

Applying Systems Thinking to Wicked Water Problems

An Accelerated Introduction for Researchers

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ABSTRACT: Increasingly at the center of many complex problems facing citizens, localities, states, and nations, water is the focus of research across many disciplines. Water issues are at the nexus of the economy, society, politics, the environment, public health, and other sectors. This level of complexity and the multiple perspectives involved makes water problems highly suited for systems thinking analysis. Yet the systems thinking field is characterized by great diversity in approaches, theories, and methods, which can be daunting and dissuade newcomers and non-experts. ThinkWater is a USDA-funded program that uses advances in systems thinking training to increase understanding about water issues. The program specifically targets primary and higher education, research, and Extension and outreach. ThinkWater conducted a case study using brief training in the underlying rules of systems thinking to see whether and how it enhanced the ongoing work of a cohort of advanced water researchers. The researchers came from a variety of disciplines and backgrounds, yet all reported benefit from their short exposure. Multiple participants reported a newfound appreciation that scientific models are approximations of reality as well as increased capacity to identify and articulate the perspectives implicit in disciplinary approaches. The researchers also appreciated systems thinking as a mechanism for incorporating societal factors into natural science models, identifying the broader relevance of their work, and for sharing their research with those outside their discipline and academia¹.

KEYWORDS: DSRP | natural resources | systems | mental model | interdisciplinary | complexity

Introduction

Few issues are deemed as vitally important in so many domains (e.g., economic, health, security, political) across the globe as water. The multifaceted nature and complexity of water-related issues and the interdisciplinary nature of their study can hinder knowledge accumulation, problem solving, and

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identification of long-term solutions. “Water” writ large is the epitome of a wicked problem, necessitating systems thinking approaches for understanding and addressing it. As an expert in nutrition and population medicine explained: “Big impacts of water are easy to see. Big problems with water management are easy to critique. What is not so easy to do is to articulate how our daily, local water decisions impact a complex web of ecosystems that exist outside of our daily experiences.” There is increasing need for ways to tackle the complexity of water issues themselves, along with the ways they are studied and addressed. This paper documents a fellowship designed to teach systems thinking to water researchers.

The term “wicked problems” was initially used to describe exceedingly complex social, political, and economic problems that are resistant to solution [1]. There are many characteristics of these problems that make them challenging. In general, wicked problems entail (1) multiple, interrelated issues that involve several sectors such as the economy, health, and the environment; (2) many stakeholders and interested parties (from individuals to institutions) that approach the problem at different levels of scale (e.g., community, national, international); (3) a diversity of perspectives on the problem, its optimal solution and the means to achieve that—which lead to power struggles; and (4) high uncertainty surrounding the possible consequences of attempts to address the problem.

While initially used primarily to characterize policy issues, wicked problems are now understood to occur across all realms. Standard problem-solving mechanisms are generally insufficient to address wicked problems; systems thinking approaches are necessary. However, systems thinking (ST) is a diverse field characterized by multiple and sometimes hard to reconcile subfields [2]. This makes it challenging for those who are not experts in the field to both (1) understand exactly what systems thinking is and (2) know which systems thinking theories, methods, tools, and approaches are suited for a particular problem. While specific ST strategies have been applied in the field of resource management before, an integrated approach is necessary. A researcher explained: “We do not have a shortage of effort in applying systems thinking to complex problems. However, we seem to still be searching for a reliable systems thinking strategy that will help us achieve desired objectives.”

We describe a newer approach to teaching the fundamentals of ST, utilizing its four underlying cognitive rules called DSRP, which stands for making distinctions and identifying systems, relationships, and perspectives [3]. This approach both accommodates the complexity and multiple perspectives involved in wicked problems and provides common ground for water researchers and practitioners from disparate disciplines and professional domains. Beyond enhancing the scholarship of leading researchers, any intervention must also be cost-effective and scalable.

In 2016, ThinkWater, a USDA NIFA-funded initiative, sought to assess the effects of concentrated systems thinking training for sophisticated water researchers. The vision and mission of ThinkWater is to engage, educate and empower a nation of water thinkers. This entails working in education (pre-K to PhD), research, and outreach/Extension, primarily by delivering free resources and cost-effective and scalable ST training. ThinkWater conducts ongoing research to understand the effects of various ST initiatives among its target audiences.

Having assessed the efficacy of teaching systems thinking in middle school education through a 2015-16 collaboration with Arizona Project WET, ThinkWater sought to affect water-related research through an ST fellowship. The first year of the USDA-funded ThinkWater Fellowship targeted researchers working on complex, water-related issues. In addition to learning systems thinking, these researchers were agreeing to participate in a study on the effects of applying what they learned to their research.

