age from 24 to 62+, with a median age of 37. In addition to citizen volunteers, the lead educator and FEW data scientists recruited several city and county managers, as well as state and national stakeholders. One of these, the communication director for a private statewide food bank, not only presented but also collaborated with one citizen volunteer to construct a map of food supply chains and distribution centers within the community and the county. Another citizen volunteer, a retired water engineer, sat on the city's water planning commission. The lead facilitator communicated intensively with volunteers and community members one-on-one through coffee hours, and email.

All citizen volunteers from Cohorts 1 and 2, and eight members of the community consented to participate in the education research study.

Education Research Data Collection and Analysis

Cohort 1

Data from citizen volunteers was collected at the individual and group level. Each individual completed pre- and post-program surveys with several components. Both the pre- and post-program surveys included scales from the Cornell DEVISE instruments (Phillips et al., 2014) to identify changes in motivation, awareness, and self-efficacy related to obtaining and analyzing local FEW data. The surveys also probed participant's perception of the value of the project for themselves and the community, and inventoried participant interests related to local FEW data collection and management. In-depth post-program semi-structured interviews were conducted with each volunteer. Several of the questions overlapped with or expanded on questions in the surveys. At the group level, the education researcher took the role of participant-observer during workshops and work sessions, generating notes with thick description (Geertz, 1973), asking for clarification, leading some activities, and collecting artifacts from presenters and volunteers. Relevant participant artifacts, such as posters, plans, and discussion summaries, were documented as photographs. Notes and artifacts were summarized into feedback that could be incorporated or reviewed again in Cohort 2.

Cohort 2

Data collection and analysis were similar to Cohort 1. Pre-surveys included an inventory of interests and skills related to the technical capacities of FEW data collection and management. Surveys also asked individuals about dimensions of social capacity, such as what they perceived to be the key issues in the community related to the FEW nexus, and whether they would continue working on local FEW issues after their participation ended. Citizens' preliminary skills and interests data were used by the lead educator to tailor the educational content of workshops, and also to work with each volunteer to identify an area of interest or strength that they could build upon that would help the project meet goals for technical or social capacity.

At the group level notes and artifacts were summarized between sessions into feedback that could be rapidly incorporated or reviewed again in future sessions. Participants' knowledge and perception of skills from a given session were captured using a brief questionnaire that included Likert-type items and short-answer responses. These were analyzed weekly for quick feedback to the leadership team, as well as over the span of participation to link volunteer experiences with developing capacities.

Recognizing that community members also held valuable perspectives related to the project, the researcher conducted semi-structured reflective interviews at the end of Cohort 2 with FEW nexus stakeholders such as the city sustainability managers, and the county emergency manager. These interviews probed community members' perceptions of the value of the project to their efforts as well as identified additional FEW nexus data that might be of use to their work in future cycles of implementation.

Lastly, the lead educator and data scientists documented volunteer progress in obtaining and representing local FEW nexus data. Two citizen volunteers worked intensively with these project staff, their fellow citizens, and members of the community to define data parameters, test visualization software, and finally map results for each FEW resource, tracing the supply chains from national and state distribution centers to local consumer outlets.

FINDINGS

Multiple findings arose from the DBR research. Here, we address two questions that emerged from our work: 1) to what extent did the F4R model generate sufficient last mile data to satisfy scientific requirements (technical capacity)?, and 2) to what extent did the F4R model build the community's ability and willingness to use data to manage FEW systems at the local level (social capacity)?

Building Technical Capacity

The F4R project was designed to build technical capacity by engaging citizens in the processes of 1) accessing and collecting mesoscale and last mile FEW supply chain data to map and monitor the local FEW nexus, and 2) building technical skills and content knowledge needed to identify local FEW applications and communicate about FEW nexus issues with other community members.

