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Interdisciplinary approach to understanding stakeholder reasoning and decision-making for water

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INTERDISCIPLINARY APPROACH TO UNDERSTANDING STAKEHOLDER REASONING AND DECISION-MAKING FOR WATER

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Dedication

This is dedicated to my mom, my dad, my brother, and my abuelos. Special dedication to those who are no longer here to celebrate this achievement with me. Todavía estoy en la escuela abuelo, pero prometo seguir trabajando con todo mi corazón y cantar tus canciones favoritas de karaoke como si nadie estuviera mirando.

INTERDISCIPLINARY APPROACH TO UNDERSTANDING STAKEHOLDER REASONING AND DECISION-MAKING FOR WATER

by

Katalina Salas, B.S., P.S.M

DISSERTATION

Presented to the Faculty of the Graduate School of
The University of Texas at El Paso
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of the Requirements
for the Degree of

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Para mis abuelos, sé que no siempre entienden lo que estoy haciendo y siempre están preocupados de que vuelva a dejar el país, pero sé que siempre estuvieron orgullosos de mí. Gracias por darme unos padres fuertes que no me dieron nada más que amor y apoyo.

Abuelo, sé que estabas esperando que terminara la escuela y me entristece que no pudiste verme defender mi trabajo, pero sé que hubieras estado orgulloso. ¡Cada vez que cante una canción de karaoke estará dedicada a ti!

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Like a sunflower with strong roots
She stood against the wind, followed the Sun
Cherished the rain, befriended the Moon
And grew to the height she was destined
A height where she could see beyond the horizon
Into the sunset and over the mountains
Like a sunflower she bloomed
-Katalina Salas

Abstract

On a global scale, humanity is compelled to address complex or ‘wicked’ resource-related issues in the face of accelerating environmental change. In our work, we use the term wicked problem to refer to an issue that has multiple potential solutions and involves various stakeholders. The paths to reach resource sustainability under environmental uncertainty are difficult to identify, plausible outcomes remain uncertain, and tradeoffs required by any path chosen are challenging to understand. Environmental sustainability issues may involve perspectives from multiple stakeholders (i.e., scientists, policymakers, community members, and industry), often leading to conflicting interests and cultural misalignments that trigger the need for a more integrated approach. Participatory modeling (PM) has been identified as an emerging strategy to address these problems. PM aims to generate a shared understanding of the challenges confronting a given resource system through social learning and collaborative thought experiments that explore potential societal responses supported by computational tools. This approach has many examples, but our understanding of how social learning, knowledge shifts, and decision-making occurs in this context remains limited. In this study, we focus on how people understand and collaborate through PM using freshwater supply models of the Middle Rio Grande River Basin. We conducted online workshops with activities targeting key competencies and collaboration, exposing participants to online scientific data and models. Through these workshops, participants identified conflicts, co-created knowledge, and developed potential solutions informed using scientific models. Results of the study allowed us to determine what mechanisms facilitated social learning and the effectiveness of various tools used to present scientific data and models to non-scientists. In this study, we extensively explore stakeholder engagement, participatory modeling, and scenario analysis in the Paso del Norte region's water challenges, utilizing SWIM 2.0. Our research underscores the significance of collaborative processes, knowledge co-creation, and diverse perspectives. The findings highlight participatory methodologies' potential in addressing complex water issues and fostering stakeholder trust. Furthermore, we emphasize the role of group dynamics and negotiations during the collective construction of a group concept map, shedding light on its impact on collaborative success, scenario analysis, and trust-building.

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Introduction

The sustainability of freshwater resources in semi-arid regions worldwide has become a matter of great concern in view of global environmental change (Rodell et al., 2018; Vollmer & Harrison, 2021). With an expected increase in water usage, conflicting user demands, rising temperatures, prolonged drought, or potential transition to permanent arid conditions, many areas will be at high risk (Armstrong et al., 2018). This complex sustainability challenge quickly develops into a "wicked problem" within a social-environmental system (SES), requiring solutions to address both water scarcity and security (Fallon et al., 2021). "Wicked problems, in the context of freshwater, are characterized by: (1) multiple possible pathways; (2) values of different outcomes and states of the world are highly contested; (3) conflicted interests exist among stakeholders; (4) seemingly intractable trade-offs; (5) disputes over the available and needed evidence to make effective decisions; and (6) substantial uncertainty about what are the consequences of the possible actions" (Quentin Grafton, 2017).

The Paso del Norte region, situated at the intersection of western Texas, southern New Mexico, and the northern Mexican state of Chihuahua, serves as an illustrative case of the challenges associated with water scarcity. In this region, both the Rio Grande River, the primary surface water source, and the subsurface aquifers are facing accelerated rates of depletion of freshwater resources (Figure 1.2). The US Department of the Interior Bureau of Reclamation and Rio Grande Water Authority (2013) project that increasing temperatures will lead to diminished snowpack in the Colorado mountains, resulting in reduced spring and summer water runoff and subsequently lower flows in the Rio Grande River—the primary water source for this region. These changes upstream will have far-reaching effects on local water resources, including heightened reliance on groundwater pumping, reduced local groundwater recharge due to increased surface evapotranspiration, and consequently, decreased availability of high-quality groundwater (*Groundwater: State of the Science and Practice*, 2018). This situation will significantly impact three key groups: 1) the agricultural sector, which currently utilizes 75% of the available surface water at minimal cost (Rio Grande Regional Water Authority, 2013); 2) rural residents who solely rely on groundwater due to inadequate infrastructure (Guerra Uribe et al., 2019); and 3) urban residents, as a result of urban expansion and the rising demand for freshwater (Daigger, 2009; Gober, 2010; McDonald et al., 2014).

Addressing these issues requires a participatory approach that engages stakeholders and decision-makers at all levels, including residents, communities, managers, regulators, and policymakers, with scientific data and models (FAO, 2020; Quentin Grafton, 2017). A non-linear approach is often required to address water security and water scarcity effectively (Endert et al., 2014; Xu et al., 2022). Popular methods include the use of models to conduct scenario analysis and participatory modeling (PM) with some sort of integrated modeling participatory approach (Carson et al., 2018; Lang & Wiek, 2022; Oteros-Rozas et al., 2015; Palmer et al., 2013; Peterson et al., 2003; Priscoli, 2004; Xu et al., 2022). Di Baldassarre et al. (2021) argued for combining quantitative and qualitative methods to inform policy decisions. Elsawah et al. (2020) identified integrating such diverse methods as one of eight grand challenges in socio-environmental systems modeling.

The participation of stakeholders through participatory modeling (PM) has been acknowledged as a crucial aspect of enhancing the practicality and applicability of models in decision-making and sustainable water resource management (Voinov et al., 2016; Voinov & Bousquet, 2010). Due to the complexity of the issues and the number of stakeholders frequently involved, PM with stakeholders has emerged as a critical strategy for learning about issues and generating shared understanding – as a prelude to discussing the best societal response (Lim, 2021; Martinez et al., 2018; Pluchinotta et al., 2018; Smetschka & Gaube, 2020; Zomorodian et al., 2018). The objective of PM is to co-create knowledge, foster shared comprehension of the challenges facing a specific resource system, and collaborate in conducting "thought experiments" using qualitative, semi-quantitative, and quantitative models that explore potential societal responses using decision visualization environments (John et al., 2018; van Bruggen et al., 2019; Voinov & Bousquet, 2010). Although numerous PM projects highlight social learning about the problem from multiple perspectives as a significant outcome, our understanding of the social learning processes in these contexts remains limited (Kenny & Castilla-Rho, 2022; Pennington, 2011, 2016). PM provides a venue for stakeholders to participate in discussions about the issues, thereby exposing various perspectives with the aim of promoting cross-perspective learning and convergence toward shared comprehension. This type of social learning is contingent upon individual transformative learning, which refers to the process of profound change in adult perspectives, becoming more inclusive, discriminating, permeable, and integrative (Pennington et al., 2021). Participatory modeling projects aspire to transform stakeholders' mental models through the social learning process and use place-based models that simulate the resource system over time (van Bruggen et al., 2019). Additionally, there has been attention directed to the use of boundary negotiation objects (BNO's) such as concept maps, data, and models to facilitate communication between groups (Lundgren, 2021). Using BNO's in PM can assist in the transformation of mental models and enhance group dynamics (Di Marco et al., 2012; White et al., 2010).

Furthermore, we want to be able to move from not only successful collaboration and solution development but to implementation of ideas or pathways identified through the convergence of stakeholder collaboration (van Bruggen et al., 2019). We recognize the need of transitioning from an incremental approach to a transformative process. For this to be transformative it must have the ability to shift existing systems, their component structures, institutions and actors to alternative development of pathways or ideas, before solutions are even considered (Pahl-Wostl, 2017). One of the key ways to shift towards a more transformative mindset will be by implementing these tools and mindsets throughout sustainability science and environmental science programs and/or classes to better prepare future scientists. In the sustainability education community, there has been a surge in discussions regarding the competencies required by the future workforce. Wiek et al. (2011) identified key competencies for sustainability education, including systems thinking, anticipatory thinking, normative thinking, interpersonal thinking, and strategic thinking. However, these competencies are rarely addressed in current environmental science programs and the sustainability education community is ramping up efforts to develop appropriate courses that target these competencies. It is worth noting that most, if not all, of the competencies recognized in environmental science implicitly rely on foundational competencies related to reasoning with data and models (Pennington et al., 2021). For instance, the ability to anticipate future conditions hinges upon effectively modeling such conditions, employing well-managed input data, and analyzing output data proficiently. Even so, there remains a gap in our understanding of the specific data and modeling competencies required and how these competencies can be effectively developed for use within courses (Pennington et al., 2021).

Objectives

The goal of this study is to integrate selected elements from participatory modeling, visual analytics, and scenario analysis to provide insights on how people collaboratively reason with data, models, and visualizations, and how such “collaborative social learning” impacts decision-making and the ability to complete scenario analysis. Therefore, this dissertation looks at how learning occurs during data and model-based reasoning using information technologies, and analog visualizations with an interdisciplinary approach. We the scientists want to know how to better communicate models to non-scientific communities. This work aims to answer the following questions: What frameworks work best to effectively develop a participatory and collaborative setting? What tools/skills most effectively assist the stakeholders in better understanding the problem and making decisions that challenge their norms to come to a solution that benefits the community as a whole? Our hypothesis is that participants will exhibit increased competencies and reasoning about future water sustainability because of employing processes informed by integrated theories, and a possible increase in trust of the model to be used for decision-making. The research objectives are:

1. Develop a participatory process using sustainability and data reasoning competencies that facilitates the exploration of possible scenarios and interpretations of results to allow non-expert users to use water simulation models developed by water resource modeling experts in the region, available through the Sustainable Water through Integrated Modeling Framework (SWIM 2.0) interface (Villanueva Rosales et al., 2016).
2. Develop metrics to better understand group dynamics when addressing water issues using concept maps as boundary objects at the individual and group level.
3. Develop and apply metrics to assess the changes in these competencies throughout the participatory process.

This research informed the research team in charge of developing the NSF-funded SWIM framework, for refinement of the SWIM interface to be used in participatory community engagement. This work was done in collaboration with a social scientist and their students to develop effective visualizations that communicate well to farmers, whom they interviewed using visual aids. The overall outcome of this project contributes novel information in the specific case of water scarcity in the Paso del Norte Region for science, policy, community, and education partners. A framework was developed incorporating key participatory processes, visualization tools, and design methods for future implementation in similar arid regions facing water stress. This framework provides structure to train those who will approach these complex sustainable and socio-environmental problems now and in the future, providing a knowledge base to approach water stress issues, but also potentially any complex problem.

Chapter 1: Integrating scenario analysis and participatory modeling to generate plausible future narratives of scarce water resources: A case study in the Middle Rio Grande River Basin

1. INTRODUCTION

There is a growing consensus within the scientific community that findings from environmental and sustainability research, such as water resources, need to be more relevant, salient, and timely for decision-makers (D. Cash et al., 2003; Rounsevell & Metzger, 2010). Effective long-term development of local strategies and policies requires the use of the most reliable and comprehensive data from diverse sources, including field campaigns, remotely sensed drone and satellite data, as well as outputs generated by simulation models. Despite the growing volume of relevant scientific data, locating and assessing their quality remains challenging (Cai & Zhu, 2015; I. Lee, 2017). The integration and analysis of such data can be laborious and time-consuming (Claramunt et al., 2017; Jagadish et al., 2014; Philip Chen & Zhang, 2014). The development of interfaces that are user-friendly and practical for stakeholders, who may or may not be technically savvy, is crucial (Jagadish et al., 2014). Simulation models employed to project future natural phenomena often utilize approaches like scenario analysis, which aim to facilitate communication but may not be easily comprehensible to stakeholders (G. Cairns et al., 2016; Marttunen et al., 2017; Swart et al., 2004).

Scenario analysis has been identified as a strategy for addressing wicked social-environmental system (SES) problems, where it is often difficult to fully comprehend the plausible futures under varying conditions of uncertainty (Swart et al., 2004). Scenario analysis provides a systematic way to think about plausible uncertain futures. Scenario analysis also combines qualitative and quantitative models. The development of plausible scenarios is qualitative. Those scenarios are then implemented in quantitative models to analyze and compare outcomes across scenarios. This approach generates a large number of output datasets that are difficult to analyze and understand, even by modeling experts (Moallemi et al., 2020). Regrettably, analyzing a robust number of scenarios to complete scenario analysis may be taxing for the diverse group of stakeholders involved in SES issues. When using new tools, there is also always a fear of participants getting lost in navigating the new tool or experiencing frustration. If this is not overcome, it is easy for participants to lose interest in learning how to use the model as a tool.

Currently, qualitative approaches have primarily been used as inputs to PM and scenario analysis. Less commonly have qualitative approaches been applied to the outputs of PM and scenario analysis. This investigation combines qualitative inputs to PM and scenario analysis with qualitative interpretation of results in the form of developing narratives with stakeholders that help them interpret and understand the information, and the impact of social learning on those capabilities (Leong, 2021). Combining qualitative narratives with quantitative model outputs has been identified as a tractable approach, although not focused on understanding social learning in these contexts (Heer et al., 2008; Segel & Heer, 2010; Tong et al., 2018).

PM and scenario analysis can have several benefits when combined in a social learning context. These methods have shown an increase in engagement of stakeholders in the modeling process and completion of scenario analysis, which leads to a sense of ownership and investment in outcomes (G. Cairns et al., 2016). There is also an increased sense of understanding because the PM process allows for knowledge exchange from a diverse group of stakeholders, providing a deeper sense of understanding, leading to co-creation of new ideas. When layered with scenario analysis, stakeholders can explore these new ideas and compare future scenarios allowing them to make more informed decisions and potentially develop more equitable and just solutions (Kepner et al., 2004; Keseru et al., 2021; Marttunen et al., 2017; Peterson et al., 2003; Reilly & Willenbockel, 2010; Walz et al., 2007).

The aim of this chapter is to investigate the following questions: 1) How do stakeholders' reason, learn, and make decisions about water facilitated by participatory modeling and scenario analysis methods? 2) Is there an increase in engagement with models through the implementation of participatory modeling and scenario analysis? 3) What insights were gained from conducting scenario analysis activities with a variety of stakeholders?

2. METHODS

This study, approved by the UTEP Institutional Review Board (IRB) was conducted through four virtual participatory workshops in 2020 and early 2021 during the COVID outbreak, each lasting three hours, with the aim of engaging stakeholders from a variety of sectors in the Middle Rio Grande River Basin (MRGRB), including both non-experts and experts (such as city residents, educators, environmentalists, farmers, regulators, researchers, rural residents, and water managers) in discussions around water issues. The virtual format of the workshops created challenges but also allowed for broad participation, including individuals from beyond the MRGRB study region. The workshops were designed to build upon one another and incorporate participant feedback, though attendance at all workshops was not required. To ensure all participants were informed, an ArcGIS Storymap and supplementary reading materials were provided via email, and participants were given access to an online shared workspace on Miro.com for reviewing workshop materials.

2.1 Workshop and activity design

The workshops were intentionally designed to foster collaboration and encourage active participation through various processes, including knowledge co-creation, team activities, and social learning exercises, all conducted within a virtual environment (Figure 1.1). The initial workshop, comprised of two iterations referred to as W1A and W1B, served the purpose of introducing participants to water-related challenges specific to the MRGRB region while also assessing stakeholder concerns. To facilitate this, participants were familiarized with the SWIM 2.0 system, an open-source web platform that houses quantitative water balance simulation and hydro-economic optimization models for the MRGRB region from Elephant Butte to Fort Quitman region (Hargrove et al., 2023) (Figure 1.2). "SWIM 2.0 provides a human-technology framework for future water projections that integrates semantic-based computational approaches, information technology, and participatory modeling with strong community engagement" (Chavira et al., 2022). SWIM 2.0 was developed as a framework for the various stakeholders to understand and explore potential solutions to their problems using models and data.

