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The Development of the INFEWS-ER: A Virtual Resource Center for Transdisciplinary Graduate Student Training at the Nexus of Food, Energy, and Water

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The Development of the INFEWS-ER: A Virtual Resource Center for Transdisciplinary Graduate Student Training at the Nexus of Food, Energy, and Water

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Problems at the nexus of Food, Energy and Water Systems (FEWS) are among the most complex challenges we face. Spanning simple to complex temporal, geographic, social, and political framings, the questions raised at this nexus require multidisciplinary if not transdisciplinary approaches. Answers to these questions must draw from engineering, the physical and biological sciences, and the social sciences. Practical solutions depend upon a wide community of stakeholders, including industry, policymakers, and the general public. Yet there are many obstacles to working in a transdisciplinary environment: unfamiliar concepts, specialized terminology, and countless "blind" spots. Graduate education occurs in disciplinary 'silos', often with little regard for the unintended consequences of our research. Existing pedagogical models do not usually train students to understand neighboring disciplines, thus limiting student learning to narrow areas of expertise, and obstructing their potential for transdisciplinary discourse over their careers. Our goal is a virtual resource center—the INFEWS-ER—that provides educational opportunities to supplement graduate students, especially in their development of transdisciplinary competences. Addressing the grand challenges at the heart of the FEWS nexus will depend upon such competence. Students and scholars from diverse disciplines are working together to develop the INFEWS-ER. To date, we have sponsored both a workshop and a symposium to identify priorities to design the initial curriculum.

We have also conducted surveys of the larger community of FEWS researchers. Our work confirms a widespread interest in transdisciplinary training and helps to identify core themes and promising pedagogical approaches. Our curriculum now centers upon several "Cohort Challenges," supported by various "Toolbox Modules" organized around key themes (e.g., communicating science). We plan to initiate the first cohort of students in October of 2018. Students who successfully complete their Cohort Challenges will be certified as the FEW Graduate Scholars. In this paper, we describe the development of this curriculum. We begin with the need for training in transdisciplinary research. We then describe the workshop and symposium, as well as our survey results. We conclude with an outline of the curriculum, including the current Cohort Challenges and Toolbox Modules.

Keywords: collaborative learning, pedagogy, convergence research, divergent thinking, team-based learning, online education, active learning, wicked problems

INTRODUCTION

Food, energy, and water systems provide fundamental resources so central to human existence that, if we are FEW-secure, we may not even spare a fleeting moment pondering their availability. Nations that succeed in maintaining low-cost food, energy, and water release their social, human, and financial capital for investment in areas far beyond the provision of life's basic resources (Brown, 1981; Hodell et al., 1995; Kick et al., 2011; van der Ploeg, 2011). FEW secure nations have made these investments, developing abundant solutions to these problems and significant social capital, both of which offer many potential benefits (Visser, 2000; Phelan, 2009). Such investments have even given rise to an economic engine of international aid organizations, intergovernmental agencies, and non-governmental organizations dedicated to the implementation of solutions alleviating pressures.

FEW solutions are desperately needed where security is not assured, especially considering shifts in population and demographics, which places increasing stress on the subsystems that deliver these vital resources. We know that if a population is insecure in its access to any one of these resources, the likelihood that it is insecure in all three is overwhelming.[1] Responding to the increasing global needs for food, energy, and water demands dramatic improvements in both sustainability and resiliency.[2] Whether we are applying lessons learned from FEW secure regions to insecure regions or developing innovations, there is no doubt increasing overall security will be increasingly challenging. This is well understood from the perspective of the FEW Nexus: influences in any one of the three subsystems will precipitate responses in at least one of the other two, but very likely both. Our FEW systems are tightly intertwined and interconnected, resulting in a "wicked problem" (Levin et al., 2012). The potential risks of unintended consequences, with impacts—technical, economic, or social—is significant. In fact, it may be inherent in our standard "silo-ed" approaches to solving problems that we need to be especially cautious as we seek to innovate in this environment. Individuals are now challenged at all levels to quantify the qualitative, to make decisions with incomplete or fuzzy information, to accept the liability associated with the intangible, to minimize the virtual impacts on bordering systems, and to collect and analyze the data describing all of these features and make it actionable. Individuals are now challenged to increase their depth of knowledge in multiple disciplines to solve these complex problems (NSF, 2014; Ruddell, 2017). Or they are challenged to develop transdisciplinary teamwork skills and transdisciplinary fluency in concepts, data, terminology, theories, and methodology.