Cohort 1 Mesoscale and Last Mile Data Collection and Mapping

Participants and community partners in Cohort 1 had strong backgrounds and interests linked to sustainability programs, and helped to provide many insights on content, potential inaccuracies in data models, and refinement of the F4R Data Model and community engagement strategies. Community members and experts from the emergency management field were engaged in Cohort 1, and provided early input on immediate community applications and potential data model structures for critical lifelines that contributed to the development of the F4R Data Model (Pfeiffer, 2017).

Citizens split into two teams in Cohort 1 for data collection: one team focused on food providers, and the other focused on energy and water providers. The food team recorded data for some local grocery stores, the main farmer's market, the main local food bank, and staff leading sustainability programs for the city. They were able to conduct in depth interviews with the city staff members and food bank representatives, but ran into challenges with grocery stores. Grocery store managers were not able to provide the last mile technical data requested. In some cases, volunteers were able to continue communication up to corporate level representatives, but were still unable to conduct an interview for final data collection during the research cycle.

Citizen volunteers in Cohort 1 reported at the end of their participation that interviews with city and food bank representatives helped to identify actions that individuals could take to support local food donations, and decrease waste. The water and energy team was able to identify both local and regional sources of water, power, and natural gas. They were able to complete interviews with representatives of the regional power and natural gas companies, as well as the local city water provider. Some last mile data for energy and water were verified in these interviews; though the team ran into challenges with requests for local resolution data due to both limitations of capacity for data extraction and limits to water and energy infrastructure and usage that are safeguarded by federal regulations and "need to know."

Volunteers were also asked to test early prototypes of a mesoscale data visualization system, and their feedback helped to inform design decisions in future versions.

While progress was made in the design of the PPSR model and preliminary development of resources, Cohort 1 feedback identified several limitations of the initial effort. Participants felt the priorities of the data collection effort took priority over community engagement. They felt passively engaged in the project, and that the last-mile research goals did not reflect either their specific interests or issues they identified regarding the local FEW nexus. Key patterns identified in post-participation interviews included recommendations for improvement of user-interfaces, and suggestions that the project use more locally relevant examples and active learning and data collection strategies earlier in the process and with higher frequency.

Cohort 2 Mesoscale and Last Mile Data Collection and Mapping

Cohort 2 activities incorporated Cohort 1 feedback and generated a larger database of provider facilities that provide food, energy, and water, including more of the government and non-profit organizations that are linked to FEW providers and FEW related issues. Cohort 2 started preliminary analyses of mesoscale FEW capacity through use of the newly developed mesoscale online data tool, constructed basic social network diagrams and contact lists, and engaged a larger number of community members through open community work sessions. Mesoscale FEW data reports completed by Cohort 2 help to provide baseline data and visualizations about the overall flows coming to the community, and the counties, states, and regions that the community depends upon. Last-mile data collected by the end of Cohort 2 connected many of the distribution centers to local retail locations and gave sufficient resolution to identify the name, location, contact information, and types of commodities provided by local facilities. **Supplementary Figure S5** shows the data identified, where the retail nodes for most FEW commodities are located in and around the local community (Northern Arizona), but they are dependent on distribution facilities and transportation from the nearest large city (the Phoenix-metro area in Southern Arizona).

By obtaining this fine-resolution data and engaging with staff, professionals, and providers in the community, citizens were able to identify where their food, energy, and water comes from, what FEW resources are available in the community, and how their community is connected to larger supply chain systems. Cohort 2 focused most time and energy on identifying and developing the data collection tools and social network connections for FEW in the community. In one example, the state and local food bank network, Cohort 2 was able to collect commodity flow data, and they identified additional work to be done to complete more extensive collection of local-scale FEW data.

Analytical Skills and Technical Knowledge of Local FEW Systems

In addition to collecting data, the technical capacity of a community is also dependent on having individuals who can understand and analyze data, and can identify applications in which data will inform policy and action.

Cohort 1

Despite challenges, we saw changes in the level of detail and technical knowledge in Cohort 1 volunteers related to FEW nexus issues. All responding participants (nine out of nine) showed positive change scores for self-rated levels of proficiency in FEW concepts and skills.

