# "Cultivating Environmental Systems Thinking with Karunatree"

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# Cultivating Environmental Systems Thinking with Karunatree

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**ABSTRACT**
Understanding environmental issues requires an ability to see how concepts from many different STEM domains—biology, Earth science, physical science and more—fit together and interact as components of a larger whole. This integrative cognitive skill is sometimes called systems thinking (Doyle, 1997; Sweeney & Sterman, 2000). Unfortunately, though systems thinking is critical for understanding the state of the world we live in, it is also a challenging, counterintuitive skill to learn (Hmelo-Silver & Azevedo, 2006). This paper describes Karunatree: a web application designed to cultivate children's scientific understanding of environmental issues. Karunatree seeks to support systems thinking in early- and pre-adolescent children (10-15 years old) by providing an intuitive means of visualizing how distributed webs of environmental cause and effect geographically intersect. Here we present a conceptual and technical overview of the Karunatree system, and evaluate its performance as part of a summer learning program for middle-school girls. By providing an example of how computational systems can support systems thinking, we hope to bolster future efforts to help children engage with complex environmental topics.

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Systems thinking, sustainability, education.

**ACM Classification Keywords**
H5.m. Information interfaces and presentation (e.g., HCI); K.3.1. Computer Uses in Education.

## INTRODUCTION: SUSTAINABILITY & SYSTEMS THINKING

Our planet currently faces an array of severe environmental challenges. A brief sampling includes:

• **Climate change.** The links between human activity and a steadily warming climate are well established (Intergovernmental Panel on Climate Change (IPCC), 2007). Anthropogenic increases in greenhouse gas concentration contribute directly to the collapse of Antarctic ice shelves (Gillett et al., 2008), sea level rise (Sahagian, Schwartz, & Jacobs, 1994), erratic changes in global precipitation (Zhang et al., 2007), and the acidification of our oceans (Orr et al., 2008). All of these changes pose hazards not only to ecosystem stability, but also to immediate human health needs such as reliable access to clean drinking water (World Health Organization, 2009).

• **Biodiversity loss.** Global demand for commodities including cattle, plywood, palm oil, and coffee is gradually eroding unique habitats such as the rainforests of the Amazon and Sumatra (e.g., Uryu et al., 2009). Rainforest destruction alone could cause the extinction of up to 10% of extant species by 2022 (Wilson, 1999). Ecosystem depletion also accelerates climate change, which in turn further damages biodiversity (Thomas et al., 2004).

• **Fossil fuel pollution.** Humans continue to consume non-renewable and polluting sources of energy such as oil and coal at an accelerating pace. Emissions from our continuing dependence on fossil fuels are in turn one of the top contributors to increasing greenhouse gas concentration in the atmosphere (IPCC, 2007).

Given the size of these problems, we need to find ways of addressing not only the specific "symptoms" of environmental decline but also the underlying disorders—of policy, technology, education, etc.—that led to our current predicament. We believe that one particularly important underlying problem, largely overlooked, arises from a mismatch between our intuitive causal reasoning and systems thinking.

The human mind is not an all-purpose information processor, but rather an instrument whose abilities and limitations bear the imprint of our evolutionary history (Gigerenzer, 2000; Lyons, 2008; Lyons & Santos, 2006). In the domain of causal reasoning, this history has made us exquisitely sensitive to cause-and-effect relationships in the "here and now," i.e., within the scales of space, time, and social distribution that are typically relevant to individuals. More specifically, our intuitive notions of causation tend to involve: (a) spatially and temporally localized causes, (b) direct, linear, and instantaneous connections between cause and effect, and (c) centralized agency (Csibra, 2003; Grotzer & Perkins, 2000; Spelke et al., 1992; Woodward et al., 2001). When it comes to the environment, however, these intuitions have little relevance (Tomlinson, 2010).

Consider our previous examples of climate change, biodiversity loss, and fossil fuel pollution. These "effects" are the outputs of "causes" that are:

- Spatially distributed, occurring over regions varying in size from rainforests to continents.
- Temporally distributed, unfolding over years, decades, and more. Moreover, causes may be temporally separated from the first noticeable manifestation of their effects by large gulfs of time.
- Socially distributed, i.e., the collective consequence of behavior by numerous individual agents.
- Indirect and unintentional. That is, environmental problems are typically side effects of many seemingly unrelated decisions rather than outcomes that were specifically desired.

Features like these make our environment the quintessential complex system. In order to understand its dynamics, we need to go beyond localized, intuitive notions of cause and effect to systems thinking's more network-oriented perspective.

Unfortunately, systems thinking can be a difficult skill to master, even for adults. In a study of college undergraduates, Raia (2005) found that students tended "to conceptualize dynamic systems in static disjointed terms," often invoking "a single causal force, or linear chain of unique causal forces to explain complex natural phenomena" (p. 297). Similarly, in a study of students at an elite business school, Sweeney and Sterman (2000) found that most were unable to apply basic concepts like feedback, stocks and flows to make predictions about simple causal networks. We argue that these difficulties in systems thinking play an important role in perpetuating the environmental problems that confront our society. Without the ability to understand distributed causal networks and their dynamics, it is very difficult for any of us—whether policymaker or scientists, adult or child—to make the right choices for advancing sustainability.

The good news, however, is that if we can address the underlying challenge of systems thinking, we stand to have a wide-ranging positive impact. A first demonstration of this point comes from work by Plate (2010), who showed that giving students instruction in systems thinking significantly improved their ability to understand a complex environmental system, even without any specific content instruction on natural resources, etc. Our goal with Karunatree was to build on this important finding. We sought to build a system that would help children to conceptualize distributed causal networks in a relatable manner, in the process making large-scale environmental challenges like global climate change less cognitively opaque. Here we will describe how we pursued these goals, beginning with a brief survey of prior work on systems thinking in education and technology mediated learning. This literature review will highlight two key learning principles (integration and grounded generalization) that will inform a description of Karunatree's system design and implementation. We will then evaluate Karunatree's pedagogical effectiveness as part of a summer learning program, and close with suggestions for continuing development.

## APPROACH & PRIOR WORK

### Audience

Following Wiggins and McTighe's (2005) backward research design philosophy, Karunatree's development began with the question of audience. We believe that children are the right audience for promoting systems thinking, as well as for the broader aim of supporting sustainability. This may initially seem counterintuitive: if reasoning about distributed causal networks is something that even adults find challenging, why focus our teaching efforts on children? Our logic here follows that of noted computer scientist and educator Seymour Papert, whose work on the LOGO programming language broke new ground in mathematics education during the 1980s.

Papert argued that many so-called "hard" concepts are difficult to master not because of their intrinsic complexity, but instead because we lack appropriate models for manipulating them (1993). In Papert's parlance a *model* is