Fundamentally neither food, energy, nor water is a discipline; indeed, they all encompass a spectrum of disciplines. As we continue to innovate, the results of our efforts are not just represented by the ideas we create, but also by the approaches we take when innovating. Individuals working in teams have a new opportunity to prepare themselves to have new access to both the depth and breadth necessary for the grand challenges of the future (**Figure 1**). The necessity for the meeting of multiple disciplines is not unique to complex problems in FEW. The convergence of engineering, computational, and the life sciences presents us today with revolutions in various aspects of healthcare, the Department of Defense ARPA-E program, industrial biotechnology, and the bio-based economy (NRC, 2014).

The success of these fields attracts a variety of groups, in addition to the US National Science Foundation (NSF, 2016; Saundry and Ruddell in review), to propose future grand challenges for our societies. Numerous other nations have proposed similarly named food, energy, and water-focused grand challenges (EC, 2013; Belmont Forum Urban Europe, 2016; Tilbury and Easterling, 2018). The National Academy of Engineering lists 14 grand challenges in engineering, half of which touch upon either energy, water, or the environment, or several simultaneously (NAE, 2008). The USDA-NIFA strategic

[1]More than 800 million are food insecure (Gustavsson et al., 2011), more than 1 billion of us are either energy (IEA, 2014) or water insecure (FAO, 2007). It is unclear what the intersection of these three sets are, but the authors assert that it is significant in number.

[2]Estimates suggest that food demand will increase by 70% (FAO, 2009), energy demand by 48% (EIA, 2017), and water demand by 55% (OECD, 2012).

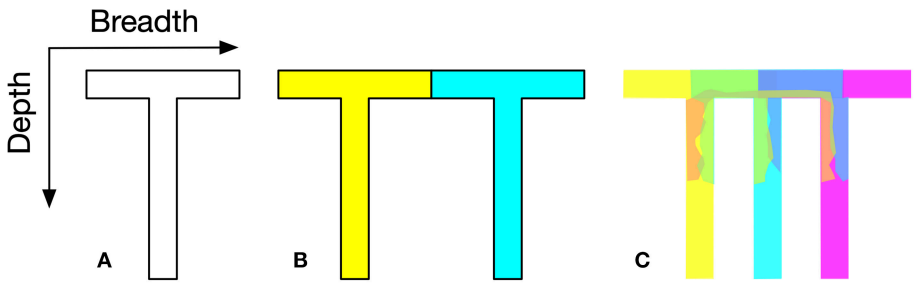

FIGURE 1 | Subject-matter depth and breadth in transdisciplinary education. In typical disciplinary education models of most universities **(A)**, individuals are encouraged to seek depth in their field, with some breadth in related areas, as represented by the T-bar shape (Enders and de Weert, 2009; Karjalainen et al., 2009; Oskam, 2009; Barile et al., 2012; Barile and Saviano, 2013; Harris et al., 2013; Sanchez et al., 2016). Multidisciplinary research **(B)** lines up multiple students, from multiple disciplines (represented by color) on common projects, but limits them to showing depth and breadth within their respective fields. Transdisciplinary research, as advocated here **(C)**, seeks to ensure that students have the tools to appreciate and build upon their peers in other disciplines. Their T-bars are closer, their disciplinary boundaries are removed, and knowledge permeates, revealing new shades of disciplinary integration, and thus new potential achievements by the participants.

goals for 2014–2018 similarly target issues of food security, climate change, and energy independence (USDA-NIFA, 2014). Seventeen sustainable development goals are advocated for by the United Nations[3], nearly all addressing the concerns of growing populations and changing demographics, more than half of which refer to core fundamental resources like food, energy, or water (UN, 2018). Explicated grand challenges are certainly useful for increasing the public awareness of ongoing efforts which support our future societies; they are also compelling motivating forces driving the research and technology development efforts associated with their resolution (NRC, 2014; Wolfe et al., 2016).