Cohort 2

As in Cohort 1, in Cohort 2 we saw changes in the level of detail and technical knowledge in volunteers related to FEW nexus issues. Cohort 2 participants were asked the same question both before and after the program: "From your perspective, what are the key issues in our community related to food, energy, and water systems?" Prior to their joining the program, participants identified general issues related to water scarcity and waste, vulnerability due to lack of awareness or self-sufficiency, food supply, and lack of attention to renewable energy. After the program, six of nine participants described specific vulnerabilities, either related to disasters or hazards, limited local resources, dependence on external supply chains, or interdependencies of two or more systems (e.g., the energy cost of water access). Water access and quality remained a strong concern post-program.

Participants' proposed actions related to FEW systems became more specific, such as the need for more outreach and education, the need to consider indigenous perspectives on resource use, and the dependency on supply chain infrastructure. All recognized that limits to natural resources preclude much increase in growing food locally; and that the city is almost entirely dependent on other parts of the country for the availability and quality of its food, energy, and water. Since the conclusion of Cohort 2, several participants have continued engagement and have described expansion of their research and data collection and visualization skills.

Through F4R, participants were able to obtain sufficient last mile data to connect mesoscale and local scale FEW resources, and they were able to identify more specific initiatives, existing programs, and applications that support FEW systems.

Building Social Capacity

In line with previous PPSR studies (Shirk et al., 2012), improvements to the community's social capacity emerged as an outcome of the PPSR process including: 1) increased awareness of the local FEW nexus, and 2) new community connections.

Increased Awareness

Cohort 1

One trend identified by many of the participants in Cohort 1 included an increased awareness about the number of people and organizations in the community who actively work to improve or support some aspect of FEW. In some cases, participants shared detailed knowledge of history and resources with other participants. In the Post-Session Survey, half of respondents described a specific connection they made with someone else as part of the program session. Types of connections included: informative discussions and local connections/awareness of community organizations (including local farm share program and the Climate Action Plan). Since community conversations is one of the primary intended outcomes, we increased the amount of structured opportunities for these connections with community stakeholders in Cohort 2. FEW related topics and issues noted during pre and post surveys and through observational notes indicated diverse levels of specificity in participant knowledge about local FEW issues and applications. While there were some examples of expansion of awareness and knowledge, the majority of Cohort 1 participants showed no increase in self-efficacy and awareness.

Cohort 2

To gauge awareness, participants were asked "What questions do you have about our community's food, energy, and water systems?" The types of questions that participants asked changed between pre and post participation. Prior to the program, the seven participants who responded asked three questions about FEW in general: 1) sources, 2) how "local" is defined, and 3) ways to expand local systems. They asked one question about growing more food, two questions about water scarcity, and one question about the use of renewable energy. Two participants had questions about what policies were currently in place or what actions the city could take to better prepare (presumably for shortages or disruptions). A participant from Cohort 1 who continued to Cohort 2 wanted to know what progress had been made on identifying local data and if any other communities were studying FEW systems.

After participating in the program, Cohort 2 participants as a group asked more questions focused on what kinds of actions they or the community could take to ensure the local FEWS were more resilient to disruptions, and used in a more sustainable manner through conservation and reduced waste. Concerns about water scarcity were still present. Two participants raised questions related to social justice: access to FEW, especially in the rural communities surrounding the city, and to people who could not afford to take actions to reduce FEW resource use, such as installing alternative energy. One participant who participated in both cohorts expressed specific interest in plans that were in place vs. those to be implemented. They expressed a renewed sense of hope with their awareness of how many organizations and people were working towards solutions, but at the same time raised a question of doubt: "Are we able—locally—to really influence the resiliency of our FEW?" Given the complex interrelationships between national level and local scale FEW systems presented in the curriculum for volunteers, this question is important to address for future cohorts. Had either Cohort 1 or Cohort 2 been able to collect and analyze robust local data sets, perhaps this level of doubt would be addressed.

