SEEING & REASONING ABOUT COMPLEX SOCIO-ECOLOGICAL SYSTEMS IN THE EARLY GRADES

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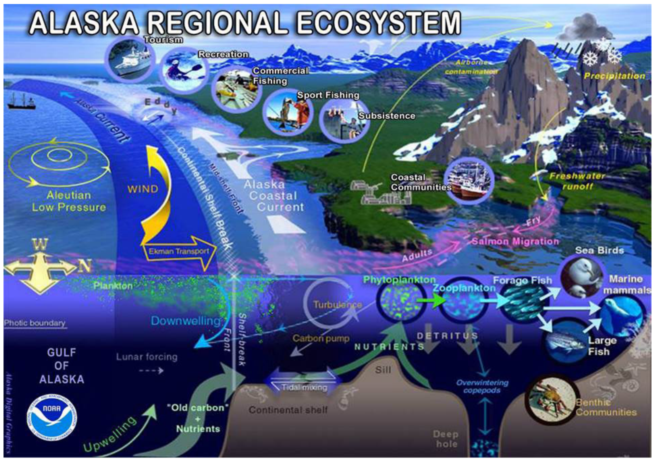
Understanding complex socio-ecological systems is increasingly important in a world that is socially and ecologically shifting at rapid rates.[1] For example, it is important to understand and be able to reason about patterns in the Earth's climate or diversity of life. Systems reasoning, or being able to understand properties and behaviors of systems, is an academic demand in science learning environments.[2] *Complex systems*, such as traffic patterns or the stock market, are web-like, have emergent properties, and are self-organizing across time and space.[3] *Complex ecological systems*, such as a coral reef or forest, refer to natural systems and the dense web of relationships and interactions of which they are comprised. Finally, *socio-ecological systems* include humans, and consider the relationships between human systems and ecological systems.

Research has suggested that teaching about complex systems is challenging, however, there is a breadth of research that addresses these challenges. First, researchers are recognizing that there is cultural variation in how people understand socio-ecological systems.[4] Second, researchers are designing and studying innovative learning environments that foster and support complex systems thinking.[5] The purpose of this brief is to highlight emerging research to support teacher, family, and community learning about complex socio-ecological systems, with implications and suggested directions for teaching practices and curricular design.

KEY STANCES FOR TEACHING ABOUT COMPLEX SOCIO-ECOLOGICAL SYSTEMS

- **Field-based Investigations:** Understanding complex ecological systems is necessary for deep science learning, and observations can assist students in developing an awareness of the components of complex systems and how they interact.
- **Authentic Inquiry:** Scientific observation needs to be connected to disciplinary contexts, sequenced learning experiences, and authentic opportunities to engage in sensemaking6 in order for students to learn to associate their observations with scientific reasoning and explanations.[7]
- **Systematic Observation:** Children learn to coordinate expectations and observational evidence when they start to think about, talk about, and publically organize their observations and knowledge in ways that are consistent with a disciplinary learning community.[8-9]
- **Cultural Connections:** Research indicates that observations are influenced by culture and practiced within a variety of cultural contexts such as children's everyday home activities.[6]



The Alaska Regional Ecosystem exemplifies the complex nature of marine ecosystems, including human interactions.

Socio-ecological systems are diverse and consist of a web of relationships. Humans are deeply interconnected in ecosystems.
http://www.ecosystems.noaa.gov/EBM101/WhatareEcosystems.aspx

COMPLEX SYSTEMS are are nonlinear, self-governing, decentralized interactions among parts of a system that lead to collective behavior that is greater than the sum of its parts.[3, 10-11]

COMPLEX SYSTEMS REASONING requires reasoning across spatial and temporal scales, and sometimes attending to "invisibile" relationships.[3]

TEACHING & LEARNING ABOUT COMPLEX SYSTEMS

Education research and scholarship are beginning to embrace working with complexity, rather than simplifying complex content. However, teaching and learning about complex systems has been considered a challenge because complexity may be counterintuitive or too cognitively demanding for students.[13-15] Many researchers have argued that students and/or "novices" are unable to understand dynamic and emergent properties of complex systems,[3] or are unable to reason across scales such as time, space, and *agent-aggregate* relationships.[11, 16-17] The overall trend in education has been to simplify systems to make them more accessible. But there is increasing research to show that novices can in fact reason complexly, and there are practices that teachers and practitioners can adopt in their classrooms to promote complexity thinking.

It is important not to conflate lack of understanding with lack of ability. There has been little consideration of cultural variation in reasoning processes, but it is becoming clear that culture impacts what and how we think, and linear reasoning about ecological systems may be a cultural phenomenon.[4, 17] For example, studies focusing on Indigenous and non-dominant communities found that they were more inclined to reason in complex ways (such as web-like reasoning, or focusing on relationships) than European American or middle-to-upper class counterparts.[18-20] These examples suggest that many "novices" (youth or non-scientists) are able to reason complexly, and call for greater attention to community and family knowledges in learning environments.