Thus, while the FEWS community has largely recognized that the grand challenges associated with this research agenda demand a transdisciplinary skill sets (Esler et al., 2016), we have relatively few resources for training students and researchers in the necessary research skills. There are some exceptions—for example, the US National Science Foundation has funded programs like the National Research Traineeship (NSF, 2018), formerly known as the IGERT, and the USDA-NIFA National Needs Fellowships (USDA-NIFA, 2017). Both seek to formulate a solid foundation in interdisciplinary and transdisciplinary training (Morse et al., 2007; Schmidt et al., 2012). As a result of these programs, several investigators have summarized the hallmarks of transdisciplinary achievement in student training (Manathunga et al., 2006; Borrego and Newswander, 2010; Graybill and Shandas, 2010; Kemp and Nurius, 2015). Still, we have a long way to go. We are building a virtual resource center (VRC)—the INFEWS-ER—to address this need, and below, we describe the work we have done thus far. We describe our efforts to define the curricular needs of the VRC, using two scholarly meetings and a survey. We also outline elements of the curriculum, including "Cohort Challenges" which will be offered beginning October 2018.

[3]Not unrelated are the Millennium Development Goals, declared by the United Nations in 2000, with a target date of 2015 (UN, 2015). We would interpret that the Sustainable Development Goals would follow the Millennium and build upon those successes.

MATERIALS AND METHODS

Kick-Off Meeting

In April 2017, we invited a group of scholars working in FEW fields to an initial kick-off meeting. The 29 participants were drawn mostly from the USDA Multistate Research Committee S-1032 on Sustainable Livestock and Poultry Production (S1032, 2013), a group of researchers who focus on the environmental impacts of food production. The goal of the meeting was to have this community identify learning outcomes and educational experiences for graduate students who engage with the INFEWS-ER. To this end, the agenda of the meeting offered presentations about online education and existing online resources for FEWS projects, as well as focus groups to help set priorities for INFEWS-ER content.

In the first set of focus groups, participants developed learning outcomes by first identifying a cognitive action verb associated with learning; that verb specified what students must be able to accomplish when engaging with transdisciplinary challenges, including, for example, "understanding," "writing," and "analyzing." These learning outcomes also included a learning statement—the specific content of the material students will be expected to master. These two elements define the conditions of acceptable performance, focusing on the desired end-product of the learning experience rather than the means or process of delivering instruction. After brainstorming, the participants placed the learning outcomes into different groups, creating general categories of inquiry, and then elevated learning outcomes that participants agreed were most important.

In the second set of focus groups, participants identified learning experiences that would generate the learning outcomes for students. Participants again brainstormed ideas for projects and curriculum, which were discussed and evaluated by other meeting participants. These groups then linked learning outcomes to learning experiences and identified the most promising options.

After the meeting, we synthesized the ideas and content discussed and developed a conceptual framework for the INFEWS-ER. In that process, we identified five thematic areas

for transdisciplinary research skills needed to work on wicked problems in FEW fields:

- Asking Transdisciplinary Questions,
- Creating High Performance Learning Communities,
- Communicating Science,
- Understanding Stakeholders, and
- Understanding Data, Modeling, and Analytics.

Based on the feedback obtained at the kick-off meeting, we determined that the INFEWS-ER should offer training in each of these areas through Toolbox Modules (described in more detail below). We also determined that the INFEWS-ER should offer students more extensive training by having them work through more complicated wicked problems, called "Cohort Challenges," in the FEWS fields. We identified three separate topics for these challenges (again, described in more detail below):

- Nutrient Loss Reduction, Recovery, and Reuse;
- Dairy Carbon; and
- Community Odor.