Building Community Connections

Cohort 1

Data from Cohort 1 indicated that citizen volunteers had success with a handful of individuals from utilities for preliminary analysis of trends, infrastructure, and capacity; however, they had neither the time nor project-related preparation to identify and build extensive relationships within the social network of agents who could obtain local FEW data. Despite these limitations, two Cohort 1 participants returned to help inform Cohort 2 participants, and were instrumental in providing guidance for Cohort 2.

Cohort 2

Overall, Cohort 2 and project staff were able to better map and understand social networks of the community, which helped to identify specific stakeholders who would be able to help develop content and applications, and contribute more data. The feedback from Cohort 1, and the increased focus on social networking and engagement of a variety of government, non-profit, and private stakeholders helped Cohort 2 greatly expand the network of programs and providers linked to F4R. More community members, including representatives from many different organizations, took part in interviews and provided context and contacts for FEW providers and issues in the community. These interviews quickly increased the number of direct connections and points of contact for multiple levels of FEW including local, county, regional, state, and national organizations (Hibbett et al., 2020; **Supplementary Figure S6**).

Ultimately, many more social connections were made and identified in Cohort 2 through social network mapping, guest speaker appearances, and community work sessions. Participants noted applications in community open houses, work sessions, and post-participation surveys. Stakeholder interviews conducted after the Cohort 2 work sessions helped to identify opportunities to improve needs assessment, research, and volunteer actions and community applications related to food access, emergency management, and public health.

Perceptions of the Value of F4R to the Community

When asked "what prompted you to get involved," community members emphasized the project's focus on obtaining data to improve local resilience or sustainability. One felt that the project's goals aligned with the mission of their organization, and greatly appreciated having one of the citizen scientists contribute their work to a project that helped their organization map distribution locations and identify food insecurity and food deserts in the area. All of the community members emphasized the need for more local data on FEW; as the emergency manager said, "Any local (last-mile) data the F4R project can provide our agency will help us improve our assumptions and plans for emergency management." One emergency manager also mentioned being "flabbergasted" by the complexity of national transportation lines and supply chains, and learning how the local community would be vulnerable to disasters in other parts of the country (e.g., a Los Angeles earthquake). A City Climate Change educator emphasized that the city's recent Climate Adaptation Plan is "a living document" and will need data to re-evaluate it every 5°years. The Director of Sustainable Communities hopes to shift faculty and student research on sustainability toward incorporating more quantitative data of the type being collected by the citizen scientists.

DISCUSSION

Our findings highlight the complex nature of building community resilience in socio-ecological systems. Results from Cohorts 1 and 2 suggest that our project improved both individual citizen's and the community's technical capacity. Developing the community's social capacity was more complex. Additional time, intentional evaluation of social structures, and development of relationships was needed to build the social capacity to engage more community members and identify meaningful community applications. Here, we explore how the challenges experienced during Cohort 1 impeded our ability to build the community's social capacity. We then outline how our re-design for Cohort 2 improved the community's social capacity. In doing so, we highlight the importance of flexibility and adaptability in citizen-led projects.

Cohort 1 Challenges

Problems related to social capacity included lower than expected development of content, definitions, and tools for both technical data and community engagement, and fewer interviews conducted for collecting FEW commodity flow data than initially hoped for. In the initial design phases, we assumed that citizen volunteers would have the necessary knowledge of and connections to gatekeepers, brokers, and FEW providers who owned datasets in their community. Whilst some volunteers did have knowledge of certain specific community programs and community events, many were not aware of specific details and status of current initiatives, infrastructure projects, or community and business plans and policies. Thus, the initial process, training, and cohort connections were not sufficient to provide access to required datasets for last-mile data collection, or to build social capacity through knowledge of, and engagement with, social networks of FEW stakeholders. Challenges in food, energy, and water data sharing practices limited the capacity of the cohort for generating last-mile data on the FEW nexus.

Re-Design to Improve Outcomes and Experiences

Based on feedback, challenges, and other findings from Cohort 1, significant changes to learning experiences and implementation were made for Cohort 2. Some changes were made to improve technical capacity. Although last mile data collection was limited in Cohort 1, the feedback, contacts, and content provided by participants helped to develop the data collection tools, inform engagement methods, and identify key resources to focus on for future cohorts. Other changes were made to improve our ability to build social capacity.