KEY COMPONENTS OF COMPLEX SYSTEMS REASONING

- **Decentralized mindset.** Students need to understand that complex phenomena is self-organizing. This is contrary to the assumption that there must be a form of centralized control, such as one factor that causes everything else to happen.
- **Thinking across scales** is critical for understanding complexity. Complex socio-ecological phenomena span multiple time scales (past, present, future) and spatial scales, and there are often many invisible relationships. Learners also need to understand interactions between agent and aggregate parts of a system.[11]
- **Agent-Aggregate Levels** are levels of a complex system that always work together. Each system is made up of individuals (agents) and groups of individuals (the aggregate).[11] In socio-ecological systems, the aggregate may consist of many interacting abiotic and biotic factors, and human and more-than-human communities.
- **Learning as a change in perception and attention:** In order to understand complex systems, learners need to interpret the world in complex, interdependent systems.[12]

FUTURE DIRECTIONS FOR RESEARCH

Teaching and learning about complex socio-ecological systems crosses domain boundaries (science, math, social studies, etc.) and is immensely important to the lived realities of all students and teachers. Understanding complex systems requires students to be able to understand webs of relationships or think across scales. Research is needed for the design and implementation of curricula that fosters complex socio-ecological thinking. Currently, researchers are using methods such as *community-based design research* (CBDR) to design and study equitable and innovative learning programs for students, teachers, and institutions.[1] CBDR involves collaborating with many different people or groups, including (but not limited to): teachers, families, principals, district leaders, community organizations, and other community members. Incorporating family or community knowledges is important for all learners, but particularly for non-dominant students who often feel disconnected from science in the classroom.[21] Designing collaborative learning environments, drawing on students' ways of knowing, and incorporating field-based learning practices are important for engaging all students in both meaningful learning *and* socio-ecological decision making.

COMPLEX ECOLOGICAL SYSTEMS refer to natural systems, such as ecosystems, food webs, or the human microbiome. They consist of abiotic and biotic factors.

SOCIO-ECOLOGICAL SYSTEMS refer to the interactions between human systems and ecological systems. The underlying premise is that humans are part of the natural world, and all of our systems (e.g. social, political, institutional) are always in relationship with ecological systems.

CONSIDERATIONS FOR PRACTITIONERS & FAMILIES

Researchers have begun to identify reasoning patterns that support complex socio-ecological systems thinking, and some conceptual frameworks, activities, and practices that can support these. These patterns include: abductive or probabilistic reasoning (considering multiple variables affecting a phenomenon);[16] mechanistic reasoning (attending to multiple causal mechanisms behind processes);[14, 16] and reasoning from multiple perspectives (seeing the same phenomenon from multiple roles and relationships).[22]

Teachers and families play critical roles in supporting learning about complex socio-ecological systems. It is important to bring in non-dominant student's family and community perspectives, experiences, and expertise to diversify scientific practices. Sharing family and community knowledges or practices also help make complex socio-ecological systems visible and relevant in children's lives. Teacher learning around complex systems is also crucial to student engagement and learning.[13, 23] When teachers begin to deepen their understanding of the dynamic nature of complex systems, they are better able to communicate that with students and to help students begin to make connections in the field and in their own lives.

Critical Reflections →

- Consider the role of complex socio-ecological systems in your life. What are some visible and invisible relationships that make up each system? How does each system span across multiple spatial and temporal scales? Where do systems intersect?
- What are some family or community knowledges that you can share with your children/students to make complex socio-ecological systems visible?
- What are some examples of complex socio-ecological systems that you have seen / may see when you are out in the field? (E.g. when you are on a walk, at the park, etc.)

It is also important to be deliberate about how to design learning environments that support complex socio-ecological systems thinking. Because complex systems span spaces and times, field-based investigations can mirror this. Conducting investigations in the field across time (such as going to the same place in different seasons) or across places (investigating different places during the same activity) can foster more meaningful experiences with these phenomena. Assessing student understanding of complex systems may require triangulation of many assessment forms (models, concept maps, discourse over time, etc).

CLASSROOM PRACTICES	FIELD-BASED SCIENCE PRACTICES	CONNECTING TO FAMILY & COMMUNITY PRACTICES
Play Games that focus attention on predictive talk about probability.	**Ask Lots of Questions** about what you see and what it might mean - keep track of all questions they might become relevant at a later date	**Get to Know Students and Communities** to help see how students might be making connections between school and home science
Role Play to take on multiple perspectives.	**Think Collectively About How you Can Answer Questions** to engage young people in authentic inquiry	**Families Can Share** traditional or cultural knowledges or practices with their children.
Use Models & Simulations to reduce cognitive demand, reason at multiple scales and perspectives.	**Observe, Collect Data, and Make Models** of the outdoors to foster deeper understanding of complex socio-ecological systems.	**Recognize and Value** these home practices as vital for student engagement and learning.
Use Scaffolds and Prompts such as asking learners to think about importance of certain roles/ relationships at different scales or for different mechanisms.	**Visit the Same Location** in the field at different times of year to track patterns and changes in patterns over time	
Find or Create Time lapse Videos to see phenomena that is difficult to experience (e.g. decomposition)	**Visit Multiple Sites** using the same investigation to observe complex phenomena across scales.	

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