In these Cohort Challenges, students will work with a transdisciplinary team to formulate research questions, find the right kind of data to answer those questions, conduct relevant analyses, and produce final projects with tangible "products."

Inaugural Symposium and Survey of Symposium Participants

The goal of the Inaugural Symposium was to elicit more feedback from our collaborators in FEWS related fields to offer additional perspectives on the curriculum and to refine the learning outcomes. The participants in the Symposium were drawn from the kick-off meeting, as well as other researchers who were active in conducting FEWS-related research. We also invited graduate students, nominated by the participants working in the field, who might be interested in contributing to the INFEWS-ER or participating in its projects. Thus, they were a group of researchers and agent scientists whose work might be featured in the INFEWS-ER, who might contribute to the INFEWS-ER curriculum, and whose students might benefit from the additional training it may offer.

In the course of planning the symposium, we had questions about what the FEW research communities might want from the INFEWS-ER and what kinds of skills and expertise prospective contributors might bring to the project. To that end, we piloted two surveys for the participants in the Symposium that we hope to deploy to the wider FEWS field. The pre-symposium survey was designed to assess the participants' experience with delivering online education, as well as their priorities—for both their students and themselves—for the skills necessary for working in transdisciplinary teams on FEW problems. We received 24 responses, which amounted to a response rate of 85%. Fifty-two percent of the responses came from faculty members; 40% were graduate students; and the remaining 8% were other educational professionals.

The participants in the Symposium had extensive experience with some aspects of online pedagogy—for example, 82% had made notes or presentations available to students online; 68% had offered tests or quizzes in some learning management system; and 46% had collected students' written work online. In addition, many participants reporting having experience with asynchronous online interactions with students (50%) and blended learning using both online and classroom techniques (41%). Less common but still present were participants who had experience with synchronous online interactions with students (32%) and flipping the classroom (32%).

The survey also showed that there was widespread interest in the topics identified for the INFEWS-ER curriculum. The modules that generated the most interest, with 80% or more respondents reporting that they thought additional training was important, were those regarding building high performing interdisciplinary teams, understanding stakeholders, and communicating science to both lay audiences and scholarly communities.

Based on these materials, we formulated an agenda for the Symposium that introduced participants to existing online resources for researchers working in the FEWS field and that solicited participant input on effective online curriculum on the six topics for Toolbox Modules: High Performance Teams, Modeling Systems and Managing Data, Asking Transdisciplinary Questions, Communicating Science, and Understanding Stakeholders. In focus groups, we generated more specific ideas for curriculum tied to these topics. In addition, the Symposium offered focus groups for designing Cohort Challenges, exploring in more details the "wicked problems" that would constitute the basis for these exercises. Finally, the Symposium offered opportunities to hear from graduate students about how to fit the demands of engagement with the INFEWS-ER into their existing graduate programs, focusing on the logistics of delivering the curriculum.

THE DESIGN OF THE INFEWS-ER

The curricula of the INFEWS-ER are centered upon the matriculation of students into Cohort Challenges (**Figure 2**). All cohorts will be composed of students from numerous disciplines interested in grand challenges defined by FEW-related research endeavors. The student groups will maneuver through a Cohort Challenge under the guidance of one or more mentors, who help define the scope of the challenge and provide basic resources for initiating the work. As students become engaged with these challenges, mentors encourage them to sharpen their skills within the context of the thematic Toolbox Modules or by leveraging extant education resources already available to them. Conceptually, depending on the composition and past experiences of a given cohort, we would anticipate that the cohort would seek to enhance their abilities in the key skills their cohort is collectively lacking until their team has a complete set of basic competencies. They should know where they are strong, where they are weak, and where they need to seek assistance outside of their immediate cohort.

