Supplementary Material

Learning across disciplines in socio-environmental problem framing

Supplementary Material A. Example EMBeRS Activities

This document contains detailed descriptions of four EMBeRS activities: 1) Share Your Research; 2) Explore the Problem Space; 3) Using Frameworks; and 4) Mock Solicitation. These four activities were taught in both workshops and are sequenced to think comprehensively about the focal problem prior to converging on an integrated research conceptualization. In both workshops additional activities were sometimes inserted between these, but these are the core activities and best demonstrate the application of the EMBeRS framework. In both workshops the focus was on water sustainability; however, any complex problem could be used depending on the general interests of participants.

1   Share Your Research (3 hours)
1.1   Materials: Newsprint, markers, sticky notes
1.2   Preparation: Read Pennington (2008) Learning and collaboration.
1.3   Introductory presentation (40 minutes)
- Drivers of interdisciplinary team science: wicked socio-environmental problems
- Vocabulary: disciplinary, multidisciplinary, interdisciplinary, transdisciplinary
- U.S. National Research Council (2014). Enhancing the Effectiveness of Team Science. Seven challenges of team science. Highlight deep knowledge integration.
- Mental models and the role of disciplinary training in formulating mental models.
- Summarize learning theories: transformative learning, experiential learning and key practical behaviors from learning theories.
- Practical advice from learning theories.

Presenter: Don't use jargon if you don't have to, and if you have to, explain; provide high level background and context; make eye contact;
Listener: active listening; summarize what you understand; ask if you don't understand; ask for explanation of unfamiliar vocabulary; don't highjack the discussion; don't be thinking about what you will say when it is your turn
- Describe model-based reasoning and boundary negotiating objects
- Describe the EMBeRS approach
- Introduce concept mapping as one kind of boundary negotiating object
1.4   Individual work (10-15 minutes)
- Instructions: Represent your research as a concept map. Start with 5 or 6 keywords, each on a sticky note. Arrange them on the newsprint, and draw labelled relationships between them. Add keywords as needed. Aim for 12 to 15 keywords. Organize the concept map in a way you believe will make sense to your teammates.
1.5   Turntaking (60 minutes)
- Instructions: One at a time, explain your research using your concept map as a visual prop. Each person will have 10 minutes. I will prompt you when it is time to move to the next person. Remember, watch out for jargon and practice active listening. There will be a test at the end to see how well you listened. If you only have three people in your group, use the last 10 minutes to follow up with whatever questions you still have.
- Break (10 minutes)
- Now it is time for that active listening test! Pass your concept map to the person on your right. One at a time, take 2 minutes to explain the research of the person whose concept map you are now holding.   (10 minutes)
- Note how quickly people forget what they just heard. The active listening test demonstrates the importance of timely reflection.

1.6   Teamwork – not required for this activity.
1.7   Reflection and reflective discourse (40 minutes)
- Instructions: Working individually, list 3 things that made this exercise difficult, and 3 things that helped overcome the difficulties.
- In your teams, compare your lists and compile a single, comprehensive list.
- Report out: Each team state one of the challenges you noted. Continue until no new challenges are identified. Each team state one of the things that helped. Continue until no new aids are identified.
- Full group discussion:

-Looking at the lists you generated, what general statements can you make about the process of engaging across disciplines?
-How was the process we used in this activity similar or different from interdisciplinary seminars or meetings that you have attended in the past?
-What do you understand about the EMBeRS approach, now that you have experienced an EMBeRS activity?

2   Explore the Problem Space (3 hours)
2.1   Materials: newsprint, markers, sticky notes
2.2   Preparation: Select and read one article from the provided list relevant to the topic of the case study. Choose one related to your research interests.
2.3   Introductory presentation (40 minutes)
- Introduction to water sustainability issues [substitute whatever is the topic of the case study; could be a guest speaker]
- Explain why it is important for them to consider the problem space from different perspectives.
- Summarize EMBeRS process again, and how model-based reasoning with boundary negotiating objects will help them achieve an integrated understanding of the problem.
2.4   Individual work (15 minutes)
- This activity will use concept maps again, and the first part of the process will be exactly like Share Your Research. You will work individually organizing your thoughts with a concept map, drawing on the article you read and your own knowledge. The concept map should include terms from your area of research, but the goal of this activity is to generate a comprehensive, high-level representation of the overall problem. Place your research in the context of the broader problem. Each of you will explain your thinking using your concept map as a visual aid, using timed turntaking. The new part in this activity is that after you each have represented and explained your perspectives, you will integrate your perspectives by co-creating a concept map.
- You have 15 minutes to complete this task.
2.5   Turntaking (40 minutes)
- You again have 10 minutes each to present your concept map. I will time it, and prompt you when it is time to change to the next person. What were some of the key behaviors for presenters? What were some of the key behaviors for listeners?
2.6   Break (10 minutes)
2.7   Teamwork
- Starting from scratch, co-create a comprehensive concept map. Include some concepts from each person's area of research. You may need to identify new, mediating concepts that are not a part of anyone's research but are important connections between areas of the concept map. (40 minutes)
- Gallery walk. Each team briefly explains their integrated concept map, and where each person's research falls on the map. [Time depends on number of groups; assuming five groups, 20 minutes].
2.8   Reflection and reflective discourse (15 minutes)
- To what degree were your individual perspectives encompassed by your comprehensive concept map?
- In what ways did exploring each of your individual research areas in Share Your Research and placing those individually in the context of this problem aid in co-creating a comprehensive concept map?
- Referring to your comprehensive concept map, if you had significantly more time would you want to spend it making improvements, or do you think you have a relatively good grasp on the