Over the course of approximately 7 months involving 22 hours of face-to-face interaction, ThinkWater Fellows were taught the skills, approaches, and theoretical frameworks of systems thinking to apply to their research topic. To gauge the efficacy of this brief intervention, fellows were required to participate in pre- and post-training assessments, including interviews, surveys, and written narratives.

In preparation for this fellowship, Drs. Derek and Laura Cabrera had taught an abbreviated systems thinking (ST) class through the Cornell Institute for Public Affairs. This class enabled them to teach ST as an analytical method to a diverse group of policy fellows, to assess their overall comprehension after the brief exposure, and to see whether and how it shaped their policy-relevant work. Students completed the course with a concise presentation and written article explaining their systems thinking analyses of their topics, all of which were featured in a special issue of the *Cornell Policy Review* [4].

Teaching Systems Thinking: Core Principles

Though ST approaches and tools come in many varieties, they do have some commonalities—in addition to the obvious focus on *systems*. Systems thinking emerged in part as a reaction to dominant modes of thinking that proved inadequate to address our increasingly complex problems. ST proponents advocated a holistic orientation to phenomena, rejecting tendencies toward reductionism, or a narrow focus on the constituent parts of a system (see [5]). This focus is accompanied by the concept of emergence, the idea that the behavior of a system cannot be reduced to its tangible parts. A systemic focus appreciates complex network structures and their operation even within human-imposed hierarchy [6]. Causality is generally understood as complex and multifaceted rather than linear, prompting a search for causes others than those most proximate in time and space [7]. Finally, systems thinkers tend to appreciate the ubiquity of perspective taking, as seen in the focus on “mental models,” or approximations of reality.

These shared traits notwithstanding, one might easily see discrete systems thinking practices (e.g., soft systems methodology, agent-based modeling, systems engineering) as strikingly different and perhaps incompatible. Ironically, while demand grows for methods and tools to understand and address complex problems, the increasing pluralism (diversity) within the ST field can be quite a deterrent for non-specialists. What has long been necessary is both an understanding of what unites the field and a mechanism for distilling universal systems thinking principles in a clear, easy to teach manner. The focus needs to be less on a specialized theory, tool, or method, and more about pragmatic understanding of what it means to *systems think*.

Four Underlying Rules

Systems thinking (and cognition in general) is an emergent property of the varied and simultaneous combination of four cognitive acts: making distinctions and identifying systems, relationships, and perspectives, or DSRP [2,3]. They underlie the entirety of the field of systems thinking, and are often referred to as rules or patterns. Understanding that these four skills underlie all systems thinking tools and approaches makes ST widely accessible and of great utility to researchers and practitioners in all realms. We will explain each rule below, but in short, distinctions (D) can be made between and among things, things can be organized into systems (S) composed of both parts and wholes, we must search out the relationships (R) between and among things, and question the perspectives (P) implicit in each of the above.

Distinctions

To make a distinction—to identify something while simultaneously distinguishing it from other things—is an act of boundary making that is often largely unconscious. As with all DSRP rules, consciousness of our distinction making enhances our thinking and understanding. Each DSRP rule is comprised of two co-implying elements, meaning the existence of each element entails the existence of the other. For distinctions, the co-implying elements are the identity (the thing that is the focus of attention) and the other (that which is *not* the identity).

Conscious distinction making heightens awareness of the conceptual boundaries all researchers must set and the tradeoffs that lie therein. The systematic application of this rule brings increased clarity and precision of thinking, while promoting awareness of the perspective(s) that inform the identifications we make (and what is inside and outside the boundary). The distinctions we make, after all, have theoretical, practical, and moral implications. How we name (identify) a phenomenon and distinguish it from other things can have unintended and sometimes long-lasting consequences, since categories, once popularized, are easily reified. Classification of all things—physical, social, conceptual—should always be viewed as distinction making according to a particular perspective, rather than as reality.

Systems

An obvious cognitive task for systems thinkers is the identification of systems—both splitting things into *parts* and grouping things into larger *wholes*. The systems rule holds that any thing can be split into parts or lumped into a whole (its two co-implying elements). Conscious application of the systems rule entails seemingly opposite mental actions. We must divide things into their constituent parts (and identify the parts of those parts, and so on), but also see every thing as part of a larger whole, then ask ourselves what larger thing that whole belongs to, etc. These two acts serve to balance out overly reductionist or holist tendencies.

The systems rule accords with the reality that a part cannot exist independent of a whole, nor can a whole exist stripped of any parts. Thus a middle way is achieved, accommodating those who proceed from a micro- or a macro-level orientation. Another implication of the systems rule is that any thing can

simultaneously be both a whole (a thing comprised of parts) and a part (belonging to a larger whole). While part-whole analysis may seem simple, its implications are profound for the study of complex phenomena.