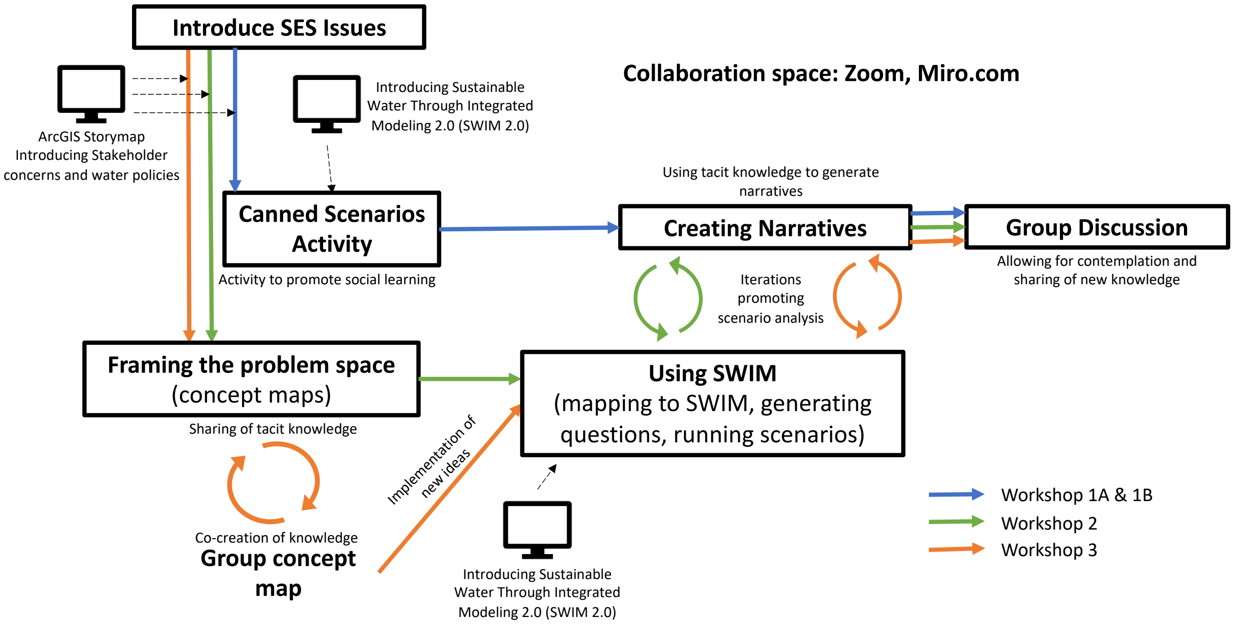


Figure 1.1. Workshop design and activities for each workshop.

The workshop activities in this study were based around the water balance simulation model, opting for its simplicity over the hydroeconomic optimization model, although the use of the latter was available to participants. The initial presentation of SWIM in W1A and W1B involved the use of pre-defined scenarios, referred to as "canned scenarios," to streamline model execution and demonstrate its results. Canned scenarios were developed based on stakeholder concerns for the MRGR gathered from previous workshop data collected by Hargrove and Heyman (2020). The selected canned scenario question for these workshops focused on the impact of specific climate scenarios (i.e., zero flow, extended drought, extreme stress, mean climate, and wet climate) on river supply and storage, resulting in a total of five canned scenarios. Key inputs for running the questions using the water balance model were identified, followed by the selection of key outputs. The deliberate choice to focus on key outputs for these canned scenarios aimed to prevent overwhelming participants with an excessive number of output variables. Consequently, participants interpreted the results in relation to the specific question posed in the canned scenario.

Examples of Canned Scenario questions:

- How will an extended drought climate scenario affect river supply and storage?
- How will an extreme stress climate scenario affect river supply and storage?
- How will an intermediate climate scenario affect river supply and storage?
- How will urban water prices and urban consumption be affected by a wet climate scenario?

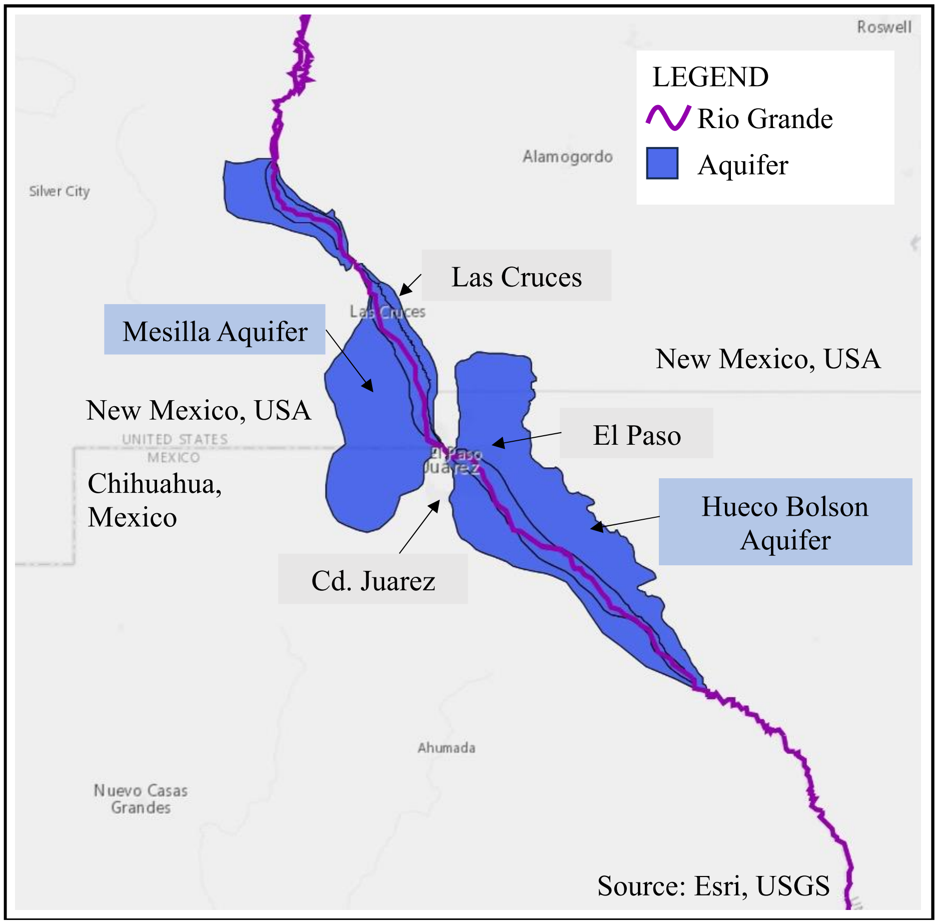


Figure 1.2. Location of the Middle Rio Grande, aquifers, basins, and major cities. Generated using SWIM 2.0 (http://purl.org/swim). Layer sources: University of Texas at El Paso, Texas A&M University, New Mexico State University, Universidad Autónoma de Ciudad Juárez.

In the second workshop (W2), the objective was to investigate the impact of scenario analysis on social learning and decision-making. Initially, participants were tasked with individually defining the problem space from their perspectives using concept maps, which were then shared on the Miro platform (https://miro.com/). This activity aimed to enable a comprehensive understanding of the diverse perspectives and existing knowledge concerning water issues in the MRGRB. A demonstration of the SWIM 2.0 interface was provided, and participants engaged in canned scenario analysis to enhance their comprehension of potential water futures in the region. Afterward, participants mapped their individual concept maps to SWIM 2.0

available models, generating their own scenario questions, running scenarios, and producing narratives. The narratives were prompted by requests to describe temporal trends, identify patterns, and summarize them in concise sentences, all in relation to the specific question of interest.

The focus of the third workshop (W3) also revolved around scenario analysis, but with a shift from individual to group-level activities. Participants utilized their individual concept maps to collaboratively create a shared group concept map. From this newly formed concept map, participants generated scenario questions, executed the scenarios in SWIM, and interpreted the results. This allowed for an investigation into whether the process of co-creation and group-level activities led to an increase in tacit knowledge, engagement, and learning compared to individual scenario analysis.

2.2 Data collection, coding, and analysis

In each workshop, surveys were administered to participants using QuestionPro (https://www.questionpro.com/) to gather valuable insights into their motivations, overall workshop experience, and self-reported metrics. To ensure comprehensive documentation, all workshops were recorded on the Zoom platform (https://zoom.us/). Audio recordings were transcribed by two researchers, with the facilitator carefully reviewing the accuracy. Additionally, participants engaged in scenario analysis activities and generated concept maps, scenario questions, and narratives either through the Zoom chat function or in their designated online collaborative workspace on Miro. To protect individual's confidentiality, each participant was assigned a unique identifier. This chapter specifically focuses on the analysis of data obtained from scenario analysis activities and survey questions related to self-reported metrics (Xexakis & Trutnevyte, 2019).

2.2.1 Coding schemas

In this study, coding schemas were employed to investigate the process of reasoning with data models and assess the frequency and impact of scenario analysis on social learning and decision-making. The NVivo software (https://lumivero.com/) was utilized to analyze the transcripts and participant behavior observed during workshop activities. The coding process was guided by theoretical frameworks pertaining to group-level learning (Radinsky et al., 2017) and engagement (Mahyar et al., 2015) (Table 1.2). By utilizing these coding schemas, we aimed to gain insights into the dynamics of reasoning with data and models and the influence of scenario analysis on social learning and decision-making.

Table 1.1. List of adapted coding schema and definitions.

Group-level learning (Radinsky, 2017)	**Activity level –** talk that references any clarification on activities. **Interface level –** talk about software, interface, or low-level function of SWIM. **Tool-use level** – talk about how the modeling tool is used, or opinions on how it could be used. **Model level –** talk that references outputs, inputs, or any aspect of the models on SWIM. **Policy-world level –** talk that references water issues, water policies, and water futures.
Engagement (Mahyar, 2015)	**Expose (Viewing)** – activity of viewing SWIM interface, documentation, and inputs. **Involve (Interacting)** – activity of browsing inputs to answer desired question & identifying key results. **Analyze (Finding Trends)** – activity of analyzing trends or patterns in selected results. **Synthesize (Testing Hypotheses)** – activity of developing a narrative, storyline, or completing scenario analysis. **Decide (Deriving Decisions)** – activity of going beyond scenario analysis and determining if decisions need to be made.

To effectively implement scenario analysis within the study, a comprehensive set of key terms and corresponding definitions were established, as presented in Table 1.3. Inductive coding was used to develop the coding schema for narratives, ensuring that it emerged directly from the data rather than being predetermined in advance. This approach allowed for a rigorous and data-driven framework to analyze and interpret the narratives and their essential elements.

Table 1.2. Definitions for scenario analysis

Scenario	**One or more selected input choices from a set of plausible inputs impacting future conditions of an SES**
Scenario question	**A question that connects an input scenario with related outputs**
Model output interpretation (MOI) – **Level 1**	**A description of the elements in an output graph or table, without reference to the input scenarios that generated the output**
Narrative – **Level 2**	**Describes input scenarios, model output interpretation, and connects the two**
Storyline – **Level 3**	**Description of plausible, coherent linkages between multiple input choices that together generate distinctive future trajectories of the SES**
Scenario analysis – **Level 4**	**The process of systematically investigating multiple scenarios by generating scenario questions, interpreting model outputs, creating narratives, and constructing storylines that facilitate comprehensive understanding of the impact of different interventions on the future of a complex SES**

The coding analysis was specifically applied to the data collected during the canned scenario activities (W1A & W1B) and the scenario analysis activities (W2 & W3). To gain an inclusive understanding of how participants learned and engaged with the modeling tool to make decisions, counts of text in transcripts for each coding schema were conducted and visualized through histograms. These histograms provided an overview of the participants' levels of group-level learning, engagement, and scenario analysis. Percentages of overall counts of each coding scheme across workshops was also calculated to better understand how dialogue changed over workshops. This was done to investigate each workshop building on the previous one.

2.2.2 Self-reported metrics

A 5-point Likert-scale survey was administered to assess the self-reported levels of trust, understanding, and engagement (Table 1.3). Participants were asked to rate their perceptions on these metrics, and the responses were quantified accordingly. The presentation of data is depicted through stacked bar charts, illustrating the percentage distribution of participants' responses in the post-survey for each workshop. These visualizations offer a comprehensive overview of the participants' self-reported levels of trust, understanding, and engagement throughout the workshops.

Table 1.3 Self-reported metric survey questions

Self-Reported Metric	Code	Survey Question
Engagement	E1	If I would want to know something about the Middle Rio Grandes water supply in the future, I would return to materials from this workshop.
Engagement	E2	The workshop was an exciting way to find out about water supply.
Trust	T1	This workshop could provide information for decisions on water supply.
Understanding	U1	The workshop explained the complex issue of water supply in a simple and understandable way.
Understanding	U2	The workshop corrected some of my misconceptions about the Middle Rio Grandes water supply.
Understanding	U3	On the whole, it was easy to understand the information.
Understanding	U4	I learned something new about the water supply in the Middle Rio Grande from this workshop.

It is important to note that due to the virtual nature of the workshops, the counts were subjective and dependent on the participant's level of engagement during Zoom sessions. To mitigate this, patterns were further analyzed by comparing the counts with the discussion transcripts. It is important to emphasize that the coding schema and analysis approach employed in this study reflect the interpretation of the researchers. This interpretative approach allowed for the exploration of patterns that are often overlooked by purely quantitative analyses, providing valuable insights into the data beyond numerical measurements.

3. RESULTS

Our workshop participants are described below to provide better context to the findings. Additionally, findings from the coding schema described above (e.g., engagement, learning, and scenario analysis level) and survey data from self-reported outcomes are described across all workshops to better identify changes and patterns in reasoning, engagement, and understanding.

3.1 Characteristics of workshop participants

A total of 45 individuals participated in the workshops, with 37 unique individuals attending the workshops. Notably, there was a significant rate of dropout, resulting in only four individuals participating in at least two workshops and only two individuals attending all three workshops.

Participants in the workshops were assigned to different water user types based on the SWIM 2.0 user categories, including city residents, educators, environmentalists, farmers, regulators, researchers, rural residents, students, and water managers. These categories were created based on previous work by (Hargrove & Heyman, 2020). In W1A (n=8), the composition included three students, two environmentalists, one educator, two water managers, and one regulator. W1B (n=14) consisted of four students, one environmentalist, two educators, one water manager, three city residents, and two farmers. W2 (n=13) comprised four students, two environmentalists, three educators, two water managers, one regulator, and one researcher. Lastly, W3 (n=10) included seven students, one environmentalist, one regulator, and one city resident.

While the initial categorization of participants into water user types was based on their stated interests and goals derived from pre-surveys, it is important to acknowledge that many participants may potentially identify with more than one water user type. Furthermore, the definitions of water user types were refined based on participants' discussions, utilizing the definitions provided by Hargrove et al. (2020). This acknowledgment is crucial as individuals' water usage patterns vary depending on their geographical location, lifestyle, and occupation. Additionally, it is worth noting that the number of participants in each workshop had some influence on the level of engagement during Zoom sessions, and the composition of participant types impacted the extent of conversations between participants.

3.2 Group-level learning

In W1A, the highest counts coded (refer to Table 1.1) from the transcripts occurred in the activity level (27, 34%) and interface level (14, 18%), the third-highest count in the model level (23, 29%), with moderate counts in the tool-use level (7, 9%) and policy-world level (8, 10%) (Figure 1.3, Figure 1.4). W1B exhibited the lowest counts in policy-world talk (3, 7%), while having moderate counts in the activity level (15, 36%), interface level (5, 12%), and model level (16, 38%), and a low count in the tool-use level (3, 7%). W2 displayed the highest counts in the tool-use level (18, 24%) and policy-world talk (24, 32%), along with moderate counts in the activity level (6, 8%), model level (22, 29%), and the same count of interface level (5, 7%) as W1B. W3 demonstrated the highest count of model-level talk, totaling 32 (56%) instances, while having the lowest counts in the activity level (1, 2%), interface level (4, 7%), and tool-use level (1, 2%), and a moderate count in policy-world talk (19, 33%). Looking at the counts, W1A and W1B were primarily made up of activity level talk, in contrast to W2 and W3 that had higher counts of policy-world and model level codes respectively. When we look at the percentages, we see that activity level and model level make up more than 50% of the conversations. W2 has the highest percentage of tool-use level across all workshops and had an increase in percentage of policy world but was on par with W1A model-level percentages and lower than W1B percentages. More than fifty percent of all conversations in W3 were model level talk, with 1% increases in policy-world compared to W2.

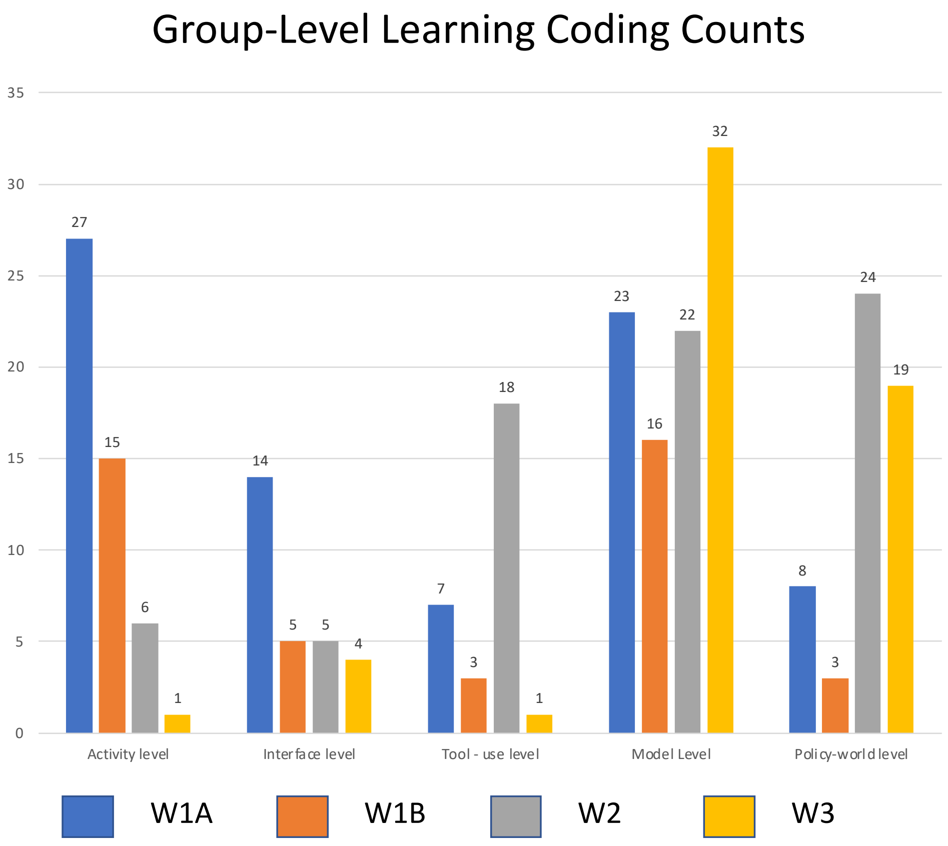


Figure 1.3. Group-level learning coding counts for each workshop, W1A (blue), W1B (orange), W2 (grey), W3 yellow.