In Cohort 2, we focused on building relationships and engaging with stakeholders beyond basic FEW providers. For example, by engaging members of the government, including emergency management, sustainability and planning offices, and local non-profit organizations, many social connections were made, and general FEW data was confirmed. These community members were engaged as guest speakers, as field experience leaders to local facilities, in short interviews, and in open community work sessions. Most of these community members had significant social capital as well as skills and knowledge of certain aspects of FEW data. They became brokers of relationships with direct FEW providers, in addition to providing direction for community specific applications of FEW data that could improve community resilience.

The redesign of learning experiences for citizens decreased the amount of overall content, added more locally relevant examples, initiated the data collection training and collection steps much earlier in the process, and worked with volunteers individually to identify skills and merge interest areas with tasks that would be mutually beneficial. We decreased the overall time commitment and changed the training and meeting structure to include more active learning, field experiences, and work sessions. We added "coffee hour" meeting opportunities in less formal open discussion-based environments. The FEW data scientists refined and improved the data collection and visualization tools to make them more user-friendly and meaningful. Utilizing formative tools like surveys during community work sessions, and follow-up interviews was key in understanding and applying the recommendations of community members to inform next steps and development of data tools and reports.

The result of this redesign was a learning experience for volunteers in Cohort 2 (2018–2019) that addressed three objectives: 1) understanding the interrelationships of food, energy, and water and the types of socio-economic systems that gave rise to the shape of the national FEW system; 2) designing how the national data tools (visualizations, models, and the back-end database) would be connected to the local database, and 3) framing relevant questions to investigate at the local level, identifying relevant actors with access to data on local FEWS, and obtaining the local data through internet searches, networking with community organizations, and conducting face-to-face interviews to obtain data.

Cohort 2 Successes Following Redesign

The Cohort 2 redesign led to deeper understanding of the FEW nexus and increased engagement of citizen volunteers. Most volunteers expressed strong positive accomplishments as a result of participating, not only meeting their initial goal or goals but several going beyond that to achieve outcomes they had not anticipated. One participant who joined "to make a contribution," experienced frustration during their work because their initial path did not seem productive, and then discovered work related to the project from another university that enabled them to contribute to progress on local water quality issues and technologies for reclaiming water. Another participant who joined the project midway explained they hoped to learn how data analysis could be integrated with a scientific problem, and felt they had learned much about both the data realm and the FEW realm in their work. The other participant who joined midway through wanted to contribute their expertize and experience with local water quality issues, and to learn how to communicate issues to the public and to "influence the process." While they felt they had learned somewhat about the social dimensions of addressing local FEW issues, they expressed a desire to continue and learn more. The one participant who felt they did not meet their initial expectations explained that "it was all on me" because they did not have time to attend meetings and learn more. They did, however, contribute useful data to the project by identifying key FEW businesses, contacts, locations, and members of the board, all of which will be extremely useful in building the local social network that project leaders and future cohorts can nurture to gain access to more local FEW data.

RECOMMENDATIONS

The F4R model presented in this paper has the potential to successfully build a community's capacity to improve resilience and manage the local FEW nexus. During the implementation process, we identified four recommendations for the successful application of the F4R model in other communities: 1) embed opportunities for co-created PPSR, 2) build social capital, 3) integrate active learning strategies with user friendly tools, and 4) adopt existing materials and structure. In the following discussion, we elaborate upon the factors of success and recommend how practitioners can incorporate these factors into their projects.

Embed Opportunities for Co-Created PPSR

Based on experiences with Cohort 1, we strongly recommend that practitioners ensure their PPSR project is co-created. Unlike passive, or top-down forms of citizen engagement, co-created PPSR methods actively engage citizens in research (Shirk et al., 2012) by allowing citizens to meaningfully influence the project design, objectives, and process. Time dedicated to passive approaches and large amounts of background content stifle the ability of participants to feel as if they are making a difference. Participants need to have the opportunity to authentically contribute to conversations and content, and they need explicit steps, templates, and scaffolds that allow them to engage in data collection early and often. Providing opportunities and resources that allow for practice, incorporation of feedback, and authentic community application empowered participants to build skills and identify and design areas of mutual benefit.