Cohort challenges culminate in the formation of one or more products suited to the specific team and challenge. The

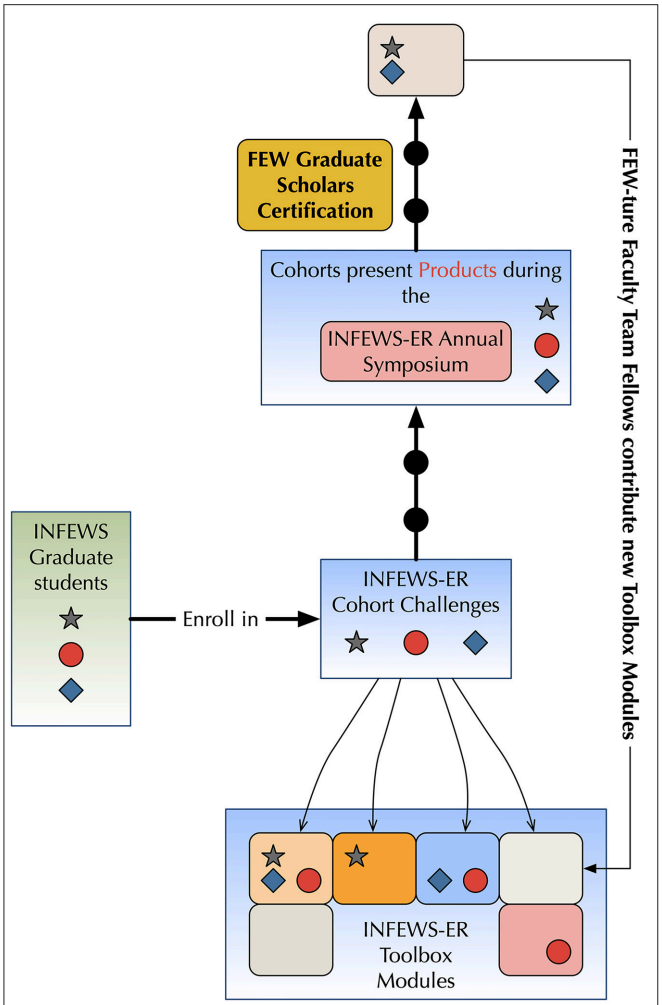

FIGURE 2 | Student participation in the INFEWS-ER. The curricula of the INFEWS-ER revolve around the Cohort Challenges. Students from multiple disciplines (represented by the symbols ★●◆) will enroll directly into open Challenges. Depending on the specifics of the cohort challenge, and their own mixture of disciplines, students will engage in a selection of Toolbox Modules. Working with a mentor, as indicated by the black dots (●) they will work toward a product responding to their challenge, to be presented during the INFEWS-ER Annual Symposium. Students completing the challenge will be certified by the FEW Graduate Scholars Program. Students interested in continuing and documenting the response to their Cohort Challenge as a case study are invited to prepare a Toolbox Module and add it to the Virtual Resource Center. These students will be invited to join the FEW-ture Faculty Team Program.

specific product for their challenge is similarly selected by the cohort, in consultation with their mentor(s); example products are described below with the current Cohort Challenges. The products will be presented publicly during the Annual INFEWS-ER Symposium. Many different products for their efforts may be possible. Some include: an extension product, a web learning module, or a science summary for a lay audience. The attendees during the symposium will include not only members of the INFEWS-ER development team, but also stakeholders with interests in the resolution of cohort challenges. This creates an environment where participants are tested to communicate their ideas effectively, while actively soliciting real feedback for their contributions to the grand challenges they are targeting.

The Cohort Challenges

The Cohort Challenges are the primary vehicle for transdisciplinary training for graduate students in the INFEWS-ER. They will be offered to cohorts of 5–10 graduate students recruited from different disciplines and are expected to require about a semester's worth of effort to complete. The students will be expected to work collaboratively in these multidisciplinary teams on a variety of different tasks that will introduce them to the complexity of working on "wicked problems." Through each Cohort Challenge, the participating student groups will be coached in critical collaborative processes of developing ground rules for decision-making and shared responsibilities, criteria to measure performance, to formulate relevant questions, to collect relevant data, to conduct necessary analyses, and to prepare the necessary reports and other final products for stakeholders and other audiences.