Relationships

An important but often neglected aspect of systems is the relationships existing between and among its parts, and with other systems. The relationships rule is that any thing can be related to any other thing. Again, things can be tangible objects, animate objects, concepts, etc. The two elements of this rule are action and reaction. Relationships are typically unseen or overlooked, making it crucial for systems thinkers to find and identify (by making a distinction) the salient relationships in the systems we study. These relationships come in many forms: X causes Y, X is positively or negatively correlated with Y, X is linked to Y through Z, etc.

Careful identification of the relationships in a system helps us understand that many phenomena result from webs of causality rather than a linear causal path. Additionally, relationships can consist of complex systems unto themselves that must be broken down and analyzed. Identifying the interrelations between and among things is a critical tool for understanding the dynamic properties of complex systems and the possible consequences (including unintended ones) of changing any part of a system.

Perspectives

According to the perspectives rule, any thing or idea can be the point or a view of a perspective. The rule's two elements are point (the "thing" doing the seeing) and view (the thing being seen). Careful application of this rule entails acknowledging that what we perceive as reality is really a mental model, an approximation of reality, and just one of many ways to understand information. Many of society's more complex and seemingly intractable problems result from a mismatch between reality and our perceptions of reality [8].

Practicing the perspectives rule means continuously trying to identify the perspectives implicit in all information we encounter, beginning with the perspectives from which we are viewing and understanding phenomena. Allowing the consideration and application of alternative perspectives is a critical systems thinking tool that facilitates problem solving and consensus building. We are increasingly accustomed to recognizing conceptual perspectives, such as a "pro-business" view or a disciplinary method of modeling problems. But it is equally useful to take the perspective of things, for example, to depict a river system from the perspective of nitrogen or local culture.

Although we have discussed the distinctions, systems, relationships, and perspectives rules separately, these four cognitive acts occur simultaneously in myriad combinations. While each cognitive act is in some ways basic, the mixing of the four can produce thought of incredible complexity. This complexity is part of what makes systems challenging to understand and also what makes their visual depiction so

useful. Let us consider some simpler combinations of the DSRP rules, starting with perspectives and systems.

The ThinkWater Fellowship was guided by the hypothesis that the underlying rules of systems thinking—DSRP—can be taught and learned across a variety of contexts. We expected that instruction in DSRP would be no less beneficial to those with advanced levels of education and training than those in middle school. In fact, we anticipated that learning the DSRP rules, rather than specialized training in a particular systems tool or theory, would be especially useful for this group, given the inherent complexity and cross-disciplinary nature of water problems.

Methods

Since the ThinkWater Fellowship was simultaneously an intervention and a study, human subjects approval for the research was obtained through the University of Wisconsin - Extension Institutional Review Board. The fellowship was advertised in early 2016, and a cohort was selected by March. Since the goal of the intervention was to enhance interdisciplinary research on wicked water problems, fellows were chosen from a variety of fields, including population health, economics, urban planning, and biological and environmental engineering. Fellows consented to participate in a research study and were offered a \$1000 stipend upon completion of the fellowship, plus the opportunity to compete for a \$2500 prize for the best presentation at a live broadcast systems thinking symposium in December 2016.

The training (see Table 1) consisted of reading a book on systems thinking followed by 2 days of in-person training on DSRP/ST. After writing up and mapping their research topics, the Fellows met in person to discuss their metamaps. Additional elements were a one-on-one consultation, and rehearsal of the symposium presentations. Fellows concluded by submitting a final paper applying DSRP to their water-related work and reflecting on that process.

Date(s)	Activity	Comments	N	Estimated time
3/16	Applications submitted; 12 fellows chosen	Cohort reduced to 11 due to schedule conflict	12	n/a
4/16 - 5/16	Read <i>Systems Thinking Made Simple (STMS)</i>	First five chapters	11	5 hours
5/31/16	Pre-training survey (n=11)	Assessing prior ST exposure and current understanding	11	n/a
6/1/16	Training day one; short interviews	Review STMS & ST concepts	10	6 hours
6/2/16	Training day two; post-training survey	Mapping their specific projects	10	6 hours

9/28/16	Training and feedback on maps of research projects	Fellows present research maps and receive feedback	8	5 hours
10/16-11/16	One-on-one consultations about research projects	Assistance applying DSRP to individual projects	8	1 hour
11/30/16	Practice presentations	Feedback from trainers/peers	8	4 hours
12/6/16	Cornell ST Symposium	Live broadcast presentations	6	variable
1/30/17	Submission of final papers describing effect of training on water-related research, approach, or thinking.	Assignment: “Explain visually and in words your research before and after your application of ST.”	8	variable

Table 1: Components of ThinkWater Research Fellows Program

2016 Cohort of ThinkWater Fellows

There were 12 applicants chosen for the 2016 ThinkWater Fellowship, all with some Cornell affiliation. One individual had to drop out due to a scheduling conflict. 4 participants were male and 7 were female with ages ranging from 22 to 60. The racial and ethnic identification of the majority of participants was white, with 1 identifying as black, 1 as Native American or Alaskan Native, and 2 as Hispanic. 8 were US citizens; international participants were from South America, Africa, and Europe. While most were advanced doctoral students, an associate professor and a research coordinator also participated. The researchers were roughly split in terms of representing the natural and social sciences.