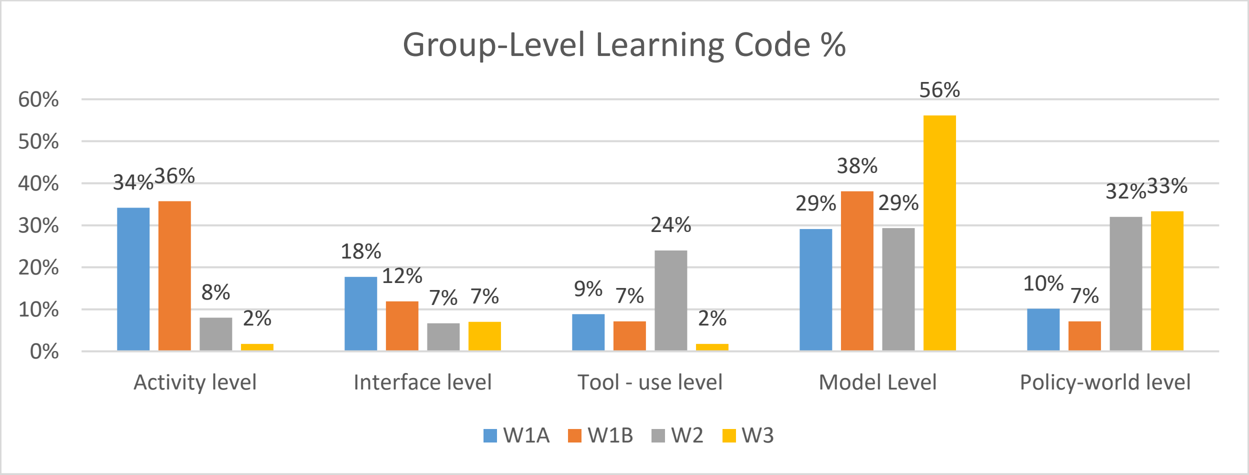
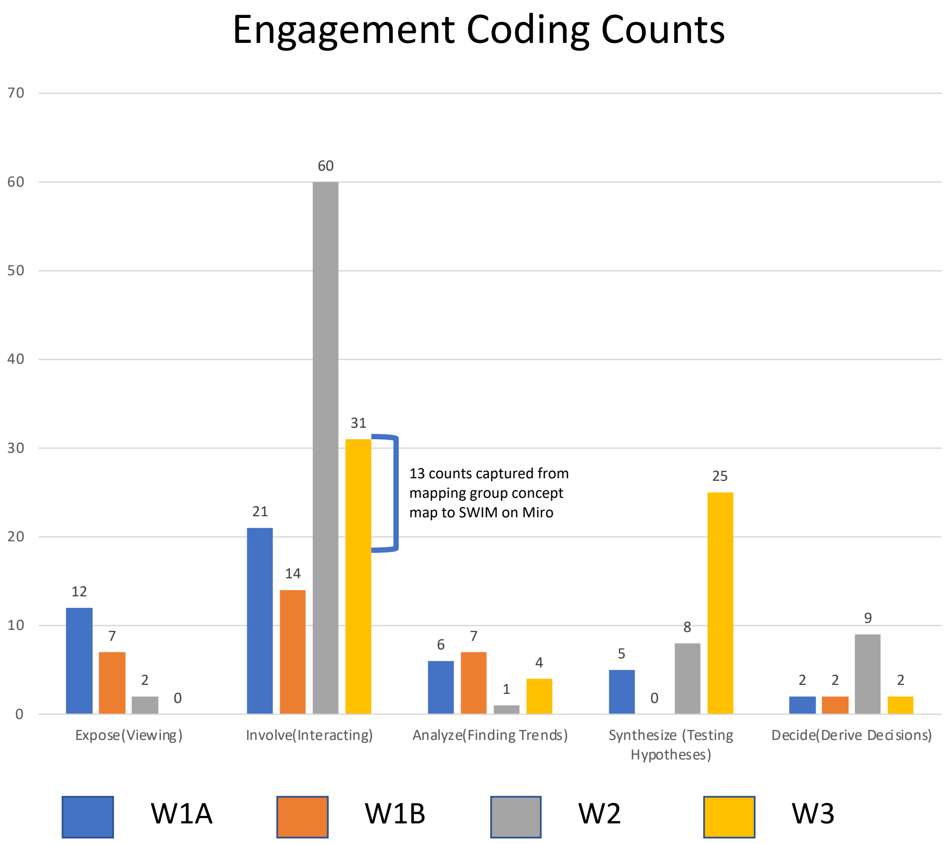


Figure 1.4. Group-level learning coded percentages of overall conversation for each workshop, W1A (blue), W1B (orange), W2 (grey), W3 yellow.

3.3 Engagement levels

In W1A, the highest count was observed in the "expose" level (12, 26%) and "involve" level (21, 46%), a relatively high count in the "analyze" level (6, 13%), a moderate count in the "synthesize" level (5, 11%), and a lower count in the "decide" level (2, 4%) (Figure 1.3, Figure 1.4). In W1B, the highest count was observed in the "analyze" level (7, 23%), with moderate counts in the "expose" level (7, 23%), "involve" level (14, 47%), and "decide" level (2, 7%), and no counts in the "synthesize" level. W2 exhibited the highest count in the "involve" level (60, 75%) and "decide" level (9, 11%), a moderate count in the "expose" level (2, 3%) and "synthesize" level (8, 10%), and a lower count in the "analyze" level (2, 1%). W3 had the highest count in the "synthesize" level (25, 40%), a moderate count in the "involve" level (31, 50%), of which 13 came from Mapping to SWIM as a group, "analyze" level (4, 6%), and "decide" level (2. 3%), and no counts in the "expose" level. The “decide" category (derive decisions) remained low across all workshops. Involve (interacting) made up the highest percentage of all workshops but we see a 20 to 30% higher coding percentage in W2 compared to W1A, W1B, and W3.



13 counts captured from mapping group concept map to SWIM on Miro

Figure 1.5. Engagement coding counts for each workshop W1A (blue), W1B (orange), W2 (grey), W3 yellow.

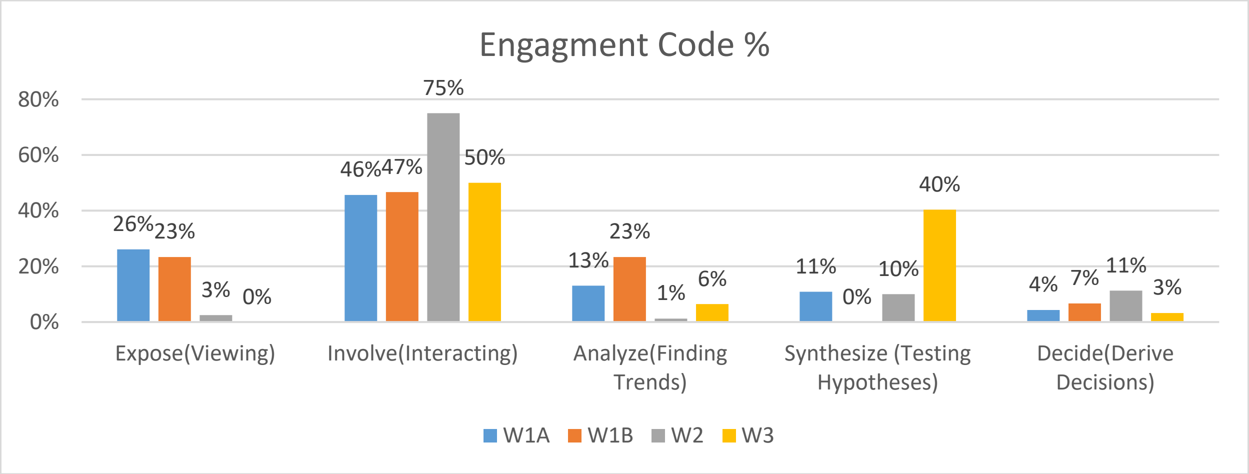


Figure 1.6. Engagement coded percentages of overall conversation for each workshop W1A (blue), W1B (orange), W2 (grey), W3 yellow.

3.4 Scenario analysis levels

The results obtained from the scenario analysis levels across all workshops indicate a substantial increase in the completion of the scenario analysis process. In W1A, participants primarily generated 5 instances of MOIs, 2 narratives, and 3 storylines. W1B participants generated 3 MOIs, 2 narratives, and 2 instances of individual-level scenario analysis. W2 participants generated 4 MOIs, 1 narrative, and 4 storylines. In W3, participants generated 4 MOIs, 5 narratives, 2 storylines, and 12 instances of group-level scenario analysis.

A significant comparison can be made between Workshop 2 (individual scenario analysis activities) and W3 (group scenario analysis activities). The analysis reveals that W3, conducted as a group, resulted in over double the number of participant-generated outputs (23 total) compared to Workshop 2 (9 total). In W2, where activities were performed individually, 44% of the generated outputs consisted of MOIs, 11% were narratives, 44% were storylines, and there were no instances of scenario analysis. In contrast, W3, characterized by group activities, demonstrated that scenario analysis accounted for 52% of all the generated scenario analysis levels.

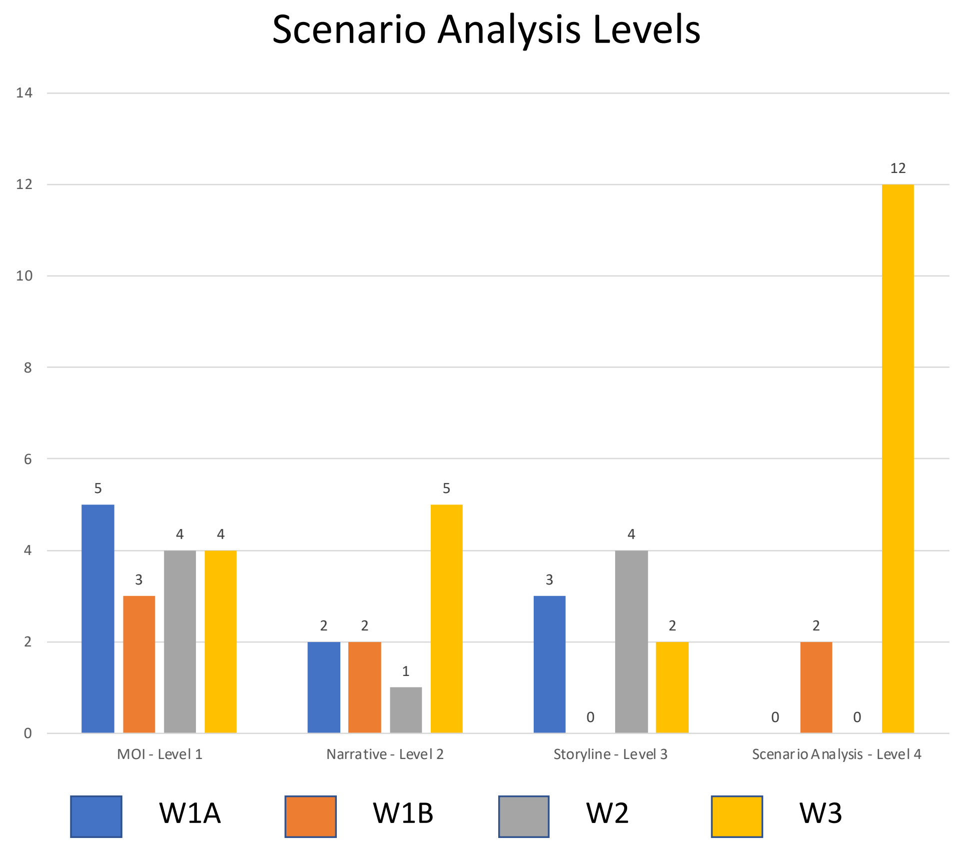


Figure 1.7. Scenario analysis level counts for each workshop, W1A (blue), W1B (orange), W2 (grey), W3 yellow.

3.5 Self-reported metrics

The post-survey was administered with questions related to engagement, trust, and understanding. These self-reported outcomes are adapted from Xexakis (2019) and serve as a valuable tool for gaining insights into participants' perceptions of their enjoyment, trust, and comprehension of the overall workshops. Throughout the study, we observed variations in post-survey completion rates across all workshops, W1A having 8, W1B having 9, W2 having 8, and W3 having 7, total survey completions. To ensure accuracy, the resulting percentages were adjusted to account for these varying group sizes, thus representing the true self-reported outcomes.

Self-reported results across the workshops and survey questions are shown in Figure 1.6. For W1A, the self-reported engagement levels for E1 showed 13% neutral, 63% agreement, and 25% strong agreement. Similarly, for E2, the responses were 13% neutral, 50% agreement, and 38% strong agreement (Figure 1.6a). Concerning trust (T1), the results indicated 13% strongly disagree, 50% agreement, and 38% strong agreement. As for understanding (U1), the responses were 13% neutral, 50% agreement, and 38% strong agreement, whereas U2 showed 75% neutral and 25% agreement. In the case of U3, the responses were 13% disagreement, 13% neutral, 63% agreement, and 13% strong agreement. For U4, 13% were neutral, 25% agreement, and 63% strong agreement.

In W1B, the self-reported engagement levels for E1 showed 11% neutral, 56% agreement, and 33% strong agreement, while for E2, the responses were 78% agreement and 22% strong agreement (Figure 1.6b). For trust (T1), the results showed 11% strongly disagree, 11% neutral, 56% agreement, and 22% strong agreement. For understanding (U1), the responses were 11% neutral, 44% agreement, and 44% strong agreement. U2 indicated 56% neutral, 22% agreement, and 22% strong agreement. In the case of U3, the responses were 11% disagreement, 22% neutral, 56% agreement, and 11% strong agreement. For U4, 11% were neutral, 78% agreement, and 11% strong agreement.

For W2, the self-reported engagement levels for E1 showed 50% agreement and 50% strong agreement, whereas for E2, the responses were 63% agreement and 38% strong agreement (Figure 1.7a). For trust T1 showed 13% neutral, 75% agreement, and 13% strong agreement. For U1, the responses were 25% neutral and 75% agreement. U2 showed 50% neutral, 38% agreement, and 13% strong agreement. For U3, the responses were 25% neutral, 50% agreement, and 25% strong agreement. For U4, 38% neutral, 25% agreement, and 38% strong agreement.

In W3, the self-reported engagement levels for E1 were 14% neutral, 57% agreement, and 29% strong agreement. E2 was 100% agreement (Figure 1.7a). T1 results showed 14% neutral, 57% agreement, and 29% strong agreement. U1 showed 86% agreement and 14% strong agreement. U2 showed 43% neutral and 57% agreement. U3, the responses were 29% neutral, 57% agreement, and 14% strong agreement. For U4, 29% were neutral, 43% agreement, and 29% strong agreement.


Workshop 1A Self Reported Metrics

Workshop 1B Self Reported Metrics

Workshop 2 Self Reported Metrics

Workshop 3 Self Reported Metrics

Figure 1.8. Self-reported metric survey percentages for each workshop, E = engagement, T = trust, U = understanding.

4. DISCUSSION

We began with three main questions: 1) How do stakeholders' reason, learn, and make decisions about water facilitated by participatory modeling and scenario analysis methods? 2) Is there an increase in engagement with models through the implementation of participatory modeling and scenario analysis? and 3) What insights were gained from conducting scenario analysis activities with a variety of stakeholders? We studied the effectiveness of participatory modeling (PM) and scenario analysis (SA) in promoting social learning, trust, engagement, understanding, and completion of scenario analysis in a series of workshops with various water users. Our aim was to assess the extent to which participants could complete SA and whether they moved beyond analysis into decision-making.

This study highlights an intriguing observation regarding the workshops under review. A significant majority of the participants in W3 had not partaken in the earlier workshops. Consequently, the training for the SWIM 2.0 modeling tool and the associated individual activities conducted during W1 and W2 did not substantially impact the effectiveness or the success of participants in W3. Indeed, the activities in the first two workshops, which were designed to scaffold learning about the tools so that they could complete higher levels of scenario analysis, may have in fact distracted participants from such higher order reasoning. This result would be consistent with Pennington (2011, Table 1), who aligned phases of experiential learning with theoretical models of technology adoption, with perceived usefulness preceding tool usability in the adoption process. Yet, tool usability is a significant barrier even when usefulness is perceived (Pennington 2011). W3 participants were able to collectively overcome the complexities of tool usage, apparently because their shared interest in learning the results from scenario analysis motivated them to work together towards surmounting the difficulties of learning the new technology.

W3 participants demonstrated a notable capacity for interaction with SWIM 2.0, talk about policy, and higher orders of scenario analysis levels. This observation intimates a salient conclusion: the collective learning process, rather than tool-based training and individual interactions with the tool, may be of greater importance to the successful outcomes of such workshops. Group-level activities also enabled rich discussion even when users were not able to overcome the barrier of model complexity. This suggests that the use of participatory processes, collaboration, and knowledge-sharing among stakeholders can lead to increased learning with models and connection to the policy-world level. A caveat in this interpretation is that the types of users in W3 differed somewhat from earlier workshops. Further analysis using a similar set of, or many more, stakeholders for all three workshops would be required to disentangle the impact of these differences.

The positive connections between group learning, data utilization, model usage, and decision-making were evident in our study. Although responses varied when participants were asked whether hearing different perspectives and utilizing scientific data from models influenced their decision-making processes regarding water, the majority acknowledged the value of considering multiple perspectives and interactive visualizations in decision-making. Interestingly, two emerging topics of discussion included the potential application of the tool in water planning and the need for improved facilitation or a clear definition of what constitutes a decision-maker in relation to the tool, as some participants did not identify themselves as decision-makers.

