Thinking like an Earthling: Children's Reasoning About Individual

and Collective Action Related to Environmental Sustainability

Tina A. Grotzer

Harvard Graduate School of Education, Project Zero, Cambridge, MA

Tina_Grotzer@harvard.edu

S. Lynneth Solis,

WestEd, San Francisco, CA

lsolis@wested.org

Keywords:

Agency
Distributed Causality
Collective Action
Emergence
Environmental Awareness
Diverse Perspectives
Action at an Attentional Distance
Climate Change

Address for Corresponding Author: Tina A. Grotzer, 421 Longfellow Hall, Harvard Graduate School of

Education, Appian Way, Cambridge, MA 02138

Abstract

Learning to accept and understand our identity as inhabitants of planet Earth is an essential aspect of living sustainably in a global community with others. What is involved in learning, that despite what divides us, we are first and foremost Earthlings and that the well-being of our planetary home is in our collective hands? What are the cognitive features of concepts that are inherent to thinking like an Earthling? This article considers themes that arise from research that inform what is involved in developing a collective, planetary perspective as it relates to engaging in environmental sustainability. It samples research on how young people understand and reason about agency—their own and that of others— and about the relationship between individual and collective action. It considers the importance of recognizing and engaging with diverse perspectives on agency and collectivity as well as being able to adopt the perspectives of those in different roles and positions. While many of the concepts that are inherent to thinking as part of a collective community of Earthlings are challenging, many are also learnable and represent important instructional targets for helping the next generation to understand how to live together in sustainable ways on a small and finite planet.

Introduction

A few years ago, Dr. Jill Tartar, a retired SETI (Search for Extraterrestrial Intelligence) researcher spoke at a Radcliffe Institute conference where a community of scientists discussed undiscovered frontiers in science. She asked people to think about their identities and how they present themselves in on-line forums. Her words then invited the audience to adopt a different perspective on their identities: *"…the message [in thinking about SETI] is, "You, you are all the same when compared to something else out there. And I think that this is the perspective, the cosmic perspective that we need globally… …We need to think and act as one species. We are Earthlings."* She then went on to cite Sharf (2014)*, "On a finite world, a cosmic perspective isn't a luxury, it is a necessity."* These words resonated, in part, because they underscore that despite the many things that divide us, as Earthlings, our very existence hinges upon our ability to realize our collective existence and to collaborate as a global community to live sustainably on a small blue planet. The importance of focusing on our collective behavior and sustainable action is underscored by research showing that engaging learners in collective action supports a sense of hope and resilience as young people grapple with eco-anxiety about the fate of the world (Ojala, 2007).

What is involved in learning to think about our collective existence on planet Earth? In this piece, we argue that a shift is needed—from viewing the world through one's individual actions to being able to view it through the actions of a collective community of Earthlings. As outlined in Table 1., this shift includes moving from a focus on: 1) one's individual actions towards a focus on the actions of populations; 2) outcomes at the individual level towards those at the population level; 3) outcomes connected to actively doing something towards including passive behaviors; 4) the direct causal links between one's actions and outcomes towards realizing that there are many different ways that the behaviors of multiple actors can add up; and 5) one's own intentions towards recognizing that the relationship between intention and the outcomes of collective behavior can be very complex. Here, we use the term collective to refer to the cumulative behaviors of many actors as they contribute to outcomes across space and time. This includes groups in the traditional sense of a physical group where the members are aware of and can see each other, but also groups that are distributed across space and time and in which the members may not be aware of each other. We reserve the term “additive” for a particular type of collective group behavior as elaborated later in the paper.

[Insert Table 1. About Here]

Research on collective behavior has been studied under the related concept of distributed causality (Grotzer, 2012; Grotzer et al., 2017). Distributed causality is a multi-faceted concept (Barth-Cohen, 2012), with a variety of features that can add complexity and that are textured by cultural diversity (Grotzer & Solis, 2019). It is sometimes referred to as “Decentralized Causality” and is often explained in relation to Centralized Causality (Resnick, 1996) in which top-down control structures result in direct and indirect outcomes. By contrast, Distributed Causality refers to a bottom-up process in which many individuals, often spread out across space and time, engage in behaviors and those behaviors interact so that outcomes emerge from the interactions of their behaviors. The individuals may not intend for the specific outcomes to occur. Common examples include “grassroots” efforts in creating civic change, “flash mobs” that collect due to information on the internet, and depletion of an environmental resource by many distributed users—such as water in the western United States.

This paper considers some of the concepts that are necessary for children to understand in order to adopt a collective, planetary perspective. It shares research on how children conceptualize: 1) agency—their ability to act independently and interdependently and the ability of others to do so; 2) the ways that behaviors at individual and population levels can interact including the concept of emergence—that collective actions can interact in synergistic ways to lead to unanticipated outcomes;

and 3) intentionality as it manifests in individual and collective actions and can result in intended and/or unintended outcomes. Table 2 provides an overview of features embedded within each concept. The research shared in the paper is not intended to be exhaustive as would be the case in a literature review; rather it is intended to illustrate key findings from the literature and to offer examples of the research behind the findings. The paper draws upon research from cognitive science, developmental science, the learning sciences, and educational research.

The paper is organized as follows. 1. We begin by offering a broad view of ways that children conceptualize agency, action, and collectivity within different cultural contexts and in ways that are independent and interdependent. This includes individualistic vs. collective conceptions, ones that entail human and non-human as well as animate and inanimate agency. It takes into account “active” conceptions of agency in contrast to passive conceptions. It suggests the importance of perspective-taking skills and understanding positionality in how children think about others with whom they share the planet. 2. Next, we consider children’s conceptions of how behaviors at individual and population levels can interact and how some of these interactions can lead to emergent population level outcomes that are challenging to predict. It considers the inherent challenges of reasoning about interacting behaviors—including the cognitive load of holding them in mind and manipulating them dynamically, being aware of the actions of others who are spread out across the planet, and connecting causes and effects that are spread out in time and space. 3. Finally, we consider how individual and collective actions can result in intended outcomes, but also in unintended outcomes that are challenging to notice and take responsibility for.

[Insert Table 2. About Here]

Conceptualizing Agency

How children reason about their agency and actions in the world, individually and collectively, is grounded in their developmental and cultural environments (Gauvain et al., 2011). From their earliest days, children grow outwards from the contexts into which they have been born. As they move from the womb, into family, and into community, they are navigating broadening concentric circles of context that involve increasing forms of complexity and challenge, in a non-linear, but expansive process of growing out (Bronfenbrenner, 1981). They may be born into a parent-child relationship, a nuclear family, or an extended family, and grow into a school community, a village community, and eventually into a broader global community. Within each holding environment, children adopt aspects of identity and relational constructs that frame their sense of being, who they are in the world, and their understandings of community. They develop assumptions about their own agency as individuals and as members of collectives. These concentric circles and children's paths through them share commonalities but are by no means universal, and as discussed below, are influenced by aspects of culture that lend texture to the specifics of development. These cultural aspects shape who children become and how they view themselves in relation to others.