With its inaugural cohorts, the INFEWS-ER will offer three different Cohort Challenges. The first is the Dairy Carbon challenge, where students will be asked to model the carbon cycle on a simulation of a dairy farm, communicate those models to lay audiences, and explore the possibilities for reducing carbon losses. Students participating in this cohort challenge will track carbon entering a farm in animal feed, fuel, or animals and exiting a farm in animal products (milk, meat, or animals), as carbon emissions (volatile organic compounds, methane, carbon dioxide), or manure. Dairy farms are a complex connection of carbon cycles producing both human edible proteins and nutrients from non-edible sources and harmful greenhouse gases and odors. Students will generate final products that improve the sustainability of dairy systems by influencing the decisions of dairy farmers, policy makers, and food supply chain companies, potentially packaging these products as a web learning module augmenting an existing "Virtual Farm" developed by a team of investigators (PSU, 2017).

The second Cohort Challenge is about modeling and managing odor associated with animal production systems and the myriad impacts this has on neighboring communities. These systems emit odor, gases, and particulate matter that present challenges to neighboring communities, workers, and the wider environment. Many argue that the sustainability of the concentrated animal production industry in the United States and around the world depends on proactively addressing odor. The project asks students to investigate technologies for minimizing air emissions, while also accounting for the regulatory and economic environment governing animal production. Students participating in this project will contribute to existing assessment and planning tools for producers and their advisors.

The third Cohort Challenge addresses problems associated with nutrient loss reduction, recovery, and reuse. The chronic nutrient loss in food production, through both point and nonpoint sources, has a number of deleterious effects on a variety of environmental sinks, often large bodies of water.

Moreover, the nutrients themselves are limited in availability at the production phase and costly to transport, thus raising the energy costs associated with food production. While nutrient recovery and reuse would lower these energy costs, as well as create sources of renewable energy, these practices have not been widely adopted. Students working on this challenge will develop recommendations for water quality standards in one of several different locations where nutrient loss has presented a special problem. Students will be asked to collect data and perform relevant analyses to support those recommendations.

The Toolbox Modules

Via our interactions and surveys with FEWS scholars, we have identified thematic areas that provide a strong foundation for transdisciplinary collaborations, but these skills are sometimes taken for granted. Graduate programs rooted in traditional disciplines may not offer the training necessary to develop these skills. Thus, the INFEWS-ER will offer "Toolbox Modules" targeting each of these thematic areas and designed to enhance the performance of transdisciplinary teams and the quality of the resulting research products. These modules are being designed to be delivered in different ways—some emphasize group meetings; others will draw on asynchronous forms of instruction.

In the thematic area entitled "Asking Transdisciplinary Questions," students will be introduced to the challenges of developing research questions from a number of perspectives. Students will learn methods to identify gaps in scientific knowledge, to evaluate the scholarship of different fields that provide insights on relevant solutions, and to identify appropriate metrics for assessing answers to the questions. Throughout this module, students will see that defining compelling transdisciplinary research questions is an iterative process that will require ongoing input and refinement from a broad base of team members, including scientists, engineers, and stakeholders.

The INFEWS-ER will also offer a thematic area to train "High Performing Learning Communities" to enhance the productivity of transdisciplinary teams that address questions about FEW systems. Too often, teamwork is attributed to personal chemistry, when in fact, successful teams depend on mutual trust, accountability, and shared leadership. Through webinars and group meetings, students will learn how to expand their access to expertise by building "Personal Knowledge Networks;" how to set goals and assign responsibilities to ensure progress toward mutually identified goals; and how to work with assessment tools for measuring team performance. Students will be able to use these team-building skills not just in their Cohort Challenges but throughout the rest of their careers when working on collaborative projects.