One of our main goals was to provide a participatory process for various stakeholders to step through scenario analysis (SA) and ultimately to begin discussions around decision-making. Although our SA process did not directly lead to decision-making discussions, there were higher levels of SA and more interpretations seen in group dynamics. In line with the findings of Cairns et al. (2016), it is evident that the process of SA alone falls short in facilitating effective decision-making and subsequent action, which is fundamentally implicit in the concept of scenario planning. Furthermore, it is important to note that the observed deficiency in decision-making discussions in our study may also be attributed to participants not perceiving themselves as active decision-makers within the scope of the study. One participant, for example, identified decision-makers as solely policymakers:

"*Not sure as I am currently not involved in water policy decisions except in this group…* "

This viewpoint may have been shared by other participants when questioned regarding the influence of multiple perspectives and data on their decision-making processes concerning water. It is possible that an underlying power struggle manifested, with participants perceiving decision-making as exceeding their areas of expertise. Participants may have held a perception characterized by uncertainty regarding their authority to actively participate in decision-making processes pertaining to water policy. The presence of such dynamics resonates with the power struggles exposed in several studies when trying to address water policy (Fallon et al., 2021; Zellner et al., 2022). Should participants perceive decision-making as predominantly confined to higher levels of policy-making, they might undervalue the importance of their own expertise and potential solutions.

However, due to the limited time frame, these discussions did not progress sufficiently to encompass decision-making considerations. The results of our study revealed that the information provided, and the utilization of the modeling tool had a significant impact on participants' perspectives regarding water in the region. Most participants reported that their thinking about water was indeed influenced by the workshop activities. When we asked participants if the information and use of the tool changed how they think about water in the region, many participants said yes. One participant said it did not change how they think about water but "solidified the commitment toward binational and multisectoral collaboration." This was a positive outcome in a region that shares water through transboundary aquifers (Hargrove & Heyman, 2020). Many respondents recommended the use of the tool in other learning settings with different kinds of stakeholders. Another common sentiment was that the workshops highlighted the need to understand what issues to prioritize.

Another issue often identified when working with models is trust in the model. Our collaborative approach enabled higher levels of engagement and scenario analysis, which, in turn, fostered trust in the model. The establishment of trust with the model was a significant outcome observed among participants, regardless of their prior experience and participation in previous workshops. This was evident through an increased frequency of tool-use discussions, heightened engagement with the model, and higher counts of synthesizing coding. Although the complexity of the model posed challenges for some participants at the group level, even individuals with limited familiarity were able to develop sufficient trust to initiate scenario analysis (SA). Participants' recommendations on how to improve the tool and utilize it for decision-making also demonstrated this growing trust. While certain participants faced difficulties in actively engaging with the model due to the inability to pose specific questions of interest, their contributions at the group level remained valuable in discussions concerning the interpretation of the obtained results. The group scenario analysis activities, including collaboratively constructing a concept map and collectively examining potential inputs and outputs, played a crucial role in simplifying the model's complexity. This increase was quantified through the observation of a rise in discussions related to model-level and policy-world level codes as depicted in Figure 1.3. Moreover, these activities yielded important feedback on the model's utility and areas for improvement to cater to users from diverse backgrounds.

PM and SA, coupled with facilitation and collaborative processes, enabled participants to acquire new knowledge, develop trust in the model, become more engaged, and attain a better understanding of water issues in the Middle Rio Grande Region. Additionally, a relatively high number of participants completed scenario analysis, signifying that the approach was successful in promoting engagement with the model and data through the tool. These results highlight the transformative effects of the group-level activities on participants' thinking about water, the increasing trust in the modeling tool, and the positive relationships observed between group learning, data utilization, model usage, and decision- making. The integration of a model such as SWIM 2.0 with PM and SA fostered a collaborative atmosphere among all participants, regardless of their knowledge, values, questions of interest, or limited engagement during virtual sessions conducted over Zoom. As emphasized by Cash et al. (2003), these processes rendered the model salient, credible, and legitimate, facilitating participants' transition from mere model viewing to engaging in discussions pertaining to policy-making.

5. LIMITATIONS & FUTURE WORK

Several limitations were identified in our study, the foremost being the exclusive virtual format of the workshop series. This virtual nature posed challenges in measuring certain metrics that would have been more easily assessable in an in-person setting. Additionally, the discussions conducted over Zoom may have been influenced by factors such as participants' comfort levels in speaking up or the dominance of strong personalities who contributed frequently. Another limitation pertains to the small number of participants who attended all three workshops, as we ideally aimed for a larger cohort to ensure greater diversity and comprehensive engagement throughout the series.

Furthermore, the study revealed that participants expressed a desire for more time to interact with the model. This indicates the potential for extended engagement, which could foster in-depth discussions on future scenarios, potential solutions, and water policies. Allocating additional time for participants to engage with the model would enable a more comprehensive exploration of diverse perspectives and facilitate more informed decision-making processes in the context of water management.

Using SWIM 2.0 within a serious game framework has the potential to increase participant engagement while simultaneously advancing the trust-building process. “This gamified approach condenses and accelerates the planning endeavors into a single event, compressing the timeline compared to traditional extended periods (Carson et al., 2018).” This dynamic approach can create a more stimulating environment where participants can take on real roles, generate more questions, develop solutions, and reach decision-making.

6. CONCLUSION

This study explores stakeholder engagement and decision-making processes in the context of water management using participatory modeling and scenario analysis methods. The study aims to address key research questions related to stakeholder reasoning, learning, and decision-making. The findings highlight the importance of participatory processes, collaboration, and knowledge-sharing among stakeholders. By fostering trust in the model, the study demonstrates increased engagement and scenario analysis. Although decision-making discussions were not directly achieved, the study identifies factors such as power struggles and participants' perceived lack of authority that may hinder decision-making involvement. The establishment of trust in the model is observed, along with the valuable contributions of participants, even with limited model comprehension. The integration of SWIM 2.0 with participatory modeling and scenario analysis promotes collaboration and inclusivity. The study concludes by emphasizing the need to bridge the gap between scenario analysis and decision-making and calls for further research to empower stakeholders in shaping water policy.

Additionally, self-reported metrics indicated that the workshops were successful in enhancing participants' understanding of the complexities of water supply management, reducing misconceptions, and increasing excitement among participants. This outcome indicates that the participatory approach was successful in engaging participants effectively.

Our study highlights the potential of participatory modeling approaches to tackle complex issues, promote collaboration, and foster trust among stakeholders. Future studies may explore ways to overcome challenges to reaching the "decide" engagement level, such as improving tool usability, providing sufficient information for decision-making, and enhancing participants' perception of their ability to make valid decisions.

In conclusion, our study emphasizes the potential of participatory modeling approaches and group-level learning dynamics to address complex issues, promote collaboration and build trust among stakeholders with a model like SWIM 2.0.

7. ACKNOWLEDGMENTS

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Chapter 2: Facilitating the use of an integrated water model with model-based reasoning and participatory modeling for non-experts.

1. INTRODUCTION

The Middle Rio Grande River is a vital shared resource that traverses multiple jurisdictions (New Mexico, Texas, and Mexico), requiring collaborative efforts to effectively allocate and manage its water. Middle Rio Grande can also be identified as a socio-environmental system (SES). The existing water policies and practices have proven inadequate, resulting in undue strain on the system and the emergence of conflicts among stakeholders. This situation has compromised the fulfillment of environmental and social needs, undermining the sustainability of the water source. The endeavor to tackle these challenges involves numerous groups with diverse needs and interests, entangled within a web of social, political, and administrative uncertainties (D. W. Cash et al., 2006). When dealing with socio-environmental systems it is key to include expert knowledge and experts outside of the research and policy making circles (R. Cairns et al., 2020). To address these challenges, we advocate for the use of SWIM 2.0 an integrated water model framework, alongside the adoption of participatory modeling (PM) approaches and model-based reasoning (MBR), to promote conflict resolution and guide discussions toward achieving a more equitable and sustainable water source for all users.

One of the features of SWIM 2.0 is the ability to run a variety of scenarios to answer questions about what our water futures could look like. This can pose a challenge in that not everyone has the same interests or questions. In cases where stakeholders have diverse perspectives about a complex SES, participatory modeling has proven useful for developing a shared understanding of at least some aspects of the system. The aim of participatory modeling is to collaboratively generate knowledge, promote a shared understanding of the challenges related to a particular resource system, and engage in "thought experiments" using decision visualization environments (Voinov et al., 2016; Voinov & Bousquet, 2010). Participatory modeling can provide a venue for stakeholders to participate in discussions about issues, exposing various perspectives with the aim of promoting cross-perspective learning and convergence towards shared comprehension. But if individuals have little understanding of, or skill using, the visualization environment provided by the model this may deter them from completing and fully engaging in the participatory modeling process. This is when model-based reasoning comes into play.

Model-based reasoning proposes that in complex problem-solving tasks, humans iteratively construct internal mental models of the situation (Nersessian, 1999). It suggests that creating external representations of these mental models facilitates the creation of new mental models, leading to conceptual changes. Model-based reasoning incorporates techniques such as analogies, metaphors, visual models, and diagrams to abstract and represent complex concepts. By externalizing these mental models as a diagram such as a concept map (Figure 2.1), it allows for the simplification and synthesis of intricate information, enabling learners to comprehend and transform larger amounts of information (Pennington et al., 2021).

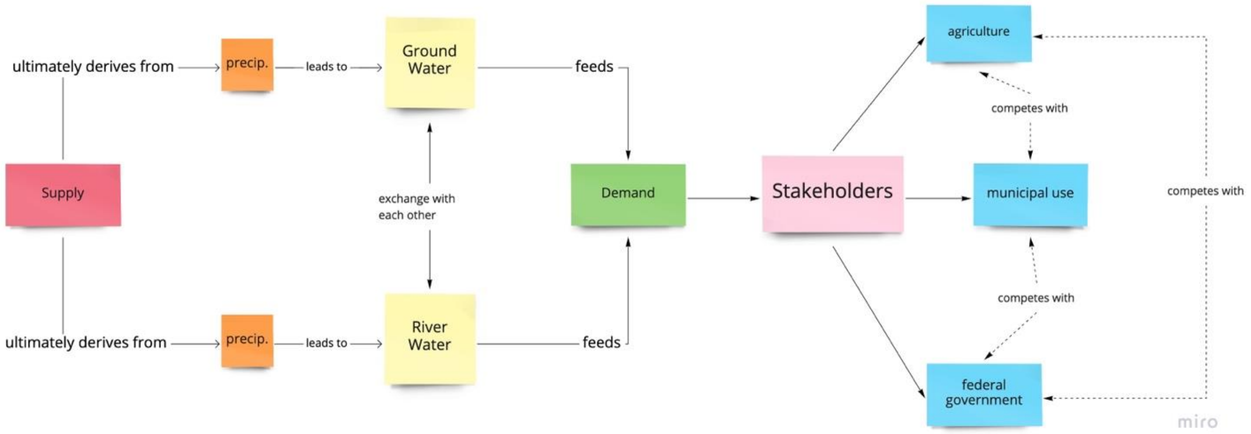

Figure 2.1. Example of concept map generated by a participant in one of this study's workshop.

Model-based reasoning is consistent with studies in social science of “boundary objects” that enable sharing of information across diverse perspectives through physical artifacts (Star & Griesemer, 1989). Examples of these can include abstract and concrete objects like diagrams, maps, or repositories that are standardized and can be used by different people for multiple purposes (Beddoes & Nicewonger, 2019). Some boundary objects serve the purpose of enabling people with diverse perspectives to collaboratively generate a common understanding of an issue or concept. These have been referred to as boundary negotiating objects (BNOs; Lee 2007). BNO’s have been shown to “temporarily bridge gaps between stakeholders and encourage co-learning and cooperation” (Jakku & Thorburn, 2010; Marcotte et al., 2020). Achieving this outcome in a group depends heavily on a structured process (C. P. Lee, 2007).

Boundary negotiating artifacts or BNO’s are better defined as a more iterative representation of perspectives that brings disparate communities of practice into alignment, to solve specific problems of a more complex issue or project (Beddoes & Borrego, 2014). The original boundary negotiating artifact typology included self-explanation, inclusion, compilation, structuring, and borrowed (Table 2.1; Lee 2007). BNOs assist in communication, aligning conceptual frameworks, simplifying complex systems, supporting iterative refinement, and aid in decision-making. Ultimately, BNO’s promote collaboration, shared understanding, and effective knowledge exchange among stakeholders with diverse backgrounds, further enhancing the quality of reasoning and problem-solving.

Table 2.1. Original BNA typology terminology from (C. P. Lee, 2007), table modified from (Beddoes & Nicewonger, 2019).

Type	Purpose	Examples
Self - explanation	For an individual to organize information for themselves.	Concept sketch, notes, journal
Structuring	To allow communication of other structuring artifacts to make a vision dominant. Allows for push and negotiation of boundaries between communities, establishes ordering principles	Narratives, Concept map

In this study, participatory modeling (PM) and model-based reasoning (MBR) with BNO's were combined to aid stakeholders in achieving a better understanding of water futures in the Middle Rio Grande. In our study, we used a variety of BNOs including concept maps generated by participants and the SWIM 2.0 interface. This was done specifically to include those users who might not be experts in modeling or in water issues. We asked the following questions:

- What did individual concept maps look like for participants from various backgrounds?
- How did individual concept maps transform into a shared group concept map?
- Did individual or group concept mapping activities aid in achieving a higher level of engagement with SWIM 2.0 (i.e., viewing, interacting, asking questions, posing solutions), or not?
- In what ways were BNOs used to communicate (i.e., amongst participants, with SWIM 2.0, about SWIM 2.0)?
- Did using these BNOs in the context of PM and MBR facilitate or hinder the process of using an integrated water model and to what extent?

2. METHODS

A series of workshops were developed to bring water users of all backgrounds to interact with the Sustainable through Integrated Water Modeling (SWIM 2.0) online interface. SWIM 2.0 was developed with the goal of supporting participatory modeling and user engagement through community-based workshops. All workshops were held virtually via Zoom due to the constraints of COVID-19. Participants were encouraged to attend all workshops consecutively, but it was not a requirement. In addition to Zoom, an online collaborative workspace was established for each workshop using Miro. This dedicated digital space served as a platform for participants to collaborate and capture their ideas or responses during the workshop activities. It was accessible both before and after the workshops, allowing participants to continue the discussion and access the shared information at their convenience.

2.1 Workshop and activity design

Workshop one aimed to familiarize participants with water issues, stakeholder concerns, and briefly introduced the functionality of SWIM 2.0. In workshop two, participants were instructed to create a concept map prior to attending using Miro or any other diagramming tool including paper. The concept map was meant to depict the water system in the Middle Rio Grande and encompass water-related issues. The prompt given to participants was: generate a concept map describing the water system in the middle Rio Grande and water issues (i.e., policy, environment, health, justice). Participants were provided with an example concept map from a different domain to avoid biasing their concept maps.

During workshop two, participants shared their concept maps, leading to discussions about the various concepts depicted. This was followed by an activity called Mapping to SWIM, in which participants utilized their concept maps to explore the inputs that could be modified in SWIM 2.0 and the outputs that could be obtained when running different scenarios. The purpose of this activity was to alleviate the challenges posed by a model with multiple inputs and outputs. By utilizing their concept maps, participants could identify specific questions they wanted to address and determine the corresponding results, as opposed to randomly changing inputs and examining outputs without a specific question in mind. Workshop three stepped through the same activities but was supplemented with the co-creation of a group concept map.

The iterative process of creating a concept map and Mapping it to SWIM was intentionally designed to support participants who lacked expertise in water modeling. The researchers guided participants through this process, encouraging them to generate specific questions of interest that could be potentially addressed using SWIM 2.0. After running a scenario in SWIM 2.0, participants were prompted to analyze and explain their results in relation to their previously identified questions of interest. This approach allowed participants to directly connect the outputs obtained from the model with their specific inquiries, enhancing their understanding and interpretation of the results. By aligning the results with their initial questions, participants could gain insights into the implications and outcomes of the scenarios based on their areas of interest.

Lastly, participants were given two discussion questions: 1) Has seeing various concept maps affected your thinking about water, if so, how? and 2) Did the concept mapping help you better formulate questions to ask about our future through the SWIM 2.0 model?

2.2 Data collection

Data collection for this chapter focuses on workshop two and three since these were the workshops where concept mapping was conducted. Concept maps were collected from participants either through email submission or directly placed onto the Miro workspace. The discussions surrounding the concept maps were conducted via Zoom and recorded for transcription. The questions developed by participants were gathered through various channels, including the Zoom chat function, verbal communication during the workshop sessions, or input on the Miro platform. At the conclusion of each workshop, several open-ended survey questions specifically related to the utilization of concept maps were posed to the participants. These questions aimed to gather feedback and insights on the participants' experiences and perceptions regarding the use of concept maps in the workshop activities.

2.3 Data Analysis

2.3.1 Concept map analysis

The analysis of concept maps involved examining the counts of concepts, connections, and clusters of main themes. The main themes identified included supply, demand, and policy, which were determined based on an overall observation of the organization of all participants' concept maps. Emerging clusters that were distinct from the main themes were kept separate and are shown in the results. We also compared counts and concepts from individual maps to the co-created group concept map. Bar charts were created to show the counts; pie charts were created to show cluster percentages for each participant. Not all individuals engaged in the development of concept maps in W2 and W3. Despite our inability to subject their respective concept maps to analysis, participants in W3 still contributed to the collaborative construction of the group concept map, even in cases where they did not produce an individual map.