Only one participant had formal systems thinking training, with the remainder divided between zero and limited exposure. Participants were asked about their systems thinking exposure in the fellowship application and prior to the first training. Of the 11, 5 reported no training; the others primarily identified a limited introduction or exposure to certain systems thinking concepts during a non-ST class previously taken. Two without training were somewhat familiar with some ST ideas through their interaction with colleagues. In almost all cases, their exposure was to systems dynamics or systems engineering.

Findings and Discussion

Systems Thinking: Relevance for Water-Related Research

Prior to the in-person training, participants were asked to explain the perceived relevance of systems thinking to their work. The most frequently referenced factors were addressing the immense complexity involved in their research, and the benefits of applying new perspectives to their work. As one respondent wrote, “I work with urban water management. As an engineer, I have purposefully avoided ... people (the “public”), to keep the system easier to understand. I would like to better understand how people interact and alter the environment, and ultimately make our water less or more polluted and/or available.” Two respondents expected that ST would facilitate broad translation and communication of their work.

Another anticipated increased understanding of the broader societal framework within which her work is situated along with the unintended consequences of policies applied in one realm on another. She concluded, “The relevance of systems thinking is so enormous and enriching that I hope to apply it to every funding proposal, project and manuscript I intend to write.”

Respondents were apt to link systems thinking with complexity and interdisciplinarity. The universality of DSRP provides a common language that facilitates cross-disciplinary collaboration. And the principles of systems thinking facilitate the explanation of complex systems, which are often emergent properties of agents following simple rules [2]. 10 participants characterized their work as interdisciplinary, with researchers working across 3-5 disciplines each. 9 of the 11 reported “currently collaborat[ing] with scholars in fields outside [their] own.” 6 described the level of complexity of their current work as “somewhat complex,” 5 as “highly complex.”

Outcomes: Reading Systems Thinking Made Simple Textbook

By the time of the pre-training survey, fellows were expected to have read the first five chapters of *Systems Thinking Made Simple* [2], hereafter STMS. They were asked to answer the question “To what degree has reading STMS increased your understanding of systems thinking” and then to elaborate that answer in an open-ended response. Viewing the results in Figure 1, it should be noted that one of the “not at all” responses was from a participant who had not yet read the book.

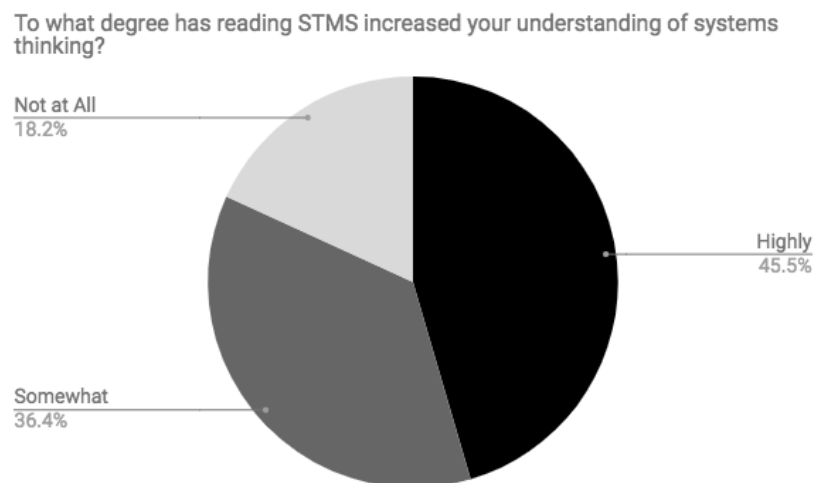


Figure 1: Role of STMS Book in Understanding ST

While two respondents expressed a preference for a PhD-targeted text, the majority of participants appreciated the “tangible,” practical approach and clarity with which systems thinking was explained STMS. As one respondent wrote, “First time I’ve actually read a definition of what is meant by the term, seen its relevance, and been given logical stepwise training on how to use this approach.”