Individualistic and Collective Agency

Reasoning about the collective actions of many Earthlings has a conceptual basis in how children reason about agency. Researchers in cognitive science and development consider agency to be a developmental primitive and an aspect of core cognition (e.g. Carey, 2009). Across research literatures, the term agency has been defined in a number of ways including characterizations as "entities" that cause other events to happen (e.g. Resnick 1996) and that possess persistent properties such as the ability to be goal-directed or to engage in mobility (e.g. Leslie, 1995). However, the primary focus has been the on goal-directed, purposeful acts of a human agent (e.g., Meltzoff, 2007; Want & Harris, 2001).

Further, most of the research focuses on individual agents as opposed to collective and/or distributed agents. It has been argued that the strongly goal-directed notion of agency in the research is due to the limited cultural contexts that have been studied (Adebe, 2019; Grotzer & Solis, 2019).

The individualistic, human characterizations of agency prevalent in developmental and science education research correspond to research that has largely focused on certain populations of children. According to Washinawatok and colleagues (2017), studies of children's biological knowledge largely represent "middle-class, European American children living in urban or suburban communities, typically located close to universities" (p. 1). Some cultures stress individuality while others place greater stress on relationality and collectivity (Markus & Kitayama, 1991; Nisbett & Norenzayan, 2002; Triandis et al., 1988). For instance, Ubuntu is a concept common in South Africa that focuses on a oneness in humanity that characterizes agency as "I am because we are" and addresses that children must have meaningful relationships to flourish (Ejuu & Opiyo, 2022). Abede (2019) argues for conceptualizing children's agency on a continuum of relational interdependence, as integral to and shaped by the familial notions related to care, obligations, and reciprocity. In some West African contexts, children are socialized into structures emphasizing collective responsibility, such as sibling to sibling care (Nsamenang, 1992). According to Abede (2019), these cultural practices support the development of interdependent agency as opposed to independent agency. This is a significant departure from individualistic, interventionist conceptions of agency prevalent in much of the research.

Some worldviews go further, including relationships to Earth as an essential aspect of life—viewing relationships across space, time and beyond individual lifetimes (Holschuh, 2021). These world views and related epistemologies are mindful of the long-term relationships and dynamics between organisms on the planet in ways that support sustainable engagement. For instance, indigenous populations in what is currently referred to as North America, consider themselves to be in relation with the natural world, adopt a long view on that relationship, and take only what they need from the natural world, and then, only with permission (Wall-Kimmerer, 2013). Bang and Marin (2015) documented how indigenous children and educators framed time-space relationships as connected n a form of “space-time synchronicity” (p. 8).

School environments can also frame a relational focus. The schools in Reggio Emilia, Italy practice emergent curriculum that builds upon the interests of the children and that supports and documents group learning as opposed to individual learning (Krechevsky & Stork, 2000). This invites a focus on the complex interactions that give rise to learning—peer exchanges, contagion of ideas, engagement of children and adults alike, and so forth.

Human/Non-Human and Animate/Inanimate Agency

Children’s assumptions about agency extend to whom they include in their conceptions of Earth’s collectivity. Most developmental research focuses on the actions of sentient beings (e.g. Moore, 2002), ones that are intentional or not (Cuzzolino et al., 2019), but some research specifically encompasses human *and* non-human agency (Bang & Marin, 2015). Grotzer et al. (2017) found that some fourth and sixth graders were able to set aside strongly agentive notions (in the sense of individual agency) to successfully reason about collective interdependence—the idea that we depend upon each other and that our actions impact each other. Cuzzolino et al. (2019) found that seventh graders who held the least agentive notions (with “agent” defined as individual, sentient beings that engaged in intentional or accidental behavior or that passively allowed something to happen by not engaging in a behavior) learned the most about complex causal dynamics in ecosystems in a technology-based learning module.

A growing literature illuminates how children’s environmental and cultural contexts influence their biological cognition (e.g., Gelman & Legare, 2011; Longbottom & Slaughter, 2016; Washinawatok et al., 2017; Waxman et al., 2007). Bang and Marin (2015) found variations in conceptions of agency in how Anishinabe families spoke about organisms and human-non-human communication. Even within the context of spoken English, they detected shifts in the framing of relationships towards recognizing an agentive perspective of non-humans. Washinawatok et al. (2017) found that when playing with toy representations of plants and animals in a forest diorama, Native American children were more than twice as likely than non-Natives to take the perspective of the animals when playing with toy representations of them—suggesting the influence of culture on children's assigning of agency.

Active and Passive Agency

What about how children think about what it means to be an agent—the very process of what agency entails in terms of cause and effect? Research in Western contexts suggests that as early as infancy, children focus on goal-oriented, active forms of agency and that this compels interest and facilitates engagement in task learning (Gopnik & Schulz, 2004; Meltzoff, 2007; Sommerville, 2007). While the research shows that babies are highly motivated by their own agentive behavior, they also attend to the demonstrated goals of other agents. By six-months-old, babies attend selectively to behaviors related to the intentions of an actor more so than to behaviors related to other factors (Woodward, 1998), thus privileging goal-directed behavior (e.g., Janovic et al., 2007; Woodward, 1998; 2003). These findings suggest that infants prioritize conceptions of agency related to human action and potentially related to their ability to imitate such behaviors. For instance, when infants witnessed a human agent producing a change to a stimulus, they inferred causality and attempted to imitate the manipulation, but they did not attempt to produce the change when they were not shown a human agent causing the change (Meltzoff, 2007).

The extant literature has explored ways in which cultural factors might shape causal cognition (Bender & Beller, 2019; Bender et al., 2017). Bender et al. (2017) presented evidence of cultural variability in physical, biological, and psychological explanations and concluded that culture helps to define, “the settings in which causal cognition emerges, the manner in which potential factors are pondered, and the choices for highlighting some causes over others or for expressing them in distinct ways” (p. 717). Researchers have further argued that making judgments about active, purposeful agency might be a matter of degree rather than kind and that variability in such judgments likely exists within and between cultural contexts (Widlok, 2014). For example, the construction of language and habitual patterns of speaking, might serve as cues for how individuals from different linguistic communities construct notions of agency (e.g., Fausey et al., 2010). Holschuh (2021), a historic, cultural, and linguistic researcher belonging to the Elnu Abenaki Tribe, discusses how linguistic framing influences one’s sense of relationship, reciprocity, and responsibility and how indigenous language focuses “on being in relation with Earth.”