To gain a deeper understanding of the individual concept maps, a rubric developed by the National Park Service (https://www.nps.gov/grsm/learn/education/classrooms/upload/Concept-Map-Scoring-Rubric.pdf) was employed to quantify their organization, content, and terminology, as well as the knowledge displayed through connections. A score was assigned for each category, 0 to 4, then scores in each category were summed up to a total score for a max possible total of 12. This rubric served as a tool to assess the varying degree of understanding of water issues in the region, allowing for a more comprehensive analysis of the maps and their respective qualities. Concept map scores were also compared using a standard regression to the participant's water knowledge and modeling experience which were each ranked on a scale of 0 to 4 (Table 2.2). This was developed using participants' background and area of study collected during introductions, these scores were only assigned to participants who completed concept maps.

Table 2.2. Water knowledge and modeling experience ranking scale created for our analysis.

Score	Water Knowledge	Modeling Experience
0	No knowledge of water system, does not know any scientific terminology.	No modeling experience – has never used or developed any kind of modeling software in any domain.
1	Basic knowledge of water system, knows generic scientific words from the water cycle	Little modeling experience – has used a model once before in any domain.
2	Basic knowledge of water system, knows scientific words from water cycle, and some basic knowledge about the Middle Rio Grande Region	Basic comprehension of models and has used or seen a water related model before.
3	Knowledge of water system and of the primary components of the Middle Rio Grande (supply and demand)	Has interacted with a model or water related model and understands the primary dynamics of input and outputs.
4	Full comprehension of the water dynamics in the Rio Grande and know about water policies and solutions.	Has developed or worked on a water related model.

2.3.2 SWIM 2.0 activity counts

We compared the count of questions and scenarios developed in both individual and group activities. This comparison aimed to assess whether the concept maps enabled a higher level of engagement with SWIM 2.0, such as in-depth scenario analysis. We also counted how many connections were made between SWIM 2.0 and the group concept map. By examining the utilization of SWIM 2.0 and comparing the outcomes between individual and group activities, a deeper understanding of the role played by concept maps in simplifying the use of the modeling tool could be obtained.

2.3.3 Boundary negotiating analysis

SWIM 2.0 activity counts were supplemented by an analysis of the discussions that took place during the sharing of individual concept maps and the co-creation of the group concept map. It's noteworthy that participants in W2 were given the opportunity to present their concept maps if they chose to do so; however, this option was not allotted any time in W3. Transcripts from all concept mapping activities were subjected to analysis using NVivo software to identify any recurring themes or patterns. The coding themes were derived from the original boundary negotiating artifact typology (as presented in Table 2.1). Codes we used included self-explanation, constructing a shared understanding, structuring across participants, and structuring across SWIM 2.0 (Table 2.3). Lastly, we complemented this analysis with an examination of the responses to open-ended questions related to the concept maps. This allowed us to gain insights into the participants' engagement with and utilization of the concept maps as tools for boundary negotiation and knowledge exchange between each other but also with SWIM 2.0.

Table 2.3. Codes derived from the original BNA typology framework and descriptions.

Code	Description
Self - explanation	Language that is describing information that was originally organized for oneself. Examples include explanation of concept map components.
Constructing a shared understanding	Language explaining ideas from individuals to gain a better shared understanding of a concept or misconception.
Structuring across participants	Language that causes any pushing or negotiating of concepts between participants.
Structuring across SWIM 2.0	Language where participants are pushing or negotiating with SWIM 2.0: trying to understand how to ask question, answer question, or limitations.

3. RESULTS

W2 included seven participants who completed concept maps, while W3 had a total of nine participants (Table 2.4). To simplify the analysis, we considered the primary user type listed first in Table 2.4 for each participant, recognizing that they may belong to various user types.

In W2, there were 4 students, 1 researcher, and 2 environmentalists, whereas W3 was comprised of 6 students, 1 environmentalist, 1 regulator, and 1 city resident. Both workshops were predominantly attended by students and residents. The main distinction between the two groups was the presence of a regulator and more water modelers in W3.

Table 2.4. Workshop two and three participants and user types, names in this table are pseudonyms to protect confidentiality.

W2 Participants and User type (n=7)	W3 Participants and User type (n=9)
Aaron (environmentalist/rural resident)	Aaron (environmentalist/rural resident)
Milo (student/researcher/water modeler)	Milo (student/researcher/water modeler)
Sam (student/researcher/city resident)	Victor (student/rural resident)
Gabriel (researcher /city resident)	Becky (student/researcher water modeler/city resident)
Hope (student/researcher/city resident)	Cristopher (student/researcher/water modeler)
Victor (student/rural resident)	Oscar (regulator/city resident)
Briana (environmentalist/educator/city resident)	Bryan (student/researcher/water modeler)
	Jimmy (student/researcher/water modeler)
	Cesar (city resident)

3.1 Concept map counts, scores, and clusters

Concept maps for Workshop W2 exhibited a range of 8 to 21 components and 2 to 33 connections, with average values of 13.14 and 15.71, respectively (Figure 2.2). In contrast, Workshop W3 concept maps had a range of 8 to 29 components and 10 to 41 connections, averaging 16.78 and 22.89, respectively (Figure 2.3).

In terms of concept map scores, W2 had a range of 6 to 12, averaging 8.86. For W3, concept map scores ranged from 8 to 12, with an average of 9.44 (Table 2.5). On average, participants in W3 scored higher on their concept maps by 0.58 points, generating more components and connections, with averages of 3.63 and 7.17, respectively.

From the cluster analysis of the concept maps, three major clusters emerged across almost all participants, which encompassed the themes of Supply, Demand, and Policy. Further examination led to the identification of additional clusters, including Values, Engagement, Concerns, Modeling, Water Dynamics, and Solutions (Figures 2.4 & 2.5).

The Supply cluster comprised concepts such as the Rio Grande River, precipitation, recharge, reducing snowpack, groundwater, discharge, aquifers, and allocations. The Demand cluster included concepts related to climate, temperature, and various water users, such as urban, industry, farmers, and environmental entities. One participant identified the Tigua community as a unique water user within their concept map. The Policy cluster encompassed concepts like water policy and agreements, regional compacts, water-related justice issues, and water management.

In W2, a distinct cluster emerged with terms related to cultural values, values in science, and values in technology, contributing to the formation of the Values cluster. Additionally, the presence of terms like engagement model for stakeholders, partnerships, and communication formed the Engagement cluster.

Upon analysis of W3 concept maps, we observed the formation of the Concerns cluster, mainly driven by the concept of privatization. Furthermore, the concept of understanding mechanisms of supply and demand clustered together, giving rise to the Water Dynamics cluster. The inclusion of the term health resulted in the formation of the Health cluster. Lastly, an emergent cluster, labelled the Solutions cluster, was evident encompassing concepts such as sustainable water management, water importation, desalination plant, and alternative resources.

W2 showed an average of approximately 2.71 clusters, while W3 averaged about 3.11 clusters. Regarding the incorporation of major clusters, 43% of concept maps in W2 included all three major clusters, while in W3, 33% of maps contained all three clusters. The remaining concept maps in both workshops included at least two of the major clusters and 63% of all concept maps across both workshops were primarily focused on demand-related topics.

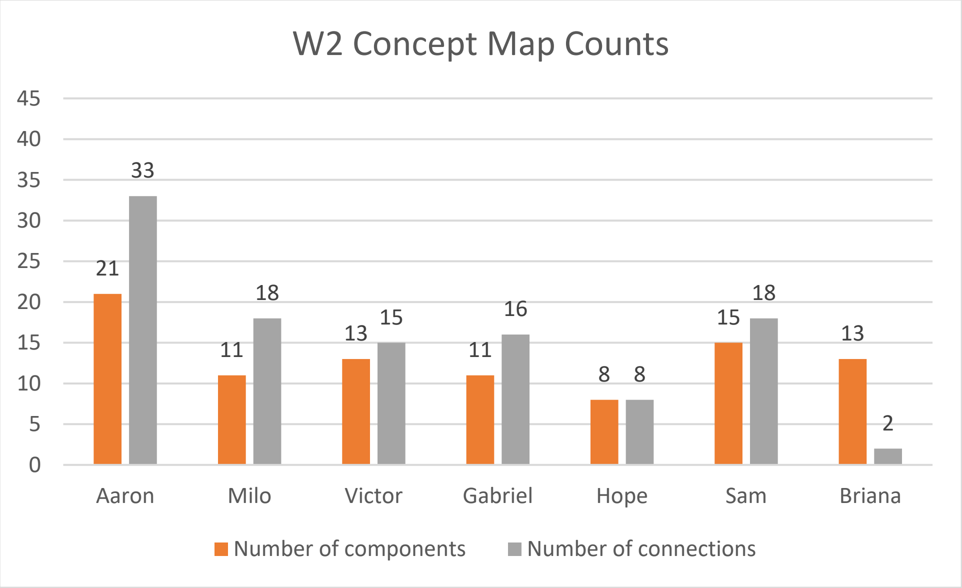

Figure 2.2. Workshop two concept map counts of components (orange) and connections (grey) for each participant.

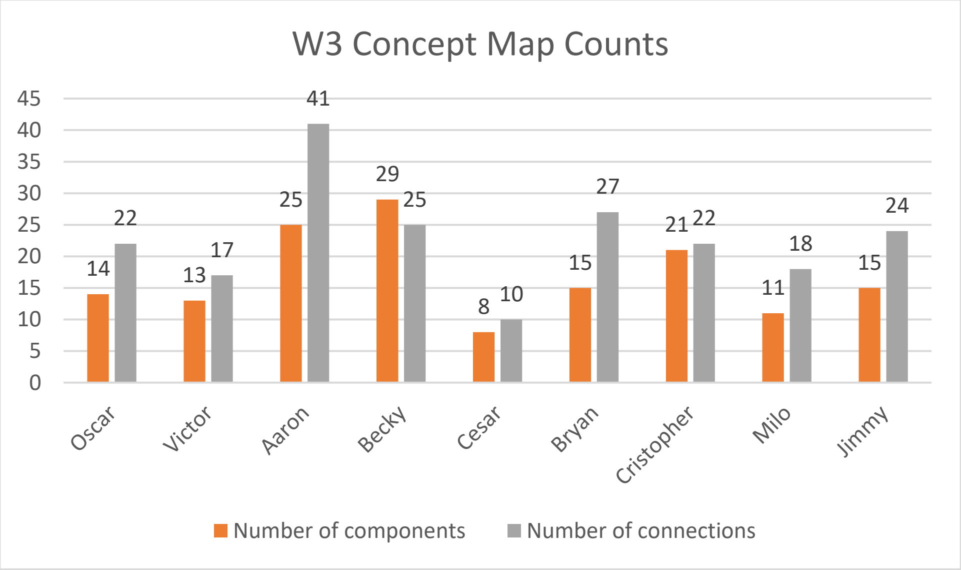

Figure 2.3. Workshop three concept map counts of components (orange) and connections (grey) for each participant.

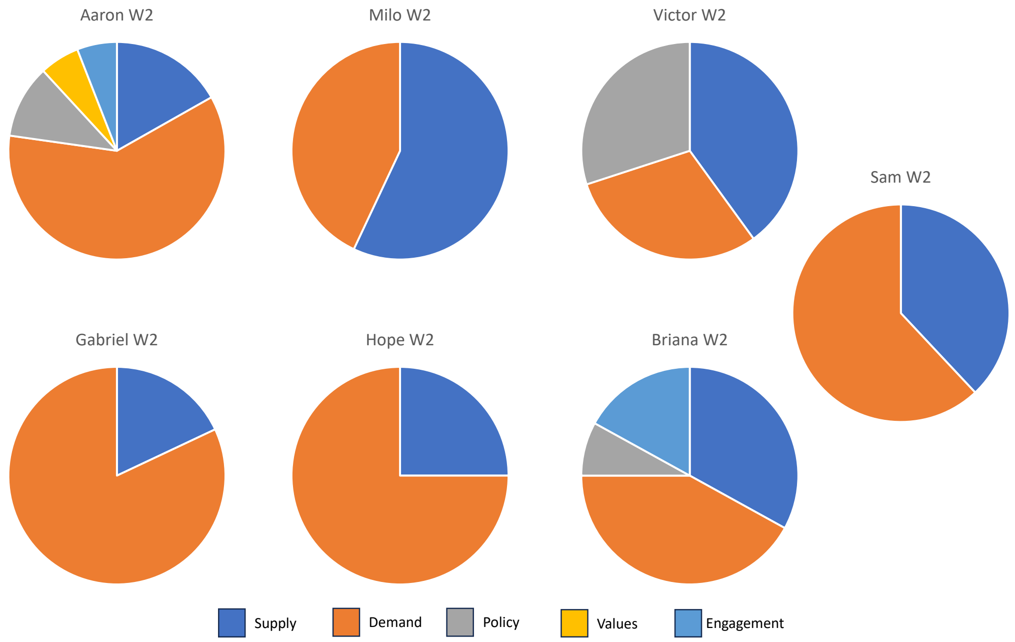

Figure 2.4. Participant concept cluster percentages for workshop two. Clusters include supply, demand, policy, values, and engagement.

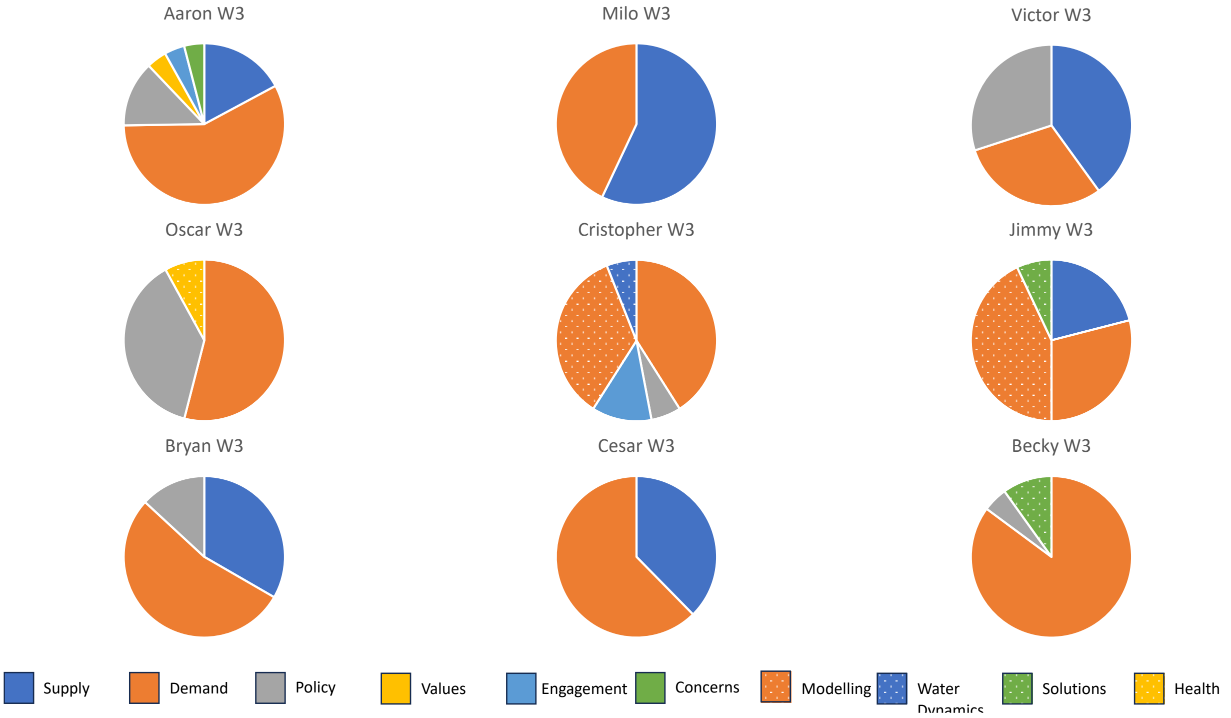

Figure 2.5. Participant concept cluster percentages for workshop three. Clusters include supply, demand, policy, values, engagement, concerns, modeling, water dynamics, solutions, and health.

Table 2.5. Workshop two and three scores per participant for concept map, water knowledges, and modeling skill.

W2 Participants and User type	**Concept Map Score**	**Water knowledge score**	**Modeling skill score**
Aaron (environmentalist/rural resident)	12	4	3
Milo (student/researcher)	11	4	4
Sam (student/researcher/city resident)	10	3	4
Gabriel (researcher)	8	3	2
Hope (student/researcher/city resident)	8	2	2
Victor (student/rural resident)	7	2	1
Briana (environmentalist/educator/city resident)	6	4	2
W3 Participants and User type	**Concept Map Score**	**Water knowledge score**	**Modeling skill score**
Aaron (environmentalist/rural resident)	12	4	3
Milo (student/researcher)	11	4	4
Victor (student/rural resident)	10	3	2
Becky (student/researcher/city resident)	10	3	3
Cristopher (student/researcher)	10	3	4
Oscar (regulator/city resident)	9	4	2
Bryan (student/researcher)	9	3	4
Jimmy (student/researcher)	8	3	4
Cesar (city resident)	6	1	1

We then wanted to see if the successful completion of a concept map had anything to do with their modeling experience or water knowledge. The average water knowledge scores for participants in W2 and W3 were found to be 3.14 and 3.11, respectively. For the modeling skill score, W2 had an average score of 2.57, while W3 had an average score of 3.00. In W2, a comparison between concept map scores and water knowledge scores revealed no significant correlation ($R^2 = 0.1887$). However, a significant correlation was observed between concept map scores and modeling skill scores ($R^2 = 0.60$) (Figure 2.6, A). Conversely, in W3, there was a significant correlation between concept map scores and water knowledge scores ($R^2 = 0.67$) (Figure 2.6, B). There was no significant correlation found between concept map scores and modeling skill scores ($R^2 = 0.20$).