overall problem (even if there are areas you don't individually understand deeply)? What might you want to do differently?

3   Using Frameworks (2 hours)

3.1   Materials: newsprint, markers, sticky notes, copies of example frameworks

3.2   Preparation: Read Binder et al. (2013) Comparison of frameworks for analyzing social-ecological systems. *Ecology and Society* 18(4).

3.3   Introductory presentation (15 minutes)
- Explain what frameworks are
- Show and explain examples of frameworks. Five are from the assigned reading.
  - DPSIR
  - Ecosystem Services
  - HES
  - MEFA
  - SES
  - PPD – Press-Pulse Dynamics. Collins et al. (2011). An integrated conceptual framework for long-term social-ecological research.
  - ARDI – Actors-Resources-Dynamics-Interactions. Etienne et al. (2011). ARDI: A co-construction method for participatory modeling in natural resource management. *Ecology and Society* (16)1:44.

3.4   Individual work (10 minutes)
- Select three different frameworks and spend a few minutes on each jotting down ideas for how concepts from your comprehensive concept map could be reorganized into that framework.

3.5   Turntaking and Teamwork (80 minutes)
- Compare the frameworks you each selected. For each selected framework, compare how each team member that chose that framework organized information around it. I will not be timing you or prompting you to take turns. In this activity, you need to monitor yourselves and ensure that each of your team members has a chance to explain their perspective. When you have discussed each of the selected frameworks, choose two different frameworks and proceed to the next step. (20 minutes)
- Tape new copies of the selected frameworks onto newsprint. Flesh out concepts for each using sticky notes and markers. Frameworks are intended to be high level representations, so show enough information to capture the the system but not much detail. (60 minutes)

3.6   Break (10 minutes)

3.7   Reflection and reflective discourse (35 minutes)
- Gallery walk. Each team briefly explains their two frameworks. [Time depends on number of groups; assuming five groups, 20 minutes].
- Does anything strike you about the similarities and/or differences between the frameworks each team selected?
- Think back to our discussions about wicked problems. How do the differences relate to the characteristics of wicked problems?
- Did you experience any benefits from thinking about the problem from two orthogonal perspectives?

4   Mock Solicitation (3 hours)

4.1   Materials: Newsprint, markers, sticky notes, laptop

4.2   Preparation: Review each other's research concept map from Share Your Research

4.3   Introductory presentation (5 minutes)
- Goal of this activity: Generate research questions and a half page abstract proposal for integrated research in response to a brief, real solicitation from the National Center for Socio-Environmental Synthesis (SESYNC) on spatial and temporal variability of water, ecological systems, and human welfare or behavior.
- Include one visual of an integrated conceptual model (on newsprint)
- Present your proposed research to the group

4.4   Individual work (10 minutes)
- Read the half page solicitation

- Sketch out some ideas about how your team's research could be integrated
- Jot down some notes about questions that might be addressed by that integrated research

4.5   Turntaking and Teamwork (2 ½ hours)
- Share your ideas among your group, self-monitoring turntaking
- When you are ready, co-create your integrative diagram, questions of interest, and half page abstract. Take a break whenever is convenient for your team.
- Proposal presentations: each group present your questions of interest and explain your diagram. After presenting the overall idea, each person on the team take 2 minutes to explain what your specific research contribution would be.

4.6   Reflection and reflective discourse (15 minutes)
- How well did your proposed research leverage the expertise of everyone on your team?
- If you had more time, do you think you would have been able to generate different ideas that might have been more integrative?
- To what extent do you think the knowledge and skills gained from prior activities facilitated your ability to accomplish this difficult task?

Supplementary Material B. Participant Description

Description of workshop participants, indicating diversity along multiple dimensions, including disciplines: Nineteen of the participants were doctoral students from eighteen physical and social science, engineering, and interdisciplinary departments at seventeen different U.S. institutions (Table B1). Five students—three in the first cohort and two in the second—were doctoral students in the University of Texas El Paso (UTEP) Interdisciplinary Environmental Science and Engineering Program. The participants had a wide range of research interests (agrarian adaptation to climate change; biochemistry and disease; biogas renewable energy; climate change and hydroecology; climate change impacts on crops; ecological water stress; human security; forecast models and stakeholders; land use and water quality; meteorology and air pollution; nano-particle soil and water toxicology; nanotechnology and agriculture; non-market water valuation; ranchers, wolves, and water; resource inequality; spatial cognition; urban hydrology, water resources, and water systems; urbanization; water allocation; water and health; water and tribes; water infrastructure resilience; water justice and sustainability; water quality; water supply variability). The participants were 58% women, 23% Latinx or Hispanic, 19% Asian, and 8% Black. A third (31%) were international students from Brazil, Ghana, India, Libya, Nepal, Nigeria and Vietnam.