The Toolbox Modules also seek to strengthen students' proficiency in engaging with the many audiences for FEWS research and scholarship. One such thematic area, "Communicating Science," focuses on communicating across disciplinary boundaries to build on existing sources of knowledge and to understand and design innovative solutions to FEWS problems. This Module seeks to formalize the communication processes within a team to identify best practices, avoid cross-disciplinary misunderstandings, and produce effective written and visual communications products. In a separate Toolbox Module, skills will be developed in transdisciplinary FEWS teams to engage with stakeholders who may vary in their familiarity and comfort with scientific knowledge. These stakeholders may be in a related scientific community, associated with different allied industries, or interested neighbors or consumers. In all cases, transdisciplinary research teams will need to convey their findings to publication outlets that serve both professional and public audiences that may be constrained by disciplinary boundaries or guided by unconscious bias. Through written and oral exercises, students will get valuable experience targeting their scientific communications for a number of different audiences.

Another thematic area will focus on "Understanding Stakeholders." Most FEWS problems have an impact on communities across many different scales—local, regional, national, and even global. Stakeholders from these many scales of communities have interests in the definition of these problems as well as the impact that the solutions might have on the social and economic life of neighbors. Moreover, the adoption of these solutions might require the cooperation of governmental authorities, where, again, jurisdiction may spread across many geographical boundaries. These modules will introduce students to different definitions and categories of stakeholders, guiding students through the process of identifying relevant organizations and assessing what level of interest the stakeholder has in the underlying problems and projects.

The final thematic area focuses on the integration of both quantitative and qualitative perspectives on FEW systems by "Understanding Data, Modeling, and Analytics." The complexity of FEW grand challenges inherently suggests that the development and testing of theory will rely on computational tools for analysis, expanding the potential reach of cohorts beyond the capabilities of most experimental methods of synthesis. Cohorts will need to conceptually visualize and articulate across disciplines the current state of "wicked problems" and opportunities for future enhancements. They will marshal existing and new forms of data indicative of the current and proposed system state. They will select from a growing variety of analytical tools, understanding and interpreting the validity and applicability of the output. Finally, by engaging with data, modeling, and analytics, cohorts will begin to substantiate their conclusions with data and analytical support, which will subsequently need to be communicated to and verified by their stakeholders.

THE POTENTIAL OF THE VIRTUAL RESOURCE CENTER

As we build the online content for the INFEWS-ER, we are emphasizing and enhancing graduate training. The Cohort Challenges and the Toolbox Modules are being designed to offer the initial cohorts of graduate students opportunities to work through FEWS problems, as well as some introduction to

supporting skills. In the longer term, however, the INFEWS-ER will become a virtual resource center, providing FEWS scholars with ongoing access to a wide range of materials to support teaching and research in the field. Indeed, we are maintaining active efforts to seek FEWS researchers from across the US and the world interested in developing content. For example, several Toolbox Modules that fit within the various thematic areas previously described are currently in the early stages of development: Effective Communications within Transdisciplinary Teams, Engaging Citizen Scientists as Stakeholder, Mesoscale FEW Datasets and Data Science, Basic Network Analytics, Geospatial Analytics using Python, and Systems Thinking. This is similarly true for Cohort Challenges where we are in the early stages of recruiting collaborators or developing cohort challenging for Disaster Relief Projects, Emergency Management, FEW Issues for Indigenous Communities, and Food and Energy Factors Affecting Water Quality in the Yangtze River.

We anticipate that over time, contributors will design modules for the INFEWS-ER content that can be offered as self-guided tutorials for individuals or small groups. Where synchronous interaction or mentor-guidance is essential, the resource center will provide future cohorts of faculty and students with learning resources including syllabi, exercises, and rubrics. We hope to encourage the use of best practices in educational design that allow single users to navigate the learning modules and even assess their mastery of the material. By using discussion forums, self-directed quizzes, and templates for finished projects, we hope that the INFEWS-ER can become a valuable resource for students and researchers in the field who need to engage with new topics to further their transdisciplinary goals. In addition, we expect that members of the FEWS community might draw on the Cohort Challenges and Toolbox Modules as sources of assignments and group projects for their own course offerings, departments, or labs.