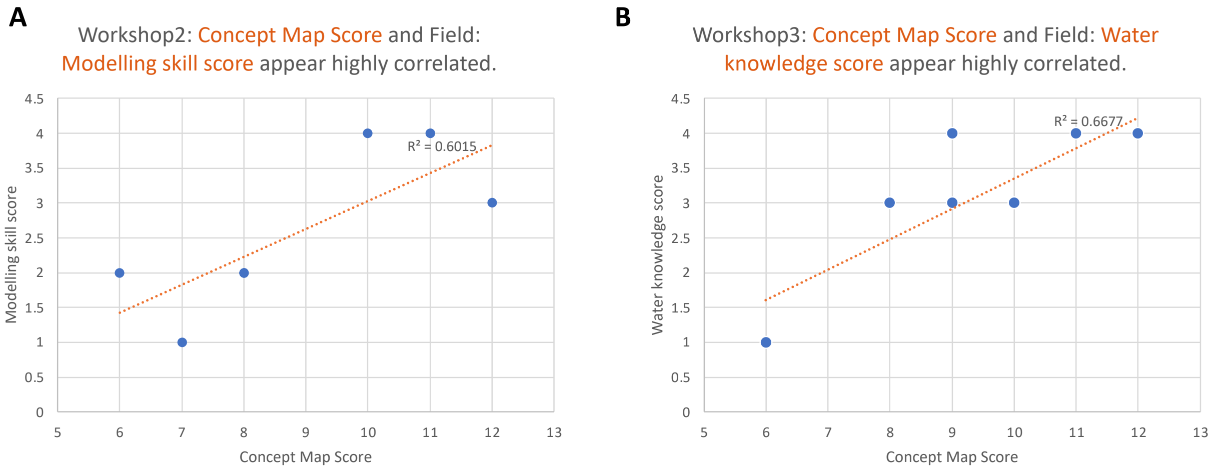

Figure 2.6. A) Scatterplot of concept map scores vs. modeling skill scores. An R2 of .60 indicates a moderate correlation and B) scatterplot of concept map scores vs. water knowledge scores. An R2 of .67 indicates a moderate correlation.

3.2 Comparison of individual concept maps to group concept map

The group concept map generated by participants in W3 using concept maps from W2 and W3, had a total of 37 components and 43 total connections. Upon comparing the concepts found in the individual concept maps with those in the group concept map, it becomes evident that the collective effort resulted in the addition of more components (37) compared to the average number of components on individual maps (16.78). While not all items on the group map were connected, the participants were still able to identify distinct clusters, namely supply (Figure 2.7, A), demand (Figure 2.7, B), and policy (Figure 2.7, C). Additionally, they incorporated emerging topics such as health and proposed solutions like cultivating less water-intensive crops and optimizing reservoir operations. They employed more precise conceptual terms, including transboundary aquifers, accurate aquifer nomenclature, water rights, water legislation, and identified all three major locations where water is shared (Texas, New Mexico, and Mexico). Despite the omission of certain concepts like Water Dynamics, Values, Engagement, Concern, and Modeling, many of the retained concepts underwent substantial refinement throughout the group concept mapping process.

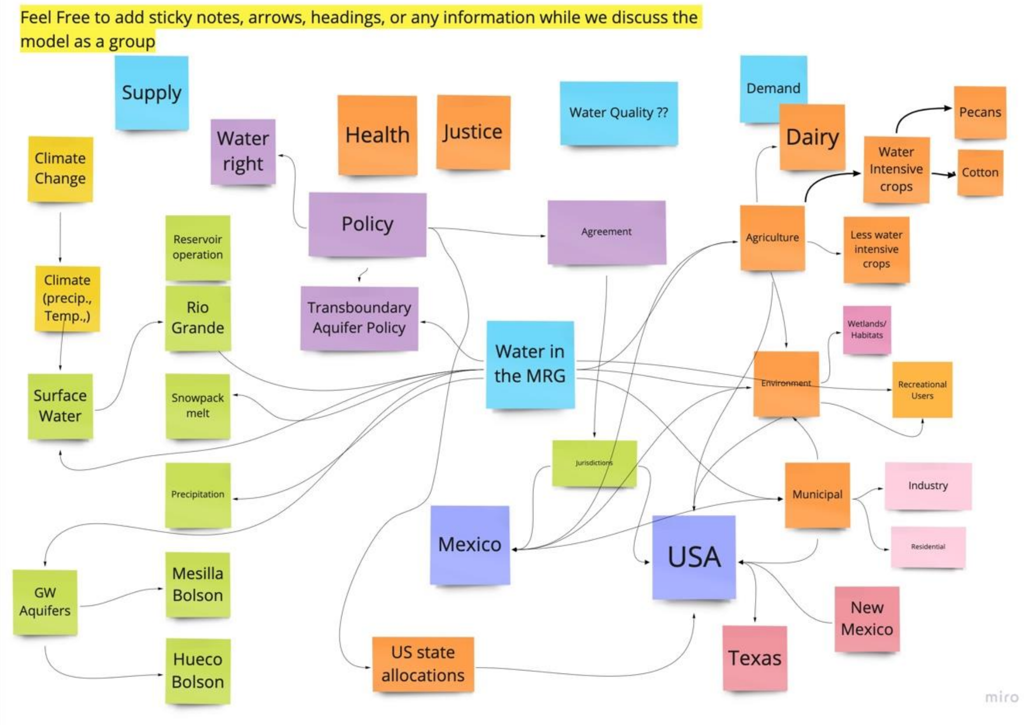

Figure 2.7. Group concept map co-created by workshop three participants. A) Supply cluster, B) Demand cluster, C) Policy cluster, the three primary clusters.

3.3 SWIM 2.0 activity counts & coding derived from Boundary Negotiation Artifact typology for communication

Given the virtual format of the workshop, it was not feasible for us to measure the connections made to different inputs and outputs during the Mapping to SWIM activity for individual concept maps in W2. Participants constructed 10 individual questions and made 9 interpretations of the results. Contrastingly, during W3, participants used Miro to perform group Mapping to SWIM using arrows, which enabled them to establish 14 connections between inputs and outputs. This process resulted in the formation of five questions and 23 interpretations of the outcomes (Figure 2.8).

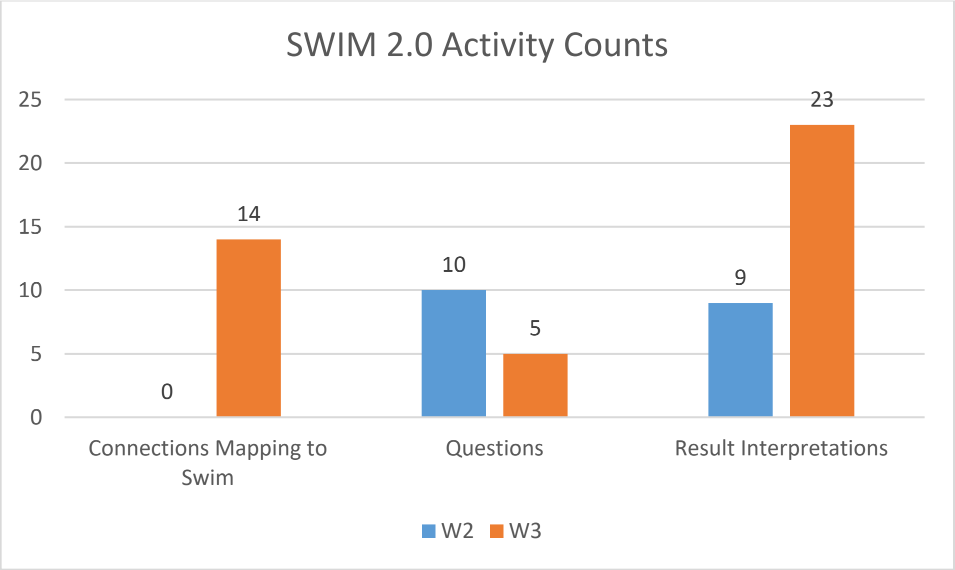

Figure 2.8. Comparison of SWIM 2.0 activity counts for workshop two (blue) individual concept maps and workshop three (orange) group concept map. Note zero connections from mapping to SWIM in W2 because it was not feasible over zoom.

When analyzing the success rate of scenario analysis completion, the results from chapter one deserve attention. A significant rise in the completion of higher-level scenario analysis was noticed in W3. The number of instances of complete scenario analysis reached 12, compared to no such cases in W2.

For a more comprehensive insight into the use of concept maps as a communicative tool among participants and with SWIM 2.0, we employed a coding process (Table 2.6). Workshop transcripts were divided into segments that covered discussions related to concept map sharing and SWIM 2.0 activities. Throughout the concept map sharing sessions in W2 and W3, the recurring themes identified were ‘Self-explanation’, counted five times in W2, and eight times in W3, and the ‘Constructing a Shared Understanding’, counted 11 times in W2, and eight times in W3. In the SWIM 2.0 Activity Discussion, ‘Constructing a Shared Understanding’, counted 2 times in W2, and 10 times in W3, ‘Structuring Across Participants’ was counted 19 times only in W3, and ‘Structuring Across SWIM 2.0’, counted 7 times in both W2 and W3.

Table 2.6. Coded themes found in workshop 2 and 3 using the BNA typology.

Code	W2 Sharing Concept Map Discussion	W3 Sharing Concept Map Discussion	W2 SWIM 2.0 Activity Discussion	W3 SWIM 2.0 Activity Discussion
Self - explanation	5	8	0	0
Constructing a Shared Understanding	11	8	2	10
Structuring Across Participants	0	0	0	19
Structuring Across SWIM 2.0	0	0	7	7

We asked them two questions, 1) Has seeing various concept maps affected your thinking about water, if so, how? and 2) Did the concept mapping help you better formulate questions to ask about our future through the SWIM 2.0 model? Seeing various concept maps has had a significant impact on the respondents' thinking about water. Some of the key insights include concept maps broadening their perspectives by allowing them to see how other people think, but also making them aware that different stakeholders view water differently based on their backgrounds, areas, and sectors. It helped them see a bigger picture of water interactions and the various dimensions that affect water in the Middle Rio Grande region. This also highlighted dimensions and parameters that the respondents hadn't initially considered, thus enriching their understanding of water and its complexity. Lastly, it reinforced the importance of collaboration among different sectors and nations in managing water resources effectively.

The responses regarding the impact of concept mapping on formulating questions for the future through the SWIM 2.0 model are mixed. Some respondents mentioned that concept mapping did help them in formulating better questions and creating new ones that could be tested in the SWIM 2.0 model. They found the concept maps to be a useful tool for conceptualizing ideas before generating specific questions for the SWIM 2.0 model. These respondents appreciated the interactive nature of concept mapping and recognized its potential to inform and improve the modeling process. However, other respondents did not directly attribute the concept mapping exercise to their ability to formulate questions for the SWIM 2.0 model. Instead, they mentioned being influenced by peers or other factors when generating their questions. Some respondents expressed challenges in formulating questions in general, finding the complexity of the topic or the structure of the SWIM 2.0 model to be obstacles.

4. DISCUSSION

We began by asking the following questions, 1) What did individual concept maps look like for participants from various backgrounds? 2) How did individual concept maps transform into a group concept map? 3) Did individual or group concept mapping activities aid in achieving a higher level of engagement with SWIM 2.0 (i.e., viewing, interacting, asking questions, posing solutions), or not? 4) In what ways were BNOs used to communicate (i.e., amongst participants, with SWIM 2.0, about SWIM 2.0)? and, 5) Did using these BNOs in the context of PM and MBR facilitate or hinder the process of using an integrated water model and to what extent? Our findings suggest that concept maps varied in components, connections, and clusters. We also saw a more refined group concept map that integrated many individual concepts but also lacked emerging clusters from individual concept maps. Our results also highlight the effectiveness of concept mapping in enhancing participants' understanding of water-related issues, promoting collaboration, and increasing engagement with a model.

One interesting find was seen in individual concept maps, where there was the emergence of modeling and water dynamics focused concepts. This could be attributed to the participants being made up primarily of students who studied water modeling. Their concept model was rooted in their academic domain. Even so, they were able to communicate their ideas to novice participants, negotiate their ideas to remain in discussion, and they were flexible enough to contribute to the group concept map. The comparison between individual concept maps and the group concept map highlighted the collective effort and the incorporation of more components in the latter. Although not all items in the group map were interconnected, distinct clusters were identified, and concepts underwent further refinement. The refinement process they completed aimed to align the concept map more effectively with SWIM 2.0, resulting in the omission of certain components that did not seamlessly integrate into the map. However, this does not diminish the significance of the excluded concepts; rather, it reflects their limited applicability within the SWIM 2.0 framework.

When assessing how concept maps were used as BNO's, the collaborative nature of the concept mapping process facilitated effective communication between participants and with the SWIM 2.0 model. Participants engaged in self-explanation and actively constructed a shared understanding while sharing their concept maps. The SWIM 2.0 activities discussions demonstrated an increase in structuring codes, particularly in W3, which can be attributed to the group concept mapping activity. This shift indicated participants' efforts to effectively communicate with SWIM 2.0 and explore potential solutions based on the model results. Several studies have shown that spatio-temporal decision-making using simulation models that project complex geographic phenomena into the future under different assumptions to explore the range of plausible conditions through time (e.g., scenario analysis) is especially difficult for people to understand and can be computationally expensive as well (Andrienko et al., 2007; Gramberger et al., 2015). Recent studies have called for creating methods and tools to generate a complete synergistic relationship between computer models and stakeholders, granting the user the ability to analyze, reason, collaborate, and make decisions (Andrienko et al., 2007; Meerow & Newell, 2017). In this case we used concept maps in parallel to a modeling tool to create a synergistic relationship not only between the model and user but from user to user.

Workshop 3 revealed interesting findings, including the effective contribution of a novice participant in mediating the group dynamic. This was the same participant who identified the Tiguas in their concept map. This reinforces the idea of incorporating both expert and non-experts when addressing SES issues, because they can often bring forth unique skills and help scientists produce usable knowledge (Clark et al., 2016). The integration of various stakeholder perspectives is also key for aiding in the co-production of knowledge (Shrestha et al., 2017).

In the previous chapter we looked at how successful users were in completing scenario analysis ‘a systematic way to think about the plausible complex and uncertain futures’ on SWIM 2.0, by running multiple scenarios. We found very few participants were able to fully understand results and develop a storyline into the future or complete scenario analysis at all. Even so, the concept maps they developed aided them in continuing the conversations around the SES issues outside of the model.

In our investigation of the group concept mapping process, we delved into the dynamics of generating the concept map collaboratively. Concept mapping, being an open-ended task, often involves negotiation when conducted in a group setting. “This negotiation process encompasses asking and answering questions, resolving disagreements, and co-constructing meanings” (Van Boxtel et al., 2002). During the group concept mapping activity, participants engaged in dialogue aimed at clarifying water-specific terminology, incorporating regional information, and discussing whether to retain or restructure certain concepts. These negotiations played a crucial role in generating a concept map that was both more robust and refined, aligning it with the requirements of SWIM 2.0. This could be attributed to the participants' increased trust in the model, coupled with a better overall understanding of its capabilities and limitations.

Overall, the concept mapping exercise facilitated active engagement, collaborative efforts, and an improved understanding of water issues and modeling implications. It provided participants with a broader perspective, enhanced communication with the SWIM 2.0 model, and emphasized the importance of collaboration in addressing water resource challenges effectively. It did not move participants into decision making but it did allow them to move past the complexities of the model to have valuable conversations about policies and water issues.

5. LIMITATIONS & FUTURE WORK

The concept mapping exercise in our study encountered certain limitations. Firstly, not all participants completed a concept map as part of the activity, which impacted the comprehensiveness of the generated maps. Secondly, due to the virtual nature of the workshop, it was challenging to track and document the engagement that took place during the Mapping to SWIM activity. To address these limitations, we suggest two potential solutions. One approach would involve utilizing tracking software to automatically label inputs and establish clear connections between concepts and participants. This would enhance the traceability of engagement within the mapping process. Alternatively, participants could have attended both workshops, allowing for the creation of individual concept maps, which would ensure a more complete participation and understanding of the mapping process. Implementing these strategies would help overcome the limitations observed in our study and enhance the quality and comprehensiveness of future concept mapping activities.

As previously noted approaches to SES issues need to shift from "conventional paradigms of science-policy interactions to interdisciplinary, international, cross-sectoral, open, continual and iterative, and flexible approaches" (Lutz-Ley et al., 2021). In the realm of water governance, interactions between scientists, stakeholders, and policymakers occur at both structural and process levels. Structurally, these interactions manifest as networks, forming connections and relationships among the various actors involved. Process-wise, these interactions are characterized by dialogic exchanges, involving dialogue, deliberation, and collaborative decision-making(Lutz-Ley et al., 2021). For future endeavors involving SWIM 2.0 or similar models, we propose adopting a policy-dialogue approach to foster effective and sustained engagement with stakeholders across all sectors. This approach aims to facilitate ongoing dialogues that address water security concerns while also acknowledging and addressing power imbalances within these dialogue networks. Given SWIM's focus on transboundary aquifers and its goal of incorporating the perspectives of non-policy-making actors, employing a policy-dialogue approach holds great potential for yielding substantial benefits. It can enhance the inclusivity of decision-making processes and contribute to the development of holistic and equitable water management strategies.

For future studies, we would also encourage the generation of post-workshop individual concept maps prior to the generation of a group concept map to better understand negotiations. This approach will provide valuable insights into the negotiation process and allow us to determine whether the negotiations played a central role in shaping the group concept map or if they were influenced by a deeper understanding of the model. This approach will help us gain a comprehensive understanding of the interaction between negotiations, comprehension of the model, and collaborative concept mapping processes.