Table B1. Participant Programs, and Institutions.

INSTITUTION	PROGRAM
Arizona State University	Civil Engineering
Boise State University	Human Environmental Systems
Colorado State University	Ecosystem Science & Sustainability
Florida International University	Earth System Science
New Mexico State University	Water Science & Management
Penn State University (x2, different cohorts)	Archeology Architecture
Pontifical Catholic University	Urban Management
Purdue University	Agricultural & Bioengineering
Temple University	Psychology
Texas A&M University	Agricultural Economics
University of Nevada at Reno	Hydrology
University of Arizona	Watershed Management
University of Arkansas	Environmental Dynamics
University of California at Irvine	Social Ecology
University of California at Los Angeles	Urban Planning
University of Idaho	Water Resources
University of Miami	Ecosystem Science
University of Missouri (x2, different cohorts)	Bioengineering
University of Texas at El Paso (x5)	Environmental Science & Engineering

Supplementary Material C. Selected Quotes

Selected quotes from surveys and interviews illustrating the range of feedback received from participants.

- *"I have used the EMBeRS concepts and methods a lot to map out my own research plans and in working through my dissertation research with my dissertation committee. I attended the EMBeRS workshop right after I defended my dissertation research proposal. I found the EMBeRS approach was extremely beneficial for responding to my committee's recommendations to further refine certain aspects of the research. For example, the concept map that I constructed at the EMBeRS workshop has actually been incorporated as the central framework in my dissertation research now (with significant insights from other research in the field). I found the EMBeRS approach was particularly effective in helping me to refine my research of a complex SES system in a way that makes it easier to explain to researchers from other disciplines."*

- *"These skills have been helpful in planning out the project, problem solving, working with other group members, brainstorming new ideas, and navigating timelines and how to integrate output from each group. Specifically, it has been helpful when considering how different disciplines approach mathematical techniques, assumptions, and statistical approaches."*

- *"I have used the ideas while moving forward with inter- and transdisciplinary research; specifically when planning on how to address and work with sensitive populations/communities equitably. I use community mapping and modeling and it's likely that I'll use it more over the next three years as I get out into the community with stakeholders."*

- *"Working with diverse backgrounds was key to problem solving and visual representation techniques enforced at EMBeRS were helpful in leading conversations and engaging with other group members."*

- *"I've used EMBeRS concepts with talking with fellow employees and industry partners. In particular, I recently wrote a "Sources Sought" document, and I developed a boundary negotiating object to give other team members an idea of how I envisioned the design of our proposed project."*

- *"I have used systems mapping extensively in communicating my research to interdisciplinary audiences. It seems to provide a "technical basis" by which a discussion about the social aspect of water can begin to take place with natural and social scientists."*

- *"I'm currently working on a number of grant proposals and research activities that require human and natural science expertise. My experience with EMBeRS has reinforced my ability to communicate between collaborators on these projects and bridge gaps between the perspectives and frameworks people bring together."*

Supplementary Material D. Terms From Reflective Writing

List of terms derived from analysis of participant reflective writing on days one and six, sorted in order of usage based on counts of reflective writings that use the term at least one.

THEME	2016	2017	COMBINED
BNOs	7	18	25
Diverse ideas	9	13	22
Communication/dialogue	11	9	20
Shared model	7	10	17
Integrating/synthesizing	4	9	13
Specific BNO	3	8	11
Iteration	3	7	10
Mental models	1	9	10
Negotiate	5	4	9
Process-based	3	6	9
Reflection	4	4	8
Learn each other/understanding	2	5	7
Organizing ideas	4	3	7
Convergent/divergent thinking	1	5	6
Reasoning/cognition	4	2	6
Time	2	4	6
Turn-taking	3	3	6
Conflict	0	4	4
Efficiency	3	1	4
Flexibility/adaptability	1	3	4
Active listening	1	2	3
Mental models	0	3	3
Negotiate	1	2	3
Process-based	0	2	2
Reflection	0	2	2
Learn each other/understanding	0	2	2
Organizing ideas	0	1	1
Convergent/divergent thinking	0	1	1
Reasoning/cognition	0	1	1
Time	1	0	1
Misalignment	0	1	1
Transforming	0	1	1
Effective engagement	1	5	6
Grasping	4	2	6
Group interaction	2	4	6
Converging	3	3	6
Effortless	0	4	4
Proactive	3	1	4
Simplifying complexity	1	3	4
Simple activities	1	2	3
Values	0	3	3