While much of the developmental research focuses mainly on goal-oriented, interventionist theories of agency (in which cause and effect is tested by intervening on the relationship), others have called for research that extends beyond this (e.g. Hagmayer et al., 2007). This extended framing encompasses steady states (in which a balance of variables leads to maintenance of a status quo) (Grotzer et al., 2013; Woodward, 2007) and/or considers passive forms of agency where lack of action can result in an outcome (Cuzzolino et al., 2019). Some research suggests that students convert passive forms of causal dynamics, for instance, relationships between physical forces or processes such as photosynthesis, into active, agency-oriented, “cause then effect” schemas (Lehrer & Schauble, 1998).

This extended framing is necessary for understanding of natural systems. Woodward (2007) has argued that natural phenomena often do not conform to notions of cause and effect with active agency at the core—in which a cause precipitates an action that results in an outcome. While humans and other sentient beings are a part of natural systems, complex causal dynamics that extend beyond the actions of sentient beings—that are essentially non-agentive—are commonplace in the natural world. These dynamics are best described by processes and steady states rather than event-like, cause then effect, schemas, for instance the balance of forces in an arch bridge or on-going processes such as photosynthesis and erosion (Weathers et al. 2012). These non-agentive, non-intentional, non-goal-directed or purposeful processes can have significant impacts on the biotic and abiotic elements of the landscape and understanding them is a part of being able to understand the dynamic processes of planet Earth.

On balance, understanding how human action—individually and collectively—impacts ecosystems dynamics is critical to sustainable life on Earth. The Climate Change Principles (NASA, 2009) include human impacts on the environment and the climate of the Earth. This suggests that reflective and flexible understandings of the nature of agency is an important conceptual foundation for thinking about sustainability in the natural world and to our individual and collective behaviors on planet Earth. It influences what forces we take into account and how students learn to reason about human impacts in the context of passive dynamics that mitigate against seeing immediate outcomes from human actions. For instance, oceans serve to insulate humans from the impacts of increased carbon as they absorb so much heat energy.

Diverse Perspectives and Positionality

Rituals, stories, explanations, and other ways of knowing are passed on across time by members of cultural communities (Holschul, 2021). Understanding how to reason about diverse perspectives and positionality and realizing that our beliefs, motivations, and actions are culturally embedded is core to being able to live sustainably with others (Wu & Keysar, 2007). Reasoning about sustainability involves considering diverse perspectives and realizing how environmental choices impact those whose positionality may differ from one’s own, for instance, how climate change affects those in low-lying areas or impacts nations that contribute the least to greenhouse gases. It also tends to have the greatest health impacts in the least resourced neighborhoods. A learner must: 1) realize their own lens and ask, “What perspective do I hold?”; 2) consider other voices and ask “Which voices are missing from the conversation?” 3) seek to understand and adopt other lenses and consider, “What are other perspectives and what influences them?”; and; 4) step outside of our own self-interest and ask, “What might I decide if I didn’t know which role in the complex situation I will inhabit?” (Donaldson et al., 2016; Sessa, 1996).

A technique for examining different perspectives called Moral Musical Chairs (Kohlberg, 1976) involves having students gather information about each perspective—being mindful of the need to set their own lenses aside as much as possible—and to engage in conversation about whose voices must be at the table. For instance, in a global community, one must consider the impacts on an island nation such as Kiribati, in addition to impacts local to the decision. Students then play musical chairs with one chair per role/perspective. They stop when the music stops and occupy the chair/role closest to them—considering the perspectives (imagining that they could be anyone in the scenario) and discuss their feelings as they rotate through each role. Using Moral Musical Chairs to consider issues such as access to water, persons displaced by climate change, carbon tax, and so on, enables learners to consider what perspectives should be brought to bear in a global community and to practice trying on different perspectives. Research found that fifth and sixth graders reasoned about greater complexity in environmental decision-making following an intervention using the approach (Donaldson et al., 2016; Grotzer et al., 2015).

Interaction: Reasoning Between Actions at Individual and Population Levels

As children reason about how collectives or populations behave, they bring their conceptions of agency forward. Few empirical studies exist to address questions about how particular cultural conceptions of agency relate to children’s understanding of the outcomes of population behaviors. However, a significant body of research informs the challenges of reasoning from individual actions towards actions at the population level. This research suggests that it is challenging to use individual actions to imagine the actions of a collective. The challenges include: 1) issues of cognitive load and visualizing dynamic processes; 2) awareness of the spatially and temporally distributed actions of others; 3) awareness of the connections between causes and effects that are separated in space and time; and 4) grasping how emergent outcomes can result from the synergies between people's actions.

Cognitive Load and Visualizing Dynamic Processes

Challenges related to the cognitive load of reasoning about complex and dynamic information come into play when trying to conceptualize linkages between the outcome of our own behavior and that of the collective population. Cognitive load refers to the amount of information that one needs to hold in working memory while thinking about it. Cognitive load tends to be higher for children and novices because they may be missing information and because the information that they do have is more likely to exist in discrete pieces as opposed to larger connected wholes (Metz, 1997). Reasoning about dynamic processes requires holding information in mind and imagining how it would change as it goes through various transformations.

Reasoning about actions at an individual level and at a population level at the same time more than doubles the inherent challenges. One needs to hold two systems and two sets of causal rules in mind at once—those related to individual actions and those related to the collective. The causal rules defining each and their levels of familiarity differ within each system (Wilensky & Resnick, 1999; White, 1993). It is common for children to be more familiar with individual actions because these are aligned with their own behaviors. Then in addition to holding two sets of dynamic systems in working memory, one must imagine them in relation to each other and picture any possible interactions between them.

Wilensky and Resnick (1999) found that reasoning about individual and collective agency at two different levels was extremely challenging even for high school students. Using a computer simulation to model the behavior of individual cars on a highway and the population effect of a traffic jam, students were surprised at what happened. The authors offer the following example, '"What's going on?" said one of the students. "The cars are going forward; how can the jam be moving backward?"' (1999, p. 3). Many population level outcomes are surprising for all ages, including fourth graders when reasoning about escalating noise in the cafeteria (Grotzer et al., 2016), and adults reasoning about flocking birds and economic systems (Resnick, 1996). Reasoning about population behaviors is dependent upon metaphorically adopting a birds-eye view of many individual actors in which one can "detect spatial and temporal patterns related to the population" (Levy & Wilensky, 2008, p.35).