Finally, we anticipate that the INFEWS-ER can become a repository for the web-based resources generated by others in the FEWS community. To date, in addition to the six universities represented by our primary team, we are now working with representatives from six new institutions to develop current and forthcoming Cohort Challenges and Toolbox Modules. With continued growth we hope to have an INFEWS-ER including representation from a wide variety of FEW challenges with entry points from every perspective in food, energy, and water. Given this basis of collaborators, we are also developing a FEWS-related bibliography, as we work on Cohort Challenges and Toolbox Modules. The bibliography is being collected in Zotero, an open-source citation management system (Zotero, 2018). The bibliography is organized thematically, offering newcomers to the field an entry into FEWS topics. As students and faculty engage through the INFEWS-ER, we expect the bibliographies to grow. The National Science Foundation's program on Innovations at the Nexus of Food, Energy, and Water Systems is designed to drive collaborative, transdisciplinary research that will lead to high-impact solutions. One key to collaboration is being able to find others working on similar problems and learn about their research. We expect that the INFEWS-ER can become a resource hub that empowers such collaborations by offering a central location for learning about the latest developments in research, teaching, and extension activities.

Despite all the promise, even an effective INFEWS-ER will not resolve all pedagogical challenges facing future graduates from programs targeting FEWS problems. Students will still transition to professional life, either in industry, the public sector, or academia, and they will still be tied to their selected discipline. The INFEWS-ER will offer certification for students who successfully complete Cohort Challenges, but until these certifications are tested in the field, we will not know their perceived value. To combat this concern, we maintain relationships allowing us to seek feedback on the quality of our programs via a steering committee and via related stakeholder groups including professionals in industry and academia. To provide this steering committee with the resources necessary for evaluation of the INFEWS-ER, the VRC shall develop a system providing templates for formative and summative assessment of student works generated via both toolbox modules and cohort challenges.

We also plan to cultivate stakeholder relationships with the academic institutions and graduate programs where our students are currently enrolled. The academic requirements associated with standard graduate training requirements are significant, and currently student engagement in the INFEWS-ER is extracurricular. Thus, far, we have been successful in recruiting students, including some students who have participated in multiple ways. Their engagement with the INFEWS-ER should not, however, come at a detriment to their programs; rather, it should augment the overall quality of their training. As a matter of fact, we recognize that there will be instances where students may need additional incentive, beyond the FEW Graduate Scholar Certification, to justify participation. To ensure that the opportunities within the INFEWS-ER are indeed valued and recognized by the students, their advisors, and their graduate programs we are working with interested graduate advisors to provide "independent study" credit via their home institutions. To facilitate this, we will share all documented products produced from both Cohort Challenges and Toolbox Modules to advisors who would later award the independent study credit to students. We would consider this a strong representation of the potential value of the learning opportunities offered here. We anticipate in the future that this will support the overall sustainability of the INFEWS-ER.

In building the INFEWS-ER, we have engaged widely with research groups around the world who are working on projects to advance FEWS sustainability. In these engagements, our colleagues have noted the need for resources to support transdisciplinary training and collaboration. They have also been enthusiastic enough about the promise of the INFEWS-ER to collaborate with our team and work to provide those resources themselves. If we are successful, we hope to see students developing systematic processes to transition from multidisciplinary behaviors to transdisciplinary. It would thus be this generation of student cohorts who would be in the best position to target large societal problems, at the nexus of food, energy, and water, and indeed beyond.

AUTHOR CONTRIBUTIONS

LR conceived of the idea, furthered the development of the idea through the kick-off meeting and inaugural symposium, outlined and drafted the manuscript, solicited suggestions from the co-authors, managed the revision process, submitted the manuscript, and stewarded the submission through the review process. A-MM conceived of the idea, furthered the development of the idea through the kick-off meeting and inaugural symposium, outlined and drafted the manuscript, and participated in the revision process. RK, JK, DM, AP, and JC conceived of the idea, furthered the development of the idea through the kick-off meeting and inaugural symposium, and participated in the revision process. DC, DS, BR, and EH furthered the development of the idea through the kick-off meeting and inaugural symposium and participated in the revision process. JH, SR, NM, XC, and PS furthered the development of the idea through the inaugural symposium and participated in the revision process.

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