6. CONCLUSION

In conclusion, this study aimed to assess the integration of individual perspectives in a co-created group concept map and investigate how the concept map aided in generating scenarios within the water model in SWIM 2.0 model selected for this study. The results highlighted the effectiveness of concept mapping in enhancing participants' understanding of water-related issues and promoting collaboration. Major clusters such as supply, demand, and policy provided a framework for organizing concepts, while additional clusters added depth and complexity to the exploration of water issues. The group concept map demonstrated a collective effort and the incorporation of more components compared to individual maps. Through dialogue and negotiation, participants refined the concept map, aligning it with the requirements of SWIM 2.0. The collaborative nature of concept mapping facilitated effective communication and a shared understanding among participants and with the model. Workshop 3 revealed the valuable contribution of a novice participant in mediating the group dynamic, emphasizing the importance of incorporating diverse stakeholder perspectives. Although participants faced challenges in fully understanding and conducting scenario analysis within SWIM 2.0, the concept maps facilitated continued conversations on socio-environmental issues beyond the model. The concept mapping exercise fostered active engagement, collaborative efforts, and improved comprehension of water issues, allowing participants to engage in valuable conversations regarding policies and water challenges. While concept mapping did not directly lead to decision-making, it provided a platform for meaningful discussions and a deeper understanding of the complexities involved in water resource management.

7. ACKNOWLEDGMENTS

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Chapter 3: Developing competencies needed to address complex sustainability issues

1. INTRODUCTION

In response to the growing prevalence of ‘wicked’ sustainability challenges within socio-environmental domains, the field of sustainability persists in its dedication to addressing them through a range of problem-driven or solution-oriented research and teaching methodologies (Swart et al., 2004). Solving these issues also requires collaboration across perspectives that cross disciplinary, cultural, institutional, and even geographical boundaries (ICSU, 2015). Often times scientists and researchers choose problem-oriented approaches that communicate research findings in one direction from scientists to policy makers, but ex-ante, iterative, and integrative processes that involve working with stakeholders and engaging a variety of perspectives are emerging (Lang & Wiek, 2022). Ex-ante and engaging approaches involve scientists collaborating with potential implementers and potentially affected actors, fostering bidirectional planning and design of solutions and better decision-making (Lang & Wiek, 2022). In this case, we adopt the ex-ante and engaging approach, placing emphasis on participatory modeling (PM) with an integrated water model, to enable scenario analysis. By employing an integrated water model and engaging a diverse array of actors, our aim was to enhance decision-making processes and foster meaningful discussions regarding potential solutions for water in the Middle Rio Grande Region. However, effectively addressing complex socio-economic issues with PM, utilizing spatio-temporal scientific data and models (e.g., water models), requires a distinct set of competencies (Brown et al., 2015; R. Cairns et al., 2020; Larson et al., 2011; Roy et al., 2020).

In sustainability science, five key competencies have been identified by Wiek et al. (2011) as needed by the workforce in the field of sustainability science. *Systems-thinking competence* (holistic thinking) is the ability to collectively analyze complex systems across disciplines, scales, and considering the entire connected system. *Anticipatory competence* (future thinking) is the ability to collectively analyze, evaluate, and craft rich "pictures" of the future and problem-solving frameworks. *Normative competence,* which is value-focused, is the ability to collectively map, specify, apply, reconcile, and negotiate sustainable principles, goals, and targets. *Strategic competence,* which is action-oriented, is the ability to collectively design and implement interventions, transitions, and transformative policies towards sustainability. *Interpersonal competence* is the ability to motivate, enable, and facilitate collaborative and participatory research and problem solving. Additionally, Wiek (2011) notes that the interpersonal competence impacts development of the other four competencies mentioned above. More recently, Horn (2022) identified epistemic stability (ES) and epistemic adaptability (EA) as additional key competencies, stating: "ES competencies are the competencies to contribute one's own academic knowledge, such as theoretical and methodological grounding in one's own field and confidence, and EA competencies are the competencies to engage with academic knowledge contributed by others, such as curiosity, openness and communicative skills." (Horn et al., 2022). Although these have been identified as the essential competencies in sustainability science, when addressing sustainability problems, one often must use scientific data, models, or visualizations, which requires data reasoning (Pennington et al., 2020). This brings up the challenge of stakeholders understanding big data or the use of complex models when addressing sustainability issues for a variety of stakeholders who each have their own perspectives and values. Data reasoning skills have not previously been investigated in the sustainability science competencies literature.

We investigated stakeholder engagement with data and models through a series of workshops using SWIM 2.0. Using visualizations such those produced by an integrated water model framework like SWIM 2.0, requires users to have a certain level of data reasoning skills to properly run scenarios, interpret results, and to further use the tool for decision-making (cite). This doesn't necessarily mean that if data reasoning skills are low, the visualization can't be utilized. We argue that the efficacy of stakeholder reasoning with data and models can be augmented by using a participatory modeling (PM) approach supplemented with model-based reasoning. Model-based reasoning has been identified in the cognitive sciences as a key reasoning process used by people in general and scientists in particular to invoke conceptual change (Nersessian 2012). It suggests that people organize their internal mental models of the system in question and that generating external representations of the system such as visual models enables reasoning (Nersessian et al. 1999). This is consistent with the identification of "boundary objects" in the social sciences as key mechanisms for transferring knowledge across differing perspectives (Star and Griesemer, 1989). When boundary objects are used to not just share knowledge but rather, to co-create new knowledge, the phrase "boundary negotiating object" (BNO) has been applied (Lee 2007; Pennington 2010). As noted in chapter 2, generating external models in the form of concept maps assisted workshop participants in communicating with each other and allowed even novice users to take part in identifying key concepts to generate scenarios on SWIM 2.0. We also saw an increase in scenario analysis levels completed after co-creating the group concept map versus only completing individual maps. Nevertheless, certain data reasoning skills are needed to achieve the highest level of scenario analysis, which proved limited as seen in chapter 1.

There remains a gap in understanding what competencies and skills are key for achieving a successful solution-based research project with a diverse set of participants (i.e., students, experts, policy makers, etc.) in sustainability science (Redman & Wiek, 2021). This chapter will investigate the competencies and skills needed to facilitate collaboration, social learning, and scenario analysis with scientific models, data, and visualizations. We focused all workshop activities to target key competencies identified by Wiek and skills required for data reasoning using PM and model-based reasoning to answer the following questions: 1) Did participants' competencies change across and within workshops? and 2) To what degree were competencies/skills needed or executed to achieve scenario analysis and decision-making when using an integrated water model?

2. METHODS

This study was conducted over three consecutive workshops, one which had two iterations (workshop 1A and W1B), workshop 2 (W2), and workshop 3 (W3). Workshop activities were designed to target competencies identified by Wiek and skills needed for data reasoning (Table 3.1). These include collaboration (interpersonal), systems thinking, future thinking (anticipatory), strategic thinking (action/transformative), values thinking (normative), and data thinking (definitions found in Glossary).

Table 3.1. List of workshops, workshop activities, and competencies targeted by the activities. BNO = boundary negotiating object.

Workshop	Activities and targeted competencies		
W1(W1A & W1B)	Knowledge Sharing Activity Introduction to water issues and stakeholder conflicts (ArcGIS Storymap) **Targeted competencies:** systems thinking	Shared Problem Space Activity Identify stakeholder concerns and conflicts **Targeted competencies:** collaboration, values thinking	Intro to scientific data visualizations 1. Introduction to SWIM 2.0 interface 2. Canned scenario activity 3. Generate individual model output interpretations **Targeted competencies:** collaboration, systems thinking, future thinking, data thinking
W2	BNO Activity Share your concept maps **Targeted competencies:** collaboration, values thinking	Knowledge integration & Scientific data visualizations 1. Map individual concepts to SWIM 2. Generate questions 3. Run SWIM scenarios 4. Generate narratives **Targeted competencies:** systems thinking, future thinking, strategic thinking, data thinking,	
W3	BNO Activity 1. Share your concept maps 2. Co-create concept map **Targeted competencies:**	Knowledge integration & Scientific data visualizations 1. Map group concept map to SWIM 2. Generate questions 3. Run SWIM scenarios 4. Generate Narratives	

	collaboration, systems thinking, values thinking	**Targeted competencies:** collaboration, systems thinking, futures thinking, strategic thinking, values thinking, data thinking

2.1 Survey design

For each workshop, participants were presented with pre- and post-workshop surveys designed to answer the specific research questions behind this investigation (refer to Table 3.1). The survey questions encompassed a mixture of items adapted from previous research surveys (Brundiers & Wiek, 2011; Misra et al., 2015; Xexakis & Trutnevyte, 2019) and new items uniquely formulated for this study (see Table 3.2). These questions principally revolved around two focal concepts: Wiek's competencies and data reasoning competencies. The competency-related questions were structured to allow participants to self-evaluate their level of agreement (on a scale from 1, strongly disagree, to 5, strongly agree) with specific statements. The scoring system was set up to indicate high confidence in competencies with high scores and low confidence with low scores.

Table 3.2. Pre/post survey metrics, targeted outcome, code, source, workshop, and question.

Target Outcome	CODE	Source	Workshop	Metric
General	G1	New	Pre/Post	I enjoy tackling the challenges posed by understanding the complexities related to water in this region
Wiek's competencies				
Collaboration (Intrapersonal)	C1	Brundiers	Pre/Post	I believe that the best societal outcomes can be achieved through collaboration between researchers, laypersons, and decisionmakers
	C2	Brundiers	Pre/Post	Collaboration between researchers, laypersons, and decisionmakers is essential to develop solutions that are credible, relevant, and feasible
Systems thinking	SY1	Misra	Pre/Post	I generally approach problems from thinking about both broader factors and fine-scale details
	SY2	Misra	Pre/Post	I have the ability to conceptualize problems both in generic ways and by considering situation-specific factors
	SY3	Misra	Pre/Post	I have the ability to think about problems from multiple, potentially conflicting, perspectives
Anticipatory (Futures) thinking	F1	New	Pre/Post	I am concerned about the future of water in this region
	F2	New	Pre/Post	I believe that decisions must be made based on the current situation because the future is unknown
Strategic thinking (Action oriented)	ST1	New	Pre/Post	I am comfortable designing solutions to address policy changes
Values thinking (Normative)	V1	Misra	Pre/Post	I would describe myself as someone who values collaboration with others
	V2	Misra	Pre/Post	I am willing to invest the time required for learning about perspectives that are different from my own
Data reasoning competencies				
Data thinking	D1	New	Pre/Post	I make decisions based on all the data I can obtain about a problem
	D2	New	Pre/Post	I rely on my own experience, intuition, and opinions of people I trust when making important decisions

2.2 Data Collection

Data collection occurred before the workshop using pre-surveys and concept maps, during the workshop (i.e., discussion, questions of interest, individual model output interpretations), and after the workshop via post-surveys. These data were collected to analyze the change in participant competency level before and after each workshop and the impact these competencies had on the ability to interact with the data visualization tool (SWIM 2.0). We also collected audio and text data from Zoom. Data collection was approved by the Institutional Review Board (IRB) at the University of Texas at El Paso.

2.3 Data Analysis

A Wilcoxon signed rank test was used to quantify any significant changes in the participants' self-reported competency level before and after each workshop. A combined competency score was then generated using the participants cumulative average post-survey scores for each group of competency questions. Additionally, we counted the instances of epistemic stability (ES), sharing of own academic knowledges, and epistemic adaptability (EA), engagement with academic knowledge contributed by others. Lastly, we created a score of 0 to 4 for levels of engagement using the scenario analysis levels identified in chapter one (Table 3.4). Engagement scores were compared to the Wiek's competency score and data competency scores, and against ES and EA counts to further identify if there was an impact of engagement related to these competencies.

Table 3.4. Engagement level scores 0 to 4.

Score	Engagement Level
0	Generated no model output interpretations
1	Level 1 – Model output interpretation
2	Level 2 – Produced a narrative
3	Level 3 – Generated a storyline
4	Level 4 – Conducted scenario analysis

3. RESULTS

The Wilcoxon signed-rank test results suggest that when comparing the pre- and post-survey responses, only question V2 (Values thinking competency question: I am willing to invest the time required for learning about perspectives that are different from my own) in W2 with a P-value of .046 and question D2 (Data competency question: I make decisions based on all the data I can obtain about a problem) in W3 with a P-value of 0.46 were statistically significant. No other questions from either workshop, or any from cross-workshop comparisons, exhibited any significance (Table 3.5).

Regarding the average total scores for Wiek's competencies in the post-surveys, W1 yielded a score of 4.25, W2 a score of 4.26, and W3, a score of 4.33 (Figure 3.1). This represents a minor increase of 0.08 points from W1 to W3. A similar trend was observed for the data competency levels in the post-survey responses. The average scores were 6.24 for W1, 6.25 for W2, and 6.29 for W3, showing a minor increase of 0.03 points from W1 to W3 (Figure 3.2).

Table 3.5. Calculated P values for Wilcoxon nonparametric test comparing pre/post surveys.

Competency	W1 n = 17	W2 n = 8	W3 n = 7	Combined
C1	1.00	.317	.317	.414
C2	.739	.317	1.00	1.00
SY1	.705	.317	.102	.808
SY2	.739	1.00	.317	.564
SY3	1.00	.102	.564	.467
F1	.564	.317	1.00	1.00
F2	.710	1.00	1.00	.791
ST1	.098	.257	1.00	.050
V1	1.00	.564	.317	.480
V2	1.00	.046	.655	.197
D1	1.00	.655	.046	.197
D2	1.00	1.00	.564	.813
G1	1.00	.157	1.00	.782

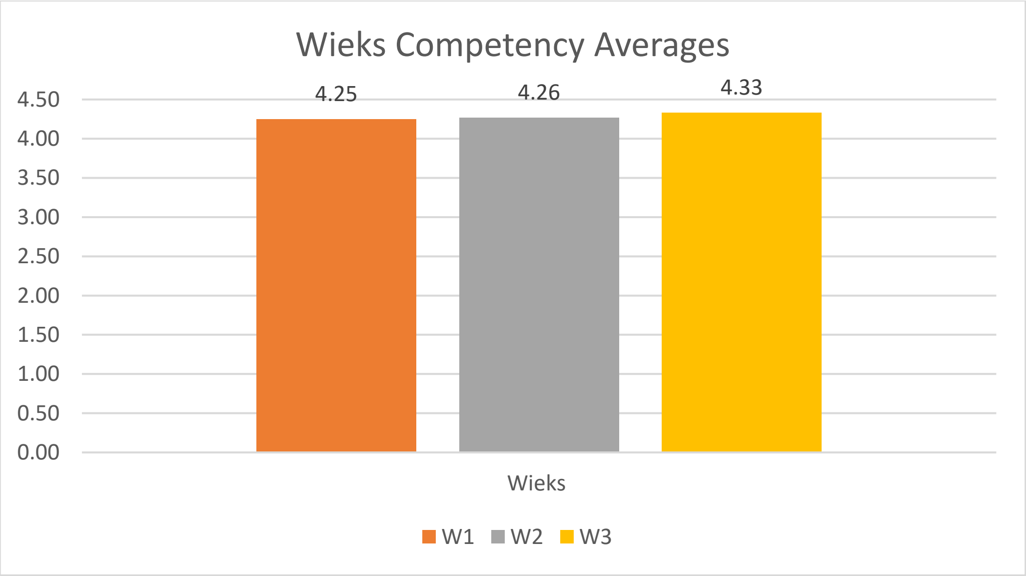

Figure 3.1. Wieks competency survey question averages for each workshop, W1 (blue), W2 (orange), W3 (grey).

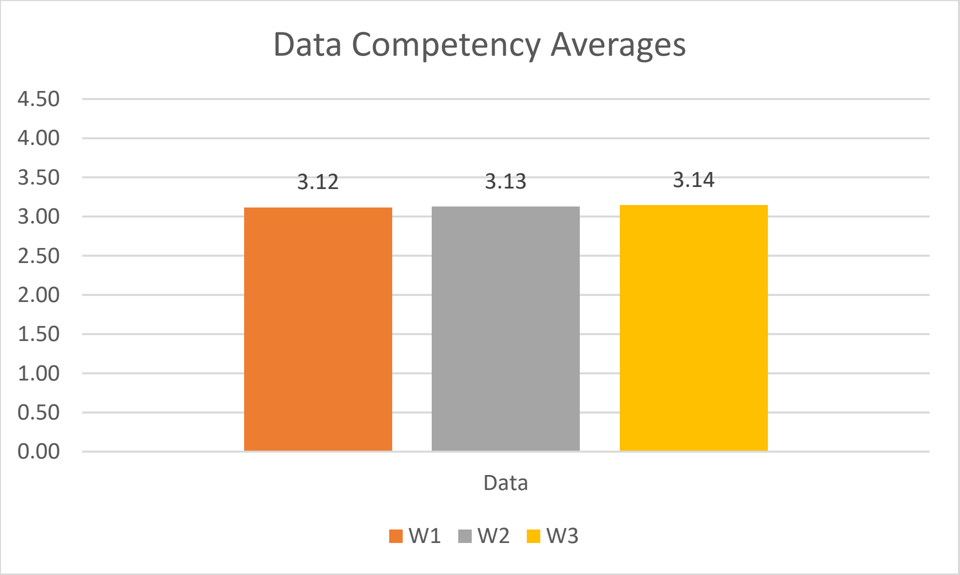

Figure 3.2. Data competency survey question averages for each workshop, W1 (blue), W2 (orange), W3 (grey).

The Engagement level scores, which were rated on a scale from 0 to 4, averaged 1.29 in W1 and 1.13 in W2, a slight decrease (Figure 3.3). With the shift from individual to group activities in W3, the average Engagement level score rose substantially to 2.86. In terms of model result interpretations, a total of 17 interpretations were generated in W1, while W2 produced 8. W3, however, produced a total of 23 model result interpretations. Notably, the Engagement scores in W3, at the group level, more than doubled compared to those in the previous workshops.