The Challenges of Spatially and Temporally Distributed Actions

Holding a metaphorical bird's-eye view of population effects for the real world is much more complicated than it might sound. It includes reasoning about the collective action of spatially and temporally distributed actors that one may not be aware of and that may hold different motivations than oneself. One must know that those actors exist and have information about what guides their behaviors. Individuals driving to the grocery store think about that trip in relation to their own needs and intentions to purchase what is needed and return home. Individuals may even be aware that their vehicle produces a small amount of carbon and pollutants—in amounts that individually seem inconsequential (even when the collective effects of many people engaging in the same action contribute significantly to climate change).

Extending information about individual actions to a collective group might be helpful in cases where the rules and actions that direct agents' behaviors are discernible. However, actors are often spatially and temporally distributed and are typically beyond one's attentional frame. Imagine being in one large room with a group of people such that you can observe what they are doing and can imagine how collectively it might have an impact. For instance, Grotzer et al. (2016) considered how fourth and sixth graders reasoned about behaviors in the school cafeteria and found that they take into account both the individual actions and the ways that the actions collectively add up. Compare that to reasoning about individual actions spread out over the entire planet and with people engaging in actions at different times. It isn't easy to know about individual actors, to keep them in mind, or to connect them to outcomes and yet, reasoning about the actions of a global collective of Earthlings towards sustainability requires the ability to think about actors who are spatially and temporally distributed.

Awareness of the Connections Between Distal Causes and Effects

Even more challenging than having spatially and temporally distributed actors is the challenge of having temporal and spatial gaps between causes and effects because it undermines one of the fundamental ways that humans discern causal connections (Grotzer & Tutwiler, 2014). A primary means of detecting causal relationships is recognizing, and perhaps intervening upon, a covariation pattern as studied in the Causal Bayesian Network research (e.g. Gopnik & Schultz, 2007; Gopnik et al., 2001). Other means of detecting causal relationships include being able to infer a relationship from mechanism knowledge (such as knowing how germs or viruses work or how remote controls behave) and basing one's judgment on trust in testimony from others (Harris & Koenig, 2006). When causes and effects reside in different attentional frames, the covariation patterns are not available or are non-salient at best.

Reasoning across spatial discontinuity between causes and effects is required in many environmental and ecological issues. For instance, the carbon emissions contributed to the environment in populated areas hold consequences for people and other organisms in distant and remote locations, the cutting of rainforest in the Amazon affects the entire planet, and changes to ocean temperatures impact global weather patterns. Building upon the concept of "action at a distance" in developmental psychology—that causes and effects can occur across a physical gap—Grotzer and Solis (2015) have referred to “action at an attentional distance” to indicate that in cases such as these, there is more than a physical gap to contend with. There is the added conceptual challenge of an attentional gap.

Ecosystem scientists incorporate the concept of spatial discontinuity and attentional gaps between causes and effects in ecological and environmental science and they employ methodologies that recognize the potential for action at an attentional distance that enable them to test the connections in a system across distant causes and effects. For instance, remote sensing allows them to collect data across broad spatial scales and discontinuities (Bechtold et al., 2013). “Tracers” are stable chemical or biochemical compounds that are deployed within an ecological system to reveal the movement of matter and energy to suggest the system’s connectedness across attentional and spatial gaps (Weathers et al., 2013). Becoming environmentally literate involves understanding that causes and effects can act across spatial and temporal distance and different attentional frames (Grotzer & Solis, 2015). It involves learning to reason across large spatial scales and socioecological systems to consider possible connections (Gunkel et al., 2012; Mohan et., 2009). This includes thinking about actors that are spread out across the planet.

Research shows that students find it hard to reason across spatial scales in general (Kastens et al., 2009), and even at the high school level, very few students offer systemic explanations that reveal a connected view of the movement of materials within the environment (Mohan et al., 2009). When reasoning across large geographical distances, students do not typically make connections between the locations (Ben-Zvi Assaraf & Orion, 2005; Gunckel et al., 2012). Even in the case of watersheds, students did not connect information about water from one location to another (Shepardson et al., 2007) despite their knowledge of the movement of fluids. Tretter, Jones, and Minogue (2006) found that all ages struggle with thinking across spatial scales and that experts typically do so by displacing their own perception from a human scale—a conceptual shift that would make a good instructional target for younger learners.

While the concept of action at a distance is well-studied in the developmental psychology literature (e.g. Spelke et al., 1995), “action at an attentional distance” in which “discontinuous causes and effects reside in different attentional frames” and the specific cognitive challenges that it entails, are less studied. Without obvious and consistent opportunities to perceive co-variation relationships between candidate causes and effects, there is little to suggest that a causal relationship exists (Grotzer & Tutwiler, 2014), and learners of all ages miss the connections. Grotzer and Solis (2015) found that when second, fourth, and sixth graders were presented with scenarios that could invoke Action at an Attentional Distance Reasoning, they tended to reason locally. However, children who did reason about Action at an Attentional Distance relied upon mechanism information and prior knowledge. This focus on mechanism knowledge makes sense given that the co-variation relationship is not salient enough to inform their causal models—thus elevating the importance of other sources such as mechanism knowledge. It also fits with other studies of the role of mechanism with older (Bar et al., 1997) and younger learners (Solis et al., 2019). This suggests that even though carbon is non-obvious, being taught its role as a contributor to climate change, will help learners to realize that actions of others in the global community that impact carbon, will impact climate change, for instance, many people engaging in plane travel or policies that lead to the cutting of the world’s forests.

Additive, Interacting, and Synergistic, Emergent Effects

If students can: 1) handle the cognitive load of holding multiple levels in mind; 2) reason about spatially and temporally distributed actors; and 3) deal with spatial and temporal gaps between causes and effects, they will have the information necessary to reason about how many individual actions add up to collective action. However, how individual actions add up is not straightforward. Research suggests that children *are able to* reason additively about individual actions. They can even consider how the multitude of actions interact with each other. Bu this is where it gets more complicated—at the point where the interactions begin to interact and there are synergistic, emergent outcomes. For instance, in the case of the traffic jam example: 1) having many cars adds to the problem; 2) then individuals begin to react to the accumulation of cars by doing things such as trying to find ways around the traffic and driving in the break-down lane, etc. and then; 3) these individual behaviors begin to interact as people copy others, get angry and decide not to let cars merge, etc. and it leads to the emergent mess that we call the traffic jam. This is not unlike the emergent problem of climate change. Many Earthlings add up to challenges in sustainability in supporting many people on a small planet, but as our collective contributions to climate change add up, people respond to the outcomes of those changes by heating and cooling to a greater extent, by relocating to different parts of the planet, and so on.