We found that ensuring active engagement in the research process facilitated the collection of last-mile data, which is critical to a community's ability to identify, understand, and then manage their local FEW systems (Hibbett et al., 2020). To address the passive experience voiced by Cohort 1, we re-designed the Cohort 2 process to ensure active engagement by involving citizens earlier in the project, and introducing scientific tools which were streamlined and more user-friendly. Activities focused on learning and science included more opportunities for volunteers and community members to engage in discussions, ask questions, and give input on content and applications. Ensuring active engagement allowed us to improve last mile FEW data collection, as highlighted by the improvements in data collection from Cohort 1 to Cohort 2. We recommend that practitioners follow the steps outlined here to ensure co-created PPSR methods when implementing their own project.

Demographic Limitations in Recruitment

The recruitment mechanism used by this project did not lead to as much demographic representation as initially hoped for, though additional community groups were represented through students and community stakeholders who were engaged in the process. In future iterations we recommend adding explicit mechanisms for diversity, equity and inclusion, which could include team leadership representation, intentional outreach and recruitment, utilization of other types of media for communication, and greater flexibility on time commitment.

Build Social Capital to Improve Capacity

We define social capital as value built through developing a network of relationships that allow a community to function effectively (Robison et al., 2002; Sander, 2002; Aldrich and Meyer, 2015). Features of social organizations, such as trust, norms, and networks are generators of social capital (Burt, 2005). Our results highlight that building technical and social capacity requires social capital. Data collection and the building of technical capacity requires access to datasets that are collated/owned by members of the community. Our initial hypothesis was that volunteers would have pre-established connections to key members in the community that would provide this data. While some volunteers did have strong ties to employees in the FEW provider network, they typically were not the FEW provider representatives who either had the data, or were able to give approval for sharing the data. Thus, volunteer data requests were often sent up organizational chains, which may have limited the ability to obtain the requested data. In other cases, organizations and individuals had data, but did not have the capacity to provide data in the format needed for public sharing practices. These findings suggest that technical capacity at the local level is integrally related to social networks and social capacity. Overall, we found that it became important for the lead facilitator and volunteers to invest extended time to conduct background research and engage gatekeepers, brokers, and policymakers to understand the current state of community level data, actions, and initiatives.

Whilst these hurdles caused us to struggle with data collection at the beginning of the project, they emphasized the important role of social capital with regards to collecting FEW data and identifying meaningful community actions. Through observation, we re-designed the project to focus more time and resources on strategies which developed social capital. We developed social capital by being focused on relationship building with gatekeepers, brokers, FEW providers, and policymakers, to ensure that we had access to relevant FEW nexus datasets. Strengthening social networks of key stakeholders, citizens, and FEW providers through individuals collaborating to understand and improve FEW will improve the community's social capacity. However, social capital can take years to build, so it is important to identify and leverage existing relationships and social networks in order to understand FEW in the community. Thus, we recommend that practitioners plan to invest time and energy both early on and throughout a project to ensure that their projects can build social capital with a variety of FEW stakeholders across the community over the course of multiple years.

Integrate Active Learning Strategies With User-Friendly Tools

Original content of this project stemmed from a systems-thinking and data-focused perspective, and occurred in simultaneous development of data tools and engagement protocols. This meant that the data, connections, and applications were potentially infinite and provided an opportunity for all participants to guide the direction of research. However, participant feedback showed that this process was too ambiguous and at times overwhelming. There were repeated requests for improvements of user-interfaces for data tools and learning and training materials. Some items like national data models were identified as too abstract or big to consider for meaningful local actions. By using formative feedback tools and adopting a co-created approach to content development, we did improve the user-interface of learning materials and data collection and visualization tools.