Respondents were asked what specific information or ideas from *STMS* resonated with them and what areas elicited confusion or a need for additional help. In terms of areas of resonance, respondents identified various tools for visualization provided in the book the most. In particular, they appreciated mapping problems in terms of distinctions, systems, relationships, and perspectives, and the chapter on “cognitive jigs,” which are common cognitive structures built from DSRP rules (see infographic, www.thinkwater.us). One researcher wrote, “I am a visual thinker, and the ways that *STMS* provides to visualize the underlying structure has already helped me to better understand and approach my research.” Others singled out the focus on the importance of perspectives (and understanding mental models) for deeper comprehension and problem solving. As one researcher wrote, “The idea that what is true for one person/institution may not be the same for another is [a] concept that is important to any (possibly all) wicked environmental problems.” Another participant explained that he derived the greatest benefit for his research from learning “how to make visible and tangible the mental models of others through visual communication of their implicit logics of part-whole relationships.”

Participants also answered the question, “Are there any areas of confusion about systems thinking that you need help with?” While more than one third reported no confusion, almost half of participants cited the chapter on structure and information and mapping ideas (using MetaMap software, developed by Cabrera Research Lab), and reported trouble comprehending and/or applying that part. Others focused on the application of DSRP, wanting more complex examples and help applying the rules to their own research.

Outcomes: In-Person Training

Participants were asked to complete a short survey about the 2-day in-person training upon its completion. 6 participants took the survey. The overall assessment of the training was favorable. Asked, “When compared to other trainings, how does this one rate?” responses were evenly divided between “useful” and “very useful.” Furthermore, all *disagreed* (half strongly so) with the statement “I am unhappy to have another problem-solving method to use in my work.”

The survey also sought feedback on the usefulness of the material, the discussion, and “hands-on work with mapping/modeling your project.” As Figure 2 indicates, participants found discussions and mapping most useful. Because of the focus on using visual mapping to identify distinctions, systems, relationships, and perspectives, researchers were asked to what extent they agreed with the statement, “I think I can *frame* a problem set using MetaMap.” Respondents were evenly split between agreeing and strongly agreeing with that statement. This response, participants’ conference presentations, and their final papers demonstrated general mastery in diagramming complex research problems using DSRP.

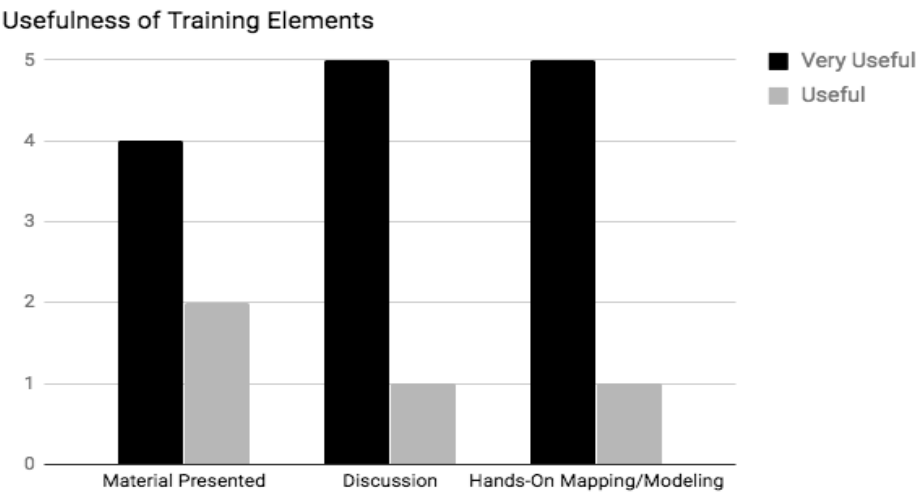


Figure 2: Usefulness of ThinkWater Fellowship Training Components

The greatest variation in participant responses concerned confidence in their ability to use ST (see Figure 3). One respondent in particular felt unprepared to fully apply DSRP to her research. The trainers observed that fellows who had the most defined research projects seemed to learn systems thinking more easily, because they had something concrete to which they could apply the new DSRP framework. Those still formulating their projects were in effect "struggling with content and structure simultaneously."

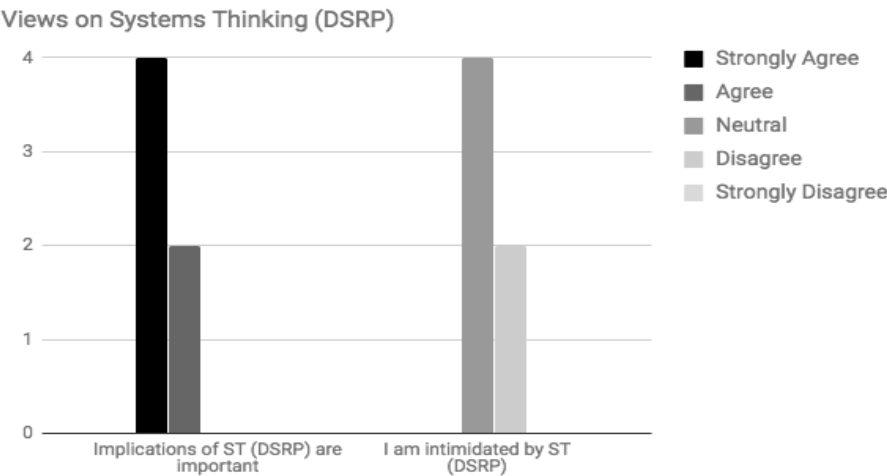


Figure 3: Views on Systems Thinking

Understandings of “Systems Thinking”