There has been considerable interest in the cognitive science literature on how collective actions can interact in ways that contribute to emergent outcomes that are difficult to predict (Chi et al., 2012; Grotzer et al., 2017; Resnick, 1996) such as in climate change. Emergence is a central concept involved in understanding complexity (Levy & Wilensky, 2008; 2011; Chi, 2005; Chi et al., 2012). In order to tease apart and study the conceptual components of reasoning about collective behaviors and the phenomenon of emergence, Grotzer, Derbiszewska, and Solis (2017) investigated how students in 4^{th} and 6^{th} grades reasoned about collectivity in three tiers: 1) additive in which there is *a straightforward adding up of contribution towards an outcome* including "aggregates resulting from additive effects that result in a broader outcome than would otherwise be enabled by individual efforts," for example, termites building a mound together or a group of people in a room involved in individual loud behaviors; 2) interacting in which there are first order interactions or *interaction between the agents* can lead to outcomes that are more than the result of just adding people to the room as in when people begin talking to each other; and 3) second order interactions in which *the interactions interact* resulting in synergistic and emergent outcomes, for example, people talking louder to someone near them to be heard over the other people who are talking. Others follow suit and soon there is an escalating noise level. The authors found that students gave many tier one and tier two explanations, but that there were fewer instances at tier three in which students recognized interactions among interactions (synergistic outcomes); instead they often stopped just short of describing synergistic interactions.

So, while it can be challenging in the sense of cognitive load to reason about collective, reasoning about second order, synergistic effects appear to be the most challenging. Resnick (1994; 1996) found that learners tend to assume central control structures instead of bottom up, emergent properties. Research has shown that even when using computer models, such as Star Logo or NetLogo, designed to illuminate the connections between interactions at the level of individual actors and the emergent population effects, students found it hard to connect the levels (e.g., Penner, 2000; Wilensky & Resnick, 1999). Chi and colleagues (e.g., Chi, 2005; Chi et al., 2012) found that most students applied direct, linear causal reasoning, the causal rules that apply at the individual or agent level, to the population levels such that they entirely missed the role of emergence. Grotzer et al, (2017) found that a few students could identify emergent effects, but that most persisted in direct causal reasoning. Promising research by Danish et al. (2011) found that kindergartners could learn to reason between levels in reasoning about bees by using simulation software and information about two levels at once that downloaded the problem of holding information about both levels in mind at once. This allowed students to consider them side by side and resulted in an increase in students' ability to reason about population behaviors and to articulate some of the mechanisms by which bees collect nectar. This suggests that learning to identify emergent effects is challenging, but possible, and represents an important instructional target.

Envisioning outcomes at all three tiers is complicated enough when the behaviors are fairly homogeneous; introducing real world heterogeneity such as in global communities living sustainably on planet Earth radically complexifies one's ability to predict. Research suggests that heterogeneous behaviors are much more challenging to reason about (Chi et al., 2012; Hmelo-Silver & Azevedo, 2006). Contrast the difficulty of reasoning about air molecules bouncing around that all follow the same set of rules for their behavior to the drivers in the traffic jam example who all play by different rules with some who are willing to drive in the breakdown lane, cut others off, use off/on ramps to get ahead, and so on. In the case of climate change, one needs to assess the potency of behaviors that work in favor of sustainability versus those that work against it.

Intentionality

Whether or not an agentive stance makes it difficult to reason towards understanding collective action and emergence hinges to some extent on the role of intention and its alignment with the outcomes. As we shall see, it can add significant complexity.

Intentional vs. Unintentional Behaviors

The role of intentional action—a set of actions enacted with a particular goal in mind (Malle et al., 2001)— is central to how humans think about agency and its outcomes at all ages, even in a rudimentary way (Brandone & Wellman, 2009) for the youngest children (Meltzoff, 2007). By age four, children show recognition of the concepts of prior intention (or thinking about what one wants to do) and intention-in-action (acting with a certain goal in mind) (Feinfeld et al., 1999). By five years of age, children differentiate between intentional and unintentional acts (Colle et al, 2007). Mull and Evans (2010) found that by around age seven, children become able to explain a range of intentional acts.

Intentionality influences how causal outcomes are assessed—with people judging those that are foreseeable and intentionally aligned with their outcomes in ways that are much harsher and more causal, than those that are not (Lagnado & Channon, 2008). For instance, if someone intentionally pollutes or cuts down trees in the Amazon, we view that as more problematic than someone who inadvertently releases an invasive species or contributes to greenhouse gases when driving to work.

Some of the research on children's understanding of intention focuses on the causal history of an event (e.g. Gopnik & Schultz, 2007). It notes that while younger children attend to causes that are proximal or close to the event, older children are able to focus on causes that are non-obvious (such as mental states) and distant from an outcome (Schult, 2002). An ability to consider the causal history related to intention provides an important basis for children in thinking about issues of caring for the earth and sustainability. However, intentionality takes on new dimensions when reasoning about the relationship between individual actions and population outcomes given the complexity of the causal history. This is especially the case when individual intentions and population outcomes are unaligned as we consider next.

Aligned vs. Unaligned Outcomes

In the case of climate change and sustainability, emergent outcomes are often entirely unaligned with the lower-level rules guiding the behavior of individual actors. Someone can intend to buy groceries or to choose the least expensive product without intending to contribute to the emergent outcomes of higher carbon levels in the atmosphere resulting from collective car emissions or buying non-local products. They may engage in airplane travel and eat red meat individually, but the collective, emergent outcome is increased greenhouse gases precipitating more extreme temperatures, increased use of air conditioners, and other forms of energy in response and so forth. Concepts related to intentionality create challenges in thinking about sustainability because the gravity of the effects have little to do with whether they are intended or not; unintended effects are just as real and problematic as intended ones.

Grotzer et al. (2017) found that while fourth and sixth graders could leverage their agent-based knowledge towards understanding some aspects of collective action, only a small number of students were able to do so when the agent level and population level outcomes were unaligned in terms of intention. Most students applied direct causal outcomes from the agentive level to the emergent level and found it difficult to reason about synergies between the interactions of interactions at the emergent level that could lead to outcomes that were unaligned with their individual intentions. This means that they expected their intentions as individual actors to carry through to the population level. This presents a considerable learning obstacle in understanding our collectivity as it applies to climate change and climate action and is an important focus for further research.