It is important to note that a DBR educational research approach entails considerable resources and is used to develop new knowledge about learning systems. We employed a DBR approach to refine the F4R model and continually reflect on the extent to which the design was influencing desired outcomes. Future local FEW nexus projects that build on our design will likely be better served by a programmatic evaluation that addresses both formative and summative findings (e.g., Mertens and Wilson, 2012). This means encouraging, collecting, and incorporating input from participants and community members throughout the process to understand and adapt to specific community needs, and whether project goals have been successfully met.

The outcomes of the F4R project were met through integrated content and active learning experiences that provide specific examples of how FEW facilities and supply chains work. These included field experiences, informal "coffee shop" community meetings, and work sessions focused on providing individual or small group technical assistance. By incorporating participant and community member feedback we have now developed a full curriculum of learning and training materials, a facilitator training program, simple data collection and visualization tools that can be used across multiple software platforms, and supplementary materials needed for community engagement, communication, and scheduling of events (**Supplementary Table S3**). We recommend that practitioners adopt an iterative process with the training, structure, and guidelines that have been established through F4R.

Adopt Existing Materials and Structure

F4R is designed to be an iterative process that can be completed once for baseline data, or multiple times for improved and more extensive data sets. Each iteration is recommended to take 4–6°months.

Each cohort of participants had the opportunity to complete the following activities:

- 40 h of training and learning
- Open source data collection and entry
- Face-to-face work sessions, field experiences, and interviews with community stakeholders
- Contribution to Stewardship Action Plans and Community Reports

Participants can be citizen scientists, students, interns, staff members, community leaders and/or FEW providers. Practitioners and researchers who wish to implement F4R must complete a training. This training includes an overview of curriculum content, software, tools, a data collection model, and community engagement methods and requirements. Participants take part in shared learning sessions to build awareness and literacy focused around available tools and community activities, which helps the team to define the scope of research, significant community needs, and opportunities for action. Training and practice provided with data collection models and visualization tools, and interview methods are included to support proper and safe data collection and sharing practices. Scaffolded community engagement activities and small group work sessions allow participants and community members to build trust and the social capital needed to improve both technical and social capacity to manage FEW systems.

CONCLUSION

Considering the importance of the FEW nexus to many socio-natural and socio-economic processes, and in the face of burgeoning resource stress and uncertain threats, building the local capacity of communities to manage their nexus is essential. We have explored ways that a PPSR process successfully generated last mile data and improved the community's capacity to identify, map, and manage their local FEW nexus. Practitioners can immediately adopt the proposed PPSR process by following the methodology outlined in this paper. During the implementation process, we strongly recommend that practitioners adopt co-created PPSR methods, ensure they have access to sufficient social capital, and integrate active learning strategies with user friendly data collection and community engagement tools. Citizens and organizations can help lead the effort by initiating discussions about the FEW nexus pertaining to a wide variety of issues, including food and water access, public health, economic development, sustainability, and emergency management.

Our results demonstrate that a citizen-led approach can effectively improve awareness about FEW issues and build a community's capacity to identify, map, and engage organizations in their local FEW nexus. Capacity building is not restricted to the process itself; in our pilot study, participants capacity continues to increase after the project ended, with promising recent developments in social capacity, including: self-activation of participants and stakeholders who are now providing research, data, and information to the community, as well as stakeholders who are engaging the project team asking for contacts and data that would help inform new solutions for FEW related problems. An initial curriculum, tools, and support structure is now in place as a resource for others communities to adopt. Further analysis is required to explore how extending social networks, set up through our PPSR approach, influence the community's ability to identify, and solve, their local FEW nexus disruptions.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The research involving human participants was reviewed and approved by the Northern Arizona University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SR helped with analysis and led the writing. ER helped design the study, conduct analysis, and write the paper. EH helped design the study and write the paper. RR, NB, KP, and CH helped design the study and edit the paper. BR led the design of the study as Principal Investigator and helped write the paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.601220/full#supplementary-material.

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