The counts of ES demonstrated a decrease of 2.76 points from W1 to W3, whereas EA counts saw an increment of 2.17 points within the same period (Figure 3.4). The most substantial drop in ES averages was observed between W1 and W3, with the same magnitude of decrease seen between W1 and W2, and W2 and W3. On the other hand, EA averages witnessed their highest increase of 2.17 points between W1 and W3, followed by an increase of 1.66 points between W2 and W3. The smallest increase in averages of 0.51 was observed in the transition from W1 to W2. Upon drawing a comparison between Engagement Level and the average scores of Wiek's Competencies, Data Competency, as well as the counts of ES and EA, we observed no significant correlation between Engagement Level and these variables in any of the workshops (Table 3.6).

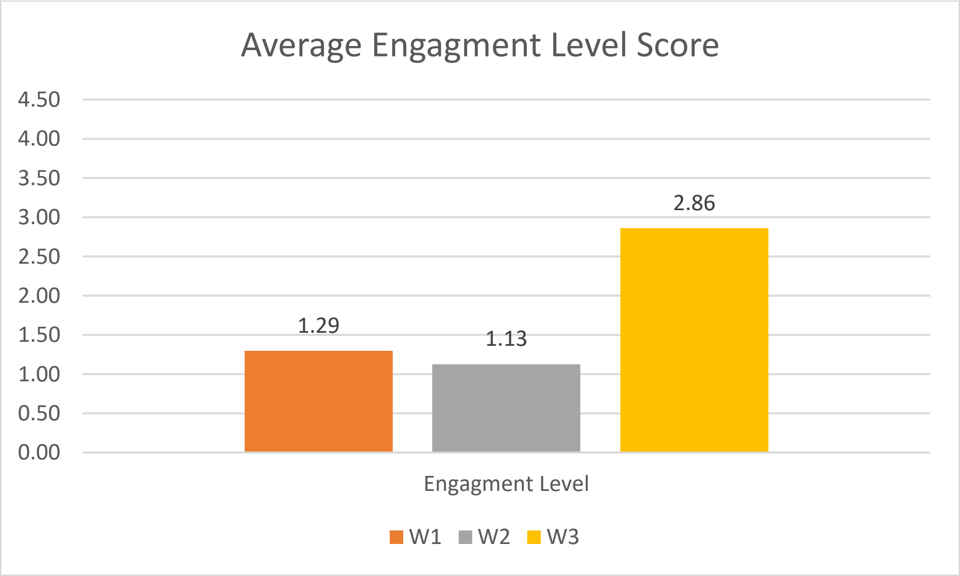

Figure 3.3. Average engagement level score across all participants for each workshop, W1 (blue), W2 (orange), W3 (grey).

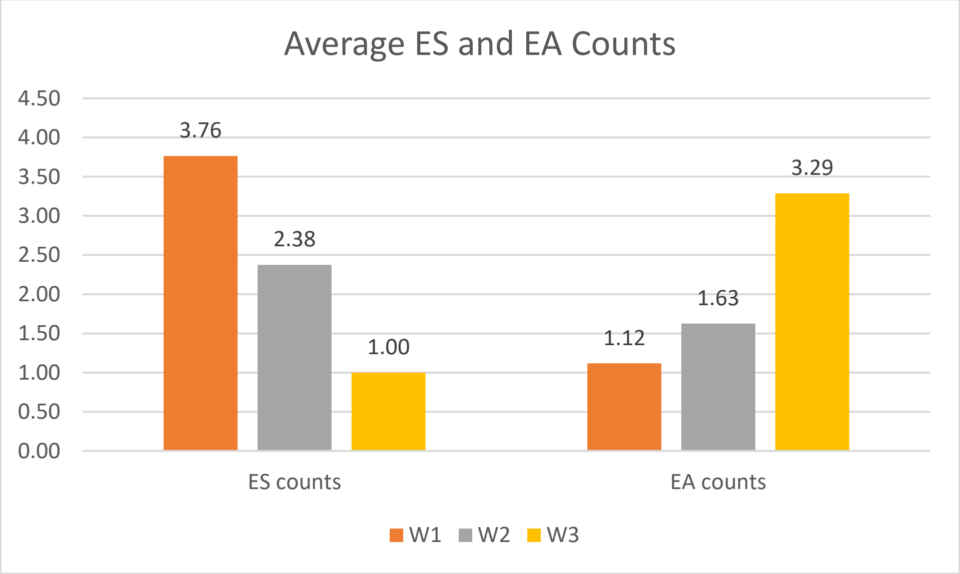

Figure 3.4. Average counts for epistemic stability (ES) and epistemic adaptability (EA) for each workshop, W1 (blue), W2 (orange), W3 (grey).

Table 3.6. Comparison of Engagement to Wiek's competency average scores, data competency average scores, ES counts, and EA counts.

Workshop	Wieks Competency Average Scores	Data Competency Average Scores	ES Counts	EA Counts
W1	$R^2 = 0.0397$	$R^2 = -8.00E\text{-}05$	$R^2 = 0.0003$	$R^2 = 0.2353$
W2	$R^2 = 0.1021$	$R^2 = 0.0809$	$R^2 = 0.0173$	$R^2 = 0.0074$
W3	$R^2 = 0.001$	$R^2 = 0.2323$	$R^2 = 0.2258$	$R^2 = 0.1906$

4. DISCUSSION

In this chapter, we explore participant competencies within and across three workshops, specifically focusing on the role these competencies played in scenario analysis and decision-making using an integrated water model. Through an analysis of the Wilcoxon signed-rank test results, post-survey responses, and engagement level scores, we aim to understand the progression of competencies and their application in a complex decision-making process. This analysis offers insights into whether participants' competencies evolved throughout the workshop series, and to what extent these competencies were utilized to interpret model results and participate in the workshop activities. Despite the complexity and multifaceted nature of these findings, they provide essential insights into the dynamics of participant engagement and competency development in a participatory modeling workshop setting, emphasizing the importance of user uptake for modeling tools and sustainability education.

The findings from the workshops indicate a slight, although not statistically significant, progression in the participants' competencies both across and within the workshops. Statistical significance was only found for question V2 in W2 and question D2 in W3, as per the results from the Wilcoxon signed-rank test. Although there was a marginal increase in the average total scores for Wiek's competencies and the data competency levels from workshop W1 to W3, these were relatively minor and statistically insignificant. Consequently, while there is an observable trend of modest competency improvement, the evidence suggests that participants' confidence in their competencies remained relatively stable throughout the workshops.

Determining the degree to which competencies were utilized in scenario analysis and decision-making through the lens of an integrated water model presents a complex challenge. We make this interpretation once again with caution when comparing across workshops because most participants who attended W3 did not attend W1 or W2. The available data does not explicitly address this concern. However, an interpretation can be derived from the upward trend in model result interpretations spanning from workshop W1 to W3 observed in chapter one. This trend, combined with the significant surge in the average Engagement Level score during W3, suggests that participants were progressively employing their skills over the course of the workshops, especially as the format shifted towards group activities. Despite these promising signs, the study did not find a significant correlation between Engagement Level and the averages of Wiek's Competency, Data Competency, and counts of Engagement Strategy (ES) and Engagement

Activities (EA) in any of the workshops. This suggests that while the participants' involvement in the workshop activities improved, there was no corresponding statistically significant rise in their competency levels or utilization of engagement strategies or activities.

The translation of these competencies into practical, actionable solutions may be influenced by factors outside the scope of this study, such as the complexity of the integrated water model or the specificity of scenario analysis and decision-making tasks. Research shows that for an individual to go from identifying issues, to creating actionable solutions requires more competencies than those identified by Wiek. Larson (2011) identified key competencies for conducting interdisciplinary work, including conducting research, communication, and interacting with others, that undoubtedly interact with the competencies investigated in this study. There is a need to better understand what combination of competencies provides the best opportunity to transform individuals into change agents but also interdisciplinary groups. Hence, further research is necessary to determine the most effective design of activities with stakeholders that enable the generation of actionable knowledge and transition stakeholders to change agents and increase competencies needed in addressing complex problems.

5. LIMITATIONS & FUTURE WORK

Our study encountered several limitations that warrant further exploration in future research. An overarching issue was the need to transition from what were originally intended to be in-person workshops to a virtual environment due to the pandemic. This limited the ability of participants to interact with each other and with the workshop facilitator. Another primary restriction was the size of the participant pool in the workshops. We anticipate that the statistical significance of the results could be enhanced if a larger cohort of participants completed the surveys. Moreover, maintaining a consistent group of participants across workshops could potentially enable a more accurate quantification of competency changes.

The development of the competency survey questions also presented a limitation; the phrasing may not have been optimally designed to assess alterations in the participants' self-confidence in their competencies. The difference in the number of questions used to measure Wiek's competencies (10 in total) compared to those used for data competency (only 2) may have also played a role in shaping the observed averages. In future research, this could be mitigated by the development of a specific metric to measure Wiek's and data competencies based on participant activities in addition to survey questions.

The absence of pre- and post-workshop concept maps limited our ability to fully quantify knowledge acquisition and group learning. Implementing concept maps for all workshops could lead to a more comprehensive group understanding, enhancing communication between participants and the SWIM 2.0 framework.

In terms of future work, it could be illuminating to replicate this workshop series incorporating concept map activities across different educational levels, from K-12 to undergraduate and post-graduate students. Such an approach could enhance our understanding of existing competencies and identify areas for development, effectively equipping the next generation of scientists who will confront our future sustainability problems in academia but also beyond academia.

6. CONCLUSIONS

This research presented a comprehensive exploration of participant competencies within the context of three interactive workshops, casting light on the intricate role these competencies play in scenario analysis and decision-making using an integrated water model. Emphasis was placed on critical aspects such as user uptake, the transition of skills into practical solutions, the role of education enhancement, and the generation of actionable knowledge. The study unearthed indications of a slight yet statistically insignificant progression in the participants' competencies both across and within the workshops. Despite the promising upward trend in model result interpretations and participant engagement levels, the study did not establish a statistically significant correlation with increased competency levels or heightened utilization of engagement strategies or activities. These observations underscore the inherent complexities in determining the precise extent to which competencies are deployed in scenario analysis and decision-making within the framework of an integrated water model. They also hint at the potential influence of external factors, such as the model's intricacies and the specificity of the assigned tasks, on the translation of these competencies into actionable solutions.

However, the limitations identified, primarily the virtual environment, participant pool size, and the design of competency survey questions, offer directions for further research. The implementation of measures such as concept mapping could not only facilitate a more robust quantification of knowledge and group learning but also foster stronger communication between participants and the SWIM 2.0 framework. Looking ahead, replicating this workshop series across different educational levels presents an opportunity to extend our understanding of existing competencies and identify potential areas for development. As we equip the next generation of scientists to confront complex sustainability problems, the insights derived from this research serve as an important step towards integrating competency development in participatory modeling workshops.

In conclusion, this study underscores the critical role of ongoing competency development to increase a diverse user uptake of models, and education in driving the generation of actionable knowledge and change agents. Despite the challenges, the findings offer essential insights into the dynamics of participant engagement in such workshops and highlight the importance of further research in this field.

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Conclusion

In conclusion, this series of three chapters has provided an extensive and insightful examination of stakeholder engagement, participatory modeling, and scenario analysis within the context of water challenges in the Paso del Norte region, utilizing the SWIM 2.0 graphical interface. The research underscores the critical significance of cohesive collaborative processes, knowledge co-creation, and the integration of diverse perspectives. The principal findings highlight the remarkable potential of participatory methodologies in addressing intricate water-related issues, fostering mutual trust among stakeholders.

As previously noted, the success of the endeavor, denoted as W3, was not contingent solely upon the training of SWIM 2.0 conducted during W1 and W2. This implies that the central factor affecting the success of collaborative efforts, scenario analysis, and the development of trust was the interplay of group dynamics and the negotiations that unfolded during the collective construction of the group concept map. The initial chapter emphasizes the importance of participatory practices, showcasing heightened engagement and scenario analysis achieved through the establishment of model credibility in W3. The discoveries in the second chapter underscore the value of the cooperative refinement process of the concept map to align more effectively with SWIM 2.0, leading to more meaningful interpretations from even those with limited expertise. While direct decision-making isn't a direct output of concept mapping, it effectively facilitates enriching discussions and a deeper comprehension of the inherent complexities of water resource management. Chapter three imparts insights into the role of competencies in scenario analysis and decision-making using SWIM 2.0. Although direct correlations were absent, the usage of data and model reasoning competencies, along with epistemic adaptability, was observed to be more prevalent.

This research has initiated the identification of essential group-level processes and the potential of participatory modeling methodologies in confronting intricate water challenges, advancing collaboration, and nurturing trust among stakeholders. The findings reveal the intricate interplay between engagement, knowledge exchange, and decision-making, all while recognizing both the hurdles and avenues for practical enhancement. The study advocates for a more profound combination of competencies, diverse viewpoints, and group-level activities to increase the effect of participatory workshops in molding sustainable water management strategies.

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Glossary

Wieks sustainability competencies (Wiek et al., 2011):

Collaboration (interpersonal) - Interpersonal competency entails the skill to inspire, empower, and facilitate collaborative and participatory endeavors in sustainability research and addressing problems.

Systems thinking - Proficiency in systems thinking involves the capability to collaboratively analyze intricate systems spanning various domains (such as society, environment, economy) and scales (ranging from local to global), thereby accounting for interrelated effects, inertia, feedback loops, and other systemic attributes tied to sustainability concerns and frameworks for addressing them.

Future thinking (anticipatory) - Anticipatory competency encompasses the aptitude to jointly assess, assess, and construct comprehensive "visions" of the future related to sustainability challenges and frameworks for solving them.

Strategic thinking (action/transformative) - Strategic competency encompasses the skill to collaboratively devise and execute interventions, transitions, and transformative governance strategies aimed at sustainability.

Values thinking (normative) - Normative competency involves the skill to collaboratively chart, define, apply, harmonize, and negotiate sustainability values, principles, objectives, and benchmarks.

Data reasoning competency – the skills to interpret graphs, figures, and data in other graphical forms, and describe interpretations.

Appendix

Pre-Survey	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
I believe that the best societal outcomes can be achieved through collaboration between researchers, laypersons, and decisionmakers					
Collaboration between researchers, laypersons, and decisionmakers is essential to develop solutions that are credible, relevant, and feasible					
I make decisions based on all the data I can obtain about a problem					
I rely on my own experience, intuition, and opinions of people I trust when making important decisions					
I generally approach problems from thinking about both broader factors and fine-scale details					
I have the ability to conceptualize problems both in generic ways and by considering situation-specific factors					
I have the ability to think about problems from multiple, potentially conflicting, perspectives					
I am concerned about the future of water in this region					
I believe that decisions must be made based on the current situation because the future is unknown					
I am comfortable implementing my solutions to change current policies					
I would describe myself as someone who values collaboration with others					
I am willing to invest the time required for learning about perspectives that are different from my own					
I enjoy tackling the challenges posed by understanding the complexities related to water in this region					
What do you expect to learn through the SWIM workshop?					
What are your motivations and or reasons for you attending this workshop?					

Post-Survey	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
I believe that the best societal outcomes can be achieved through collaboration between researchers, laypersons, and decisionmakers					
Collaboration between researchers, laypersons, and decisionmakers is essential to develop solutions that are credible, relevant, and feasible					
I make decisions based on all the data I can obtain about a problem					
I rely on my own experience, intuition, and opinions of people I trust when making important decisions					
I generally approach problems from thinking about both broader factors and fine-scale details					
I have the ability to conceptualize problems both in generic ways and by considering situation-specific factors					
I have the ability to think about problems from multiple, potentially conflicting, perspectives					
I am concerned about the future of water in this region					
I believe that decisions must be made based on the current situation because the future is unknown					
I am comfortable implementing my solutions to change current policies					
I would describe myself as someone who values collaboration with others					
I am willing to invest the time required for learning about perspectives that are different from my own					
I enjoy tackling the challenges posed by understanding the complexities related to water in this region					
The conversations about different values during workshop activities with others was respectful					
I learned something new about the water supply in the Middle Rio Grande from this workshop.					
The workshop corrected some of my misconceptions about the Middle Rio Grandes water supply.					
The workshop explained the complex issue of water supply in a simple and understandable way.					
Overall, water supply and its impacts are presented clearly in the workshop.					
This workshop could provide information for decisions on water supply.					
Using the information in this workshop was a valuable use of my time.					
If I would want to know something about the Middle Rio Grandes water supply in the future, I would return to materials from this workshop.					
I enjoyed this workshop to learn more about water supply.					
The workshop was an exciting way to find out about water supply.					
Did you learn what you expected from the SWIM workshop?					
What content would you like to see expanded in future SWIM workshops?					
What recommendations do you have to enhance your experience in this workshop and for the following workshops?					

Vita

Katalina Salas completed her Bachelor of Science in Geological Sciences from the University of Texas at El Paso in 2014. Then attended St. Edwards University and received a Professional Science Master's in Environmental Management and Sustainability in 2016. She then returned to UT El Paso to complete a PhD in Environmental Science and Engineering in 2023. As a PhD student Katalina received the Natalicio Environmental Fellowship in 2018 where she worked with La Semilla, then received the H-AGEP fellowship in 2019 and worked with Dr. Pacheco and EPCC Northwest campus. She was the recipient of the 2020 Woman's Auxiliary fellowship and the 2021 GMiS scholar. She was accepted to be part of the 2021 Graduate Archer fellowship and interned with the Global Council for Science and the Environment in Washington, DC. Throughout her PhD she presented at several conferences including AGU, SACNAS, GMiS, and GCSE and placed second in the Spring 2021 Three Minute Thesis competition at UTEP. Katalina also helped organize and run three high school summer camps, countless Earth Science week community fairs, and aided in K-12 outreach and recruitment. She will now begin as a Community-Driven Inclusive Excellence and Leadership Opportunities in the Geosciences (CIELO-G) postdoctoral fellow at the University of Texas at El Paso.

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