Summary

The above consideration of the conceptual challenges of participating thoughtfully in a global community of earthlings is by no means complete; there are many related topics, for instance, cooperation and equity (Blake et al., 2015), that would further inform the problem space. In addition, this paper suggests themes and offers exemplars from the research literature. It is intended to be a sampling of the extant literature rather than an extensive literature review which is beyond the scope of this paper. With those limitations in mind, what does the consideration here suggest for takeaway points for instructional design and as targets for future research?

Some broad level takeaway points include the following: 1.) It underscores the importance of helping learners to realize that what unites us as Earthlings is far more than what divides us by difference and that our differences and diversity can be a source of strength. 2) Contextual supports can help children learn to consider a broader range of voices as part of our collectivity on the planet—human and non-human. 3) Viewing themselves as cultural beings may help children to realize the need to learn to look for and to try to adopt varied perspectives and positionality. 4) Children need support in learning to understand the dynamics of collective behaviors, particularly that emergent effects differ from straight-forward accumulation and how challenging it is to predict outcomes. However, as part of this effort, instruction can support children in learning that many small, distributed actions add up towards more powerful outcomes than anticipated and that they can look for ways to leverage their collective, distributed agency towards good. 5) Further, children need support in learning that their actions impact people and organisms that are beyond their attentional frames and that learning about mechanisms in the natural world can help them to infer connections even when they can't readily see the connection between causes and effects—when the co-variation information is not available.

The consideration here also suggests instructional points of promise. If some cultural contexts enable children to adopt a greater sense of interdependent agency and a deeper sense of how they are part of a collective community than other contexts, this suggests that these conceptions are malleable and can be learned. In addition, more research is needed to inform the conceptual foundations of how we understand ways of thinking about our collectivity that support our sustainability on the planet. For instance, studying ways that children think about intentionality when individual intentions and population level outcomes are unaligned and investigating how to help them to connect actions at one level with outcomes at another level would productive areas for further research. Additional study of the ways that children can connect distal causes and effects that exist in separate attentional frames and of how children's perspectives are impacted by games such as Moral Musical Chairs would further inform educational practice. In summary, the consideration here presents serious challenges but also points of promise. It signals that there is much to learn and to do in order to best support the next generation in growing up as a collective community of Earthlings and living sustainably together on planet Earth.

References

Abebe, T. (2019). Reconceptualizing children's agency as continuum and interdependence. *Social Sciences, 8*(3), 81.

Bang, M., & Marin, A. (2015). Nature-culture constructs in science learning: Human/Non-Human agency and intentionality. *Journal of Research in Science Teaching, 52*(4), 530-544.

Barth-Cohen, L.A. (2012). *The role of prior knowledge and problem contexts in students' explanations of complex systems.* Doctoral Dissertation, University of California, Berkley, Berkley, CA. Available: http://eprints.cdlib.org/uc/item/84m5s1zt

Bar, V., Zinn, B. and Rubin, E. (1997). Children's ideas about action at a distance, *International Journal of Science Education,19*(10), 1137 - 1157.

Bechtold, H.A., Duran, J., Strayer, D.L., Weathers, K.C., Alvarado, A.P., Bettez, N.D., Hersh, M.A., Johnson, R.C., Keeling, E.G., Morse, J.L., Previtali, A.M., & Rodriguez, A. (2013). Frontiers in ecosystem science. In K. Weathers, D. Strayer, & G., Likens, (Eds.). *Fundamentals of Ecosystem Science*. Academic Press.

Bender, A., & Beller, S. (2019). The cultural fabric of human causal cognition. *Perspectives on Psychological Science, 14*(6), 922–940.

Bender, A., Beller, S., & Medin, D.L. (2017). Causal cognition and culture. In M. R. Waldmann (Ed.), *The Oxford Handbook of Causal Reasoning* (717-738). Oxford University Press.

Ben-Zvi Assaraf, O. & Orion, N. (2005). Development of system thinking skills in the context of earth system education, *Journal of Research in Science Teaching, 42*(5), 518-560.

Blake, P.R., McAuliffe, K., Corbit, J., Callaghan, T.C., Barry, O., Bowie, A., Kleutsch, L., Kramer, K.L., Ross, E., Vongsachang, H., Wrangham, R., & Warneken, F., (2015) The ontogeny of fairness in seven societies. *Nature,* doi:10.1038/nature15703

Brandone, A. C., & Wellman, H. M. (2009). You can't always get what you want: Infants understand failed goal-directed actions. *Psychological Science, 20*, 85–91.

Bronfenbrenner, U. (1981). *The ecology of human development: Experiments by nature and design.* Harvard University Press.

Carey, S. (2009). *The origin of concepts.* New York: Oxford University Press.

Chi, M. T. H. (2005). Common sense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14,* 161–199.

Chi, M.T.H., Roscoe, R., Slotta, J., Roy, M., & Chase, M. (2012). Misconceived causal explanations for "emergent" processes. *Cognitive Science, 36, 1-61.*

Colle, L., Mate, D., Del Giudice, M. Ashwin, C., Baron-Cohen, S. (2007). Children's understanding of intentional vs. non-intentional action. *Journal of Cognitive Science* 8: 37 – 63.

Cuzzolino, M.P., Grotzer, T.A. Tutwiler, M.S., & Torres, E.W. (2019). An agentive focus may limit learning about complex causality and systems dynamics: A study of seventh graders' explanations of ecosystems. *Journal of Research in Science Teaching, 56*(8), 1083-1105.

Danish, J., Peppler, K., Phelps, & Washington, D. (2011). Life in the hive: Supporting inquiry into complexity within the Zone of Proximal Development. *Journal of Science and Educational Technology, 20*(5) 454-467.

Donaldson Gramling, M., Solis, S.L. & Grotzer, T.A. (April, 2016). *Testing a curriculum designed to build students' understanding of distributed causality.* National Association for Research in Science Teaching (NARST), Baltimore, MD.

Ejuu, G. & Opiyo, R.A. (2022). Nurturing Ubuntu: The African Form of Human Flourishing Through Inclusive Home-Based Early Childhood Education. *Frontiers in Education, 17*(7). https://doi.org/10.3389/feduc.2022.838770

Fausey, C.M., Long, B.L., Inamori, A., & Boroditsky, L. (2010). Constructing agency: the role of language. *Frontiers in Psychology, 1*(162).

Feinfield, K. A., Lee, P. P., Flavell, E. R., Green, F. L., & Flavell, J. H. (1999). Young children's understanding of intention. *Cognitive Development, 14,* 463–486.