Likely due to limited prior exposure, most respondents did not fully answer a pre-training survey question on their current understanding of systems thinking. However, one respondent wrote “My current understanding of systems thinking stems primarily from my work in public health in which we discussed the iceberg model, stocks and flows, and feedback loops.” In the post-training survey, many respondents

defined systems thinking in terms of the underlying rules, for example, “Systems thinking is a method of thinking and understanding complex problems using the theory of DSRP.”

Participants with greater initial ST exposure tended to offer a more nuanced definition of systems thinking after the training. One researcher’s initial understanding of systems thinking was “a conceptual approach that focuses on the interdependent and underlying structures that affect phenomena.” This changed to the view “Systems thinking is a way of approaching life so that your understanding of things best approximates reality.” Similarly, another researcher after the training described ST as offering a “structured framework to help us analyze the problem from various perspectives... [and address] gaps that arise from assumptions built into our common thinking habits.” In keeping with these understandings, at the end of the training, all participants agreed (two thirds strongly so) that: “It is important to see the mental models my colleagues and I are building when we collaborate.” Mental models and perspectives were similarly salient for the policy students previously taught DSRP [4].

Participants were asked open-ended questions on their perceptions of the training and its import for their research. Participants liked the examples, the flexibility, interaction with peers and the trainers, and the comfortable, participatory atmosphere of the training. One respondent wanted an entire day (one-half the training) to be devoted to application of the mapping software, while another wanted more time for working through examples as a group. The response of one of the researchers illustrates the importance of the in-person training of the cohort of fellows:

The interactive dynamic of the class was fantastic (and necessary!). The concept of "learning how to think" is not easy to convey. Since few people "think about thinking," teaching ST and DSRP is a challenge. I thought the examples were well selected. At the end of the day, it is up to us to internalize the concepts and to experience a shift in how we approach problems.

Given that some degree of commitment and practice is required in applying any methodology or approach, it is reasonable to ask whether participants anticipated that DSRP would benefit their current and future work. Figure 4 illustrates strong agreement on the benefits of ST.

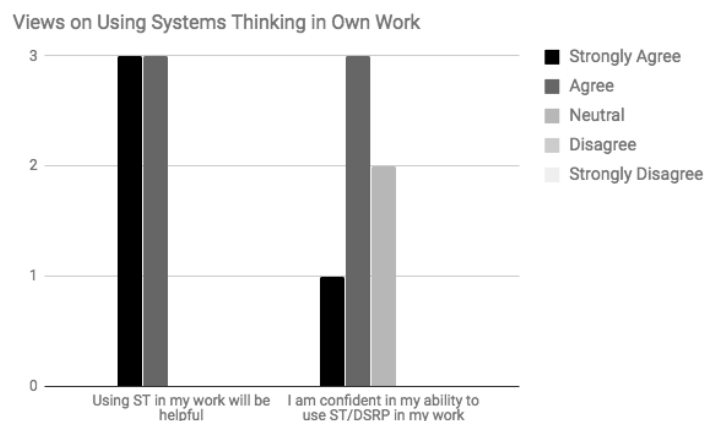


Figure 4: Views on Using Systems Thinking in Own Work

To that end, participants were asked: “In what ways will the material presented in this training affect your research?” Responses varied considerably, though most shared a promising degree of specificity, presumably denoting implementable ideas of practical utility. Many commented on the specific ways that applying DSRP helped them to organize their projects with greater precision and situate them in a larger interdisciplinary academic and policy context. For example, a PhD candidate wrote:

I have already started to use the material presented to (i) simplify research questions and designs, (ii) target research questions, designs, and manuscripts, (iii) draw connections between my research projects to organize my dissertation, and (iv) to draw connections between my research and others research to identify research gaps and inconsistencies.

A couple researchers gained considerable clarity about their topics through the application of DSRP, and used these epiphanies to hone in on the most relevant parts of their projects. Finally, others anticipated that an increased capacity to articulate alternative perspectives on water-related issues could make their work more persuasive and broadly appealing.