Gauvain, M., Beebe, H. & Zhao, S. (2011). Applying the cultural approach to cognitive development, *Journal of Cognition and Development, 12*(2):121–133

Gelman, S.A. & Legare, C.H. (2011). Concepts and folk theories. *Annual Review of Anthropology, 40*, 379-398.

Gopnik, A. & Schulz, L. (2007). *Causal learning,* Oxford Press.

Gopnik, A., Sobel, D., Schulz, L., & Glymour, C. (2001). Causal learning mechanisms in very young children: Two, three, and four-year-olds infer causal relations from patterns of variation and covariation. *Developmental Psychology*, *37*(5), 620-629.

Grotzer, T.A. (2012). *Learning causality in a complex world: Understandings of consequence*. Rowman & Littlefield.

Grotzer, T.A. Derbiszewska, K., Donaldson, M., Solis, L.S., & Bialik, M. (2015). *Becoming Responsible Individuals: Understanding Distributed Causality,* Causal Learning in the Classroom (CLIC) Modules, President and Fellows of Harvard College.

Grotzer, T.A., Kamarainen, A., Tutwiler, M.S, Metcalf, S, & Dede, C. (2013). Learning to reason about ecosystems dynamics over time: The challenges of an event-based causal focus. *BioScience, 63(4),* 288-296.

Grotzer, T.A. & Solis, S.L. (2015). Action at an attentional distance: A study of children's reasoning about causes and effects involving spatial and attentional discontinuity. *Journal for Research in Science Teaching, 52*(7) 1003-1030.

Grotzer, T.A., Derbiszewska, K., & Solis, S.L. (2017). Leveraging fourth and sixth graders' experiences to reveal understanding of the forms and features of distributed causality. *Cognition and Instruction 26(1), 1-47.*

Grotzer, T.A. & Solis, L.S. (2019). How agentive perspectives interact with the developing concepts of distributed causality and emergence. Technical Report, Causal Cognition in a Complex World Lab. President and Fellows of Harvard College.

Grotzer, T.A. & Tutwiler, M.S. (2014). Simplifying causal complexity: How interactions between modes of causal induction and information availability lead to heuristic driven reasoning. *Mind, Brain, and Education*, 8(3), 97-114.

Gunckel, K, Covitt, B.A., Salinas, I., Anderson, C.W. (2012). A learning progression for water in socio-ecological systems. *Journal of Research in Science Teaching, 49*(7) 843-868.

Hagmayer, Y., Sloman, S., Lagnado, D., & Waldmann, M. (2007). Causal reasoning through intervention. In A. Gopnik and L. Schulz (Eds.) *Causal learning* (pp. 86-100), Oxford University Press.

Harris, P. L., & Koenig, M. A. (2006). Trust in Testimony: How Children Learn about Science and Religion. *Child Development*, *77*(3), 505–524. http://www.jstor.org/stable/3696543

Holschuh, R. (2021, November) "N'Sibo: The River to Which I Belong." Presentation to the Lincoln Land Conservation Trust and Rural Land Foundation, https://lincolnconservation.org/events/nsibo-the-river-to-which-i-belong-rich-holschuh/

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *Journal of the Learning Sciences, 15*(1) 53–61.

Janovic, B., Kiraly, I., Elsner, B., Gergely, G., Prinz, W., & Aschersleben, G. (2007). The role of effects for infants' perception of action goal. *Psychologia, 50*, 273-290.

Kastens, K., Manduca, C.A. Cervato, C., Froderman, R., Goodwin, C., Liben, L.S., Mogk, D.W., Spangler, T.C., Stillings, N.A. & Titus, S. (2009). How geoscientists think and learn. *EOS Trans. American Geographical Union, 90*(31), 265-269.

Kimmerer, R.W. (2013). *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge, and the Teaching of Plants.* Milkweed Editions.

Kohlberg, L. (1976). Moral stages and moralization: The cognitive-developmental approach. In Lickona, T. (Ed.). *Moral Development and Behavior: Theory, Research and Social Issues*. Rinehart and Winston.

Krechevsky, M. & Stork, J. (2000). Challenging educational assumptions: Lessons from an Italian-American collaboration. *Cambridge Journal of Education 30*(1), 57-74.

Lagnado, D.A., & Channon, S. (2008). Judgments of cause and blame: The effects of intentionality and foreseeability. *Cognition, 108*(3), 754-770.

Lehrer, R., & Schauble, L. (1998). Reasoning about structure and function: Children's conceptions of gears. *Journal of Research in Science Teaching*, *35*(1), 3-25.

Leslie, A.M. (1995). A theory of agency. A.J. Premack, D. Premack, & D. Sperber (Eds.) *Causal Cognition: A Multidisciplinary Debate*, (pp 121-141) Clarendon Press.

Levy, S.T., & Wilensky, U. (2008). Inventing a "mid-level" to make ends meet: Reasoning between the levels of complexity. *Cognition and Instruction, 26*(1), 1-47.

Levy, S.T. & Wilensky, U. (2011). Mining students' inquiry actions for understanding of complex systems. *Computers & Education, 56*(3), 556-573.

Longbottom, S.E. & Slaughter, V. (2016). Direct experience with nature and the development of biological knowledge. *Early Education and Development, 27*, 1145-1158.

Malle, B. F., Moses, L. J., & Baldwin, D. A. (2001). Introduction: The significance of intentionality. In B. F. Malle, L. J. Moses, & D. A. Baldwin (Eds.), *Intentions and intentionality: Foundations of Social Cognition* (pp. 1–24). MIT Press.

Markus, H., & Kitayama, S. (1991). Culture and the self: implications for cognition, emotion, and motivation. *Psychological Review 98*, 224–253. doi: 10.1037/0033-295X.98.2.224

Meltzoff, A.N. (2007). Infants' causal learning: Intervention, observation, imitation. In A. Gopnik & L. Schulz (Eds.), *Causal learning: Psychology, philosophy, and computation* (pp 37-47). Oxford University Press.

Metz, K.E. (1997). On the complex relation between cognitive developmental research and children's science curricula. *Review of Educational Research, 67*(1), pp. 151-163. http://www.jstor.org.ezp-prod1.hul.harvard.edu/stable/1170622

Mohan, L., Chen, J., & Anderson, C. W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. *Journal of Research in Science Teaching, 46*(6), 675-698. doi:10.1002/tea.20314

Moore, R., Mitchell, G., Bally, R., Inglis, M., Day, J., & Jacobs, D. (2002). Undergraduates' understanding of evolution: Ascriptions of agency as a problem for student learning. *Journal of Biological Education, 36*(2), 65-71.

Morris, M.& Peng, K. (1994). Culture and cause: American and Chinese attributions for social and physical events. *Journal of Personality and Social Psychology, 67*(6), 949-971.

Mull, M, & Evans, E.M. (2010). Did she mean to do it? Acquiring a folk theory of intentionality. *Journal of Experimental Child Psychology* 107 (2010) 207–228

NASA, (2009*). Climate literacy: The essential principles of climate science.* Retrieved from https://pmm.nasa.gov/education/articles/climate-literacy-essential-principles-climate-sciences

Nsamenang, A. B. (1992). *Human Development in Cultural Context: A Third World Perspective*. Sage.

Nisbett, R.E. & Masuda, T. (2003). Culture and point of view. *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 100*(19) 11163-11170; https://doi.org/10.1073/pnas.1934527100

Nisbett, R.E. & Norenzayan, A. (2002). Culture and cognition. In D. L. Medin (Ed.) *Stevens' Handbook of Experimental Psychology, Third Edition*. Available: http://www-personal.umich.edu/~nisbett/cultcog2.pdf

Ojala, M. (2007). Confronting macrosocial worries: Worry about environmental problems and proactive coping among a group of young volunteers, *Futures, 39*(6), 729-745.

Penner, D. (2000). Explaining systems: Investigating middle school students' understanding of emergent phenomena. *Journal of Research in Science Teaching, 37*(8), 784-806.

Resnick, M. (1994). *Turtles, termites, and traffic jams.* MIT Press.

Resnick, M. (1996). Beyond the centralized mindset. *Journal of the Learning Sciences, 5*(1), 1-22.

Schult, C. A. (2002). Children's understanding of the distinction between intentions and desires. *Child Development, 73*, 1727–1747.

Sessa, V. I. (1996). Using perspective taking to manage conflict and affect in teams. *Journal of Applied Behavioral Science, 32*, 101-115.

Shepardson, D.P., Wee, B., Priddy, M., Schellenberger, L., Harbor J. (2007). What is a watershed?: Implications of student conceptions for environmental science education and the National Science Education Standards. *Science Education, 91*, 544-578.

Solis, S.L., Grotzer, T.A. & Curtis, K.N. (2019). "There must be a cat nearby": Kindergarteners' reasoning about 'Action at an Attentional Distance.' *Journal of Educational and Developmental Psychology, 9*(2) 182-202.

Sommerville, J. A. (2007). Detecting causal structure: The role of interventions in infants' understanding of psychological and physical causal relations, In A. Gopnik & L. Schulz (Eds.), *Causal learning: Psychology, philosophy, and computation* (pp 48-57). Oxford, UK: Oxford University Press.

Spelke, E.S., Phillips, A., & Woodward, A.L. (1995). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack, & A.J. Premack (Eds.), *Causal Cognition: A Multidisciplinary Debate* (pp 44-78). Clarendon Press.

Tarter, J. (2018). The undiscovered: Searching for aliens, finding ourselves. Presentation at the Radcliffe Institute, https://www.radcliffe.harvard.edu/event/2018-undiscovered-symposium 34:50-36:24 (2018, October).

Tretter, T.R., Jones, M.G. & Minogue, J. (2006). Accuracy of scale conceptions in science: Mental maneuverings across many orders of spatial magnitude. *Journal of Research in Science Teaching, 43*(10), 1040-1060.

Triandis, H. C., Bontempo, R., Villareal, M. J., Asai, M., and Lucca, N. (1988). Individualism and collectivism: cross-cultural perspectives on self-ingroup relationships. *Journal of Personality and Social Psychology 54*, 323–338. doi: 10.1037/0022-3514.54.2.323

Want, S. C. & Harris, P.L. (2001). Learning from other people's mistakes: Causal understanding in learning to use a tool. *Child Development, 72*(2), 431-443.

Washinawatok, K., Rasmussen, C., Bang, M. Medin, D., Woodring, J., Waxman, S., Marin, A,, Gurneau, J., & Faber, L. (2017). Children's play with a forest diorama as a window into ecological cognition. *Journal of Cognition and Development, 18*(5), 617-632.

Waxman, S., Medi, D., & Ross, N. (2007). Folk-biological reasoning from a cross-cultural developmental perspective: Early essentialist notions are shaped by cultural beliefs. *Developmental Psychology, 43*, 294-308.

Weathers, K., Strayer, D. & Likens, G. (2013). *Fundamentals of Ecosystem Science.* Academic Press.

White, Barbara. (1993). Intermediate causal models: A missing link for successful science education. *Advances in Instructional Psychology, 4,*177-152.

Widlok, T. (2014). Agency, time and causality. *Frontiers in Psychology, 5*(1264).

Wilensky, U. (1999). *NetLogo.* Center for Connected Learning and Computer-Based Modeling, Northwestern University.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology, 8*(1), 3-19.

Woodward, J. (2007). Interventionist theories of causation in psychological perspective, In A. Gopnik & L. Schulz (Eds.), *Causal Learning: Psychology, Philosophy, and Computation* (pp 19-36). Oxford University Press.

Wu, S., and Keysar, B. (2007). The effect of culture on perspective taking. *Psychological Science, 18,* 600–606. doi: 10.1111/j.1467-9280.2007.01946.x

Table 1. Components of a Shift from an Individual to a Collective, Planetary View

An Individual View	⟹	A Collective, Planetary View
Focus on:		Focus on:
One's Individual Actions (as a Human)	⟹	Behavior of Populations (Including Non-Human) Including Groups and Individuals Spread Over Space and Time Considered Collectively as a Group
Outcomes of One's Own Actions	⟹	Collective, Population Level Outcomes
Outcomes Related to Actively Doing Something	⟹	Outcomes Related to Actively Doing Something and to Passive Behaviors
Direct Causal Links from Actions to Outcomes	⟹	Realizing that Outcomes from the Behaviors of Many can be Additive, Interactive, or Emergent
One's Own Intentions	⟹	Realizing that the Relationship Between Intention and Outcome Can be Complex

Table 2. Concepts Embedded in Reasoning About Our Global Collectivity

Agency	**Interaction**	**Intentionality**
1. Individualistic/ Collective	1. Cognitive Load and Dynamic Processes	1. Intentional/Unintentional
2. Human/Non-Human, Animate/Inanimate	2. Awareness of the Actions of Others who are Spatially and Temporally Distributed	2. Aligned/Unaligned
3. Active/Passive	3. Awareness of the Connection between Spatially and Temporally Distributed Causes and Effects	
4. Perspective-Taking and Positionality	4. Additive, Interacting, and Synergistic, Emergent Outcomes	