A Bridge to Social Science

Many who work in the natural sciences in the lab or in the field lamented knowing yet not accounting for the fact that the systems they study are strongly affected by (and in turn affect) people. One bio-environmental engineer expressed a “struggle with adapting what I know theoretically and technically to a broader human aspect or population aspect, or how it can really come into play with all of the political and economic systems in our world.” These scientists reported that DSRP gave them the tools to begin to incorporate the people involved in various water systems (e.g., farmers, policymakers, residents).

Another natural scientist initially oriented to systems “from a really physical science infrastructure networks type of engineering design framework” explained that DSRP training helped her bring people into the system (her model) and examine the important relationships. This fact “opened up social science as a link that I can put into my [research]... It's an absolutely critical component of a system where I had previously had the people kept on the periphery.”

Another participant related difficulty addressing social impacts to the classic “why do we care?” question all academics face:

I knew denitrification was the only complete way to remove nitrogen from waterways, and I also knew black carbon was being globally distributed. But, I was so eager to jump into problem solving mode I neglected to tie these facts into the bigger picture. The ThinkWater training helped me take the perspective of “human impacts” and realize eutrophication from excess nitrogen can lead to harmful algae blooms, toxic to humans, and also reduce fish populations which are a valuable food source. Additionally, black carbon inhalation leads to respiratory health impacts [9].

His conclusion was that the relationship between these two pollutants and human life merited greater study so that these effects might be mitigated. In this case and others, the ST training provided a new way for researchers to communicate their work, and as importantly, *its significance* to individuals outside their disciplinary niche and beyond academia.

While this is crucial for those researching important ecological issues as complex and important to society as water, it of course comes at the cost of time and effort. The ThinkWater Fellowship was designed to equip researchers with an understanding of the underlying rules of systems thinking that they could then apply to their ongoing research—all without the demands of taking a formal class, which would be difficult for those already engaged in advanced research. This necessitates a tradeoff between expenditure of the effort and time of participants and trainers and obtaining a desirable level of proficiency among participants.

Dosage and Startup Costs

Researchers appreciated the power of DSRP to broaden, translate, and communicate their research to a wider audience. The fellows used MetaMap software and applied the DSRP rules explicitly in their presentations at the systems thinking symposium concluding the fellowship. Perhaps because of this, some fellows felt that capturing the most utility from systems thinking would require teaching it to others. As one researcher interested in the translational aspect said:

...DSRP is a language, and the audience must share the language for the strongest communication. This holds true for the visual grammar used in metamaps as well. ...The researcher must practice, revisit, and refine both her mental model and the visual display to achieve clarity. She then must teach the audience how to read the metamap.

So the startup costs to learning DSRP may be higher for those who need to present their work in this way to laypeople. Most participants deemed the training of sufficient length. Asked about the duration, one participant opined:

Personally, I felt that it was more than sufficient because, as academics, as trained research professionals, 1) we don't have much time, and 2) it's much more a matter of finding how we can incorporate these concepts into our existing training rather than starting from scratch. I don't think any of us had never thought about complex systems or where our research fit into the broader arena of knowledge, but what the training allowed us to do was give a framework for that.

All participants seemed to appreciate the need to practice applying DSRP, both with respect to their specific projects but also more generally in their thinking. One researcher described this process for her: “[A]s you internalize it and you learn it, it becomes how you start interpreting or comprehending the world around you.” She described increasingly recognizing how DSRP analysis might assist colleagues working on complex problems of all varieties.

Nonetheless, the majority agreed they would benefit from more time, particularly through applying DSRP as a group and receiving feedback on their own research applications. And one participant expressed a strong desire for more hands-on practice time, reporting, “I do not feel like I got to really dig into the mechanics of DSRP enough to competently apply it. This does not mean I cannot use the DSRP ideas to check for biases and gaps in my mental models, but I doubt I will be really leveraging the entire power of systems thinking either.”

Conclusion

The cohort of advanced researchers studying water-related issues readily grasped the importance of systems thinking for their work. We will quote one participant at length:

As physical and social scientists interested in water issues, our goal is to understand complex water problems and identify possible solutions. As a water research community, our objective should be to communicate the relevance of our findings to stakeholders and policy makers, for they are ultimately responsible for applying appropriate strategies to reduce or eliminate the problems. DSRP tools can help us improve our communication in two specific ways. First, we can clarify our thinking in a way that helps us visually communicate complex interactive and adaptive systems. More importantly, the DSRP approach can theoretically facilitate conversation between stakeholders by explicitly engaging them in imagining multiple perspectives and helping them think across both temporal and spatial scales.

What was learned by the ThinkWater team through this first fellowship for high-level researchers? A key lesson pertained to teaching the four DSRP rules underlying systems thinking in that brief of a course. With the recent comparative reference of teaching policy students in a structured course at Cornell, the trainers noted the difficulty of teaching new skills to and sustaining high voluntary engagement among research professionals with competing demands.

Nonetheless, the trainers deemed the amount of contact with the research fellows and their level of engagement adequate for an introduction to systems thinking for the purpose of application to their ongoing research. While the addition of one more in-person training between the June and September meetings would have been ideal, participants’ summer schedules (e.g., many were doing field work) made this impossible.

To learn the underlying rules of systems thinking, constant practice and application are critical. The trainers have found that some initial degree of immersion along with ongoing interaction is particularly useful for getting people to see DSRP everywhere (i.e., notice that we are all always making distinctions and identifying systems and relationships, all from particular perspectives). And while the fellows were not a captive audience whose grades depended upon their performance, participation in the systems thinking symposium provided both an organizing focus and its own form of incentive. The prospect of having to make a professional, TED-style talk in front of a large live audience with hundreds watching

online seemed more motivating for participants than the modest stipends awarded on completion of the fellowship.

Based on self-report survey results and the observations of the experts, participants on the whole appeared to benefit equally from the training, irrespective of degree of prior exposure to systems thinking and particular methods. This is an important finding, as learning and applying the underlying rules of ST should be useful to both newcomers to the field and those who already practice particular systems methods. That said, extensive training and experience in a single disciplinary approach or model proved a challenge for some fellows to overcome, in that they needed to unlearn disciplinary orthodoxy in order to embrace a new analytical approach. As with all learning, a fixed mindset can inhibit new learning.

What are the implications of this study for those who conduct research on water issues? The complex nature of water issues and the relevance and pervasiveness of this natural resource in all sectors of human activity makes interdisciplinary approaches essential. ThinkWater Fellows appreciated learning as a cohort and interacting with those working on water issues from different perspectives, disciplines, and methodologies.

Natural scientists appreciated DSRP as a mechanism to incorporate human elements into their models, and also as a way to present the importance of their research. A near universal benefit mentioned was in organizing and clarifying one's ideas, including highlighting what was important and what could be deemed extraneous or tangential to their work. Researchers also tended to appreciate the systems thinking approach in terms of framing their work in a way that highlighted its broader significance and interdisciplinary appeal. Finally, researchers lauded the focus on mental models, including understanding that their own best models can only ever approximate reality. As one researcher explained, her greatest insight from the training was:

...to simply "mind the gap" between my understanding and reality. We are constantly creating complex mental models that approximate reality, but we must remain cognizant that these models are always going to fall short. We must be ready to assess, reiterate, expand, and/or discard models as new information broadens our understanding.

Thus participants acquired both immediately useful tools for their ongoing work as well as more abstract skills to aid their thinking.

Study Limitations and Future Directions

There are, as with all studies, several limitations to be considered. This was a brief intervention, and the ThinkWater Fellows were a relatively small, self-selected group limited to water researchers with some type of Cornell affiliation. Our primary means of assessing outcomes relied on self-report. In addition, not all participants completed all surveys. However, we could discern no obvious pattern to survey participation that would have implications for our results. Finally, variable degrees of effort and involvement (e.g., participation in surveys, writing papers, making presentations) limit our ability to compare outcomes.

When asked for the factor that most differentiated successful learning and application of DSRP and systems thinking concepts from this brief training, the trainers noted that participants were in varying stages of their research projects. Those who brought more defined projects found it easier to apply ST principles to improve their work. Having clearly defined projects enabled them to focus on learning and applying DSRP to a discrete, well understood project.

Asked to identify their “take-away” from the in-person training, researchers offered varied responses. Two participants emerged from the training with a new outlook on and orientation to systems thinking. One wrote that “systems thinking is challenging to initially wrap your mind around, but will prove to be very helpful once mastered.” Still another acquired “an overview of systems thinking. Though I still feel a little intimidated by systems thinking, I feel more comfortable with the topic now than prior to attending the training. I am excited to continue cultivating systems thinking in my work.” Similarly, another expressed a need to practice thinking through and applying the strategies learned. Finally, one researcher’s take-away was concordant with the mission and vision of ThinkWater: “Systems thinking has underlying principles (distinctions, parts & wholes, relationships, and perspectives) that can be taught for clearer thinking on complex environmental problems.”

In keeping with its focus on influencing education, research, and Extension/outreach, the next cohort of ThinkWater Fellows was drawn from across the country and features professionals engaged in education and outreach, as well as research. This group will learn systems thinking primarily through webinars, and will take an online training that complements the book and engages the user in hands-on mapping. This group will also have access to an instrument that measures their conscious application of the DSRP rules and can assess their progress in making distinctions and recognizing systems, relationships, and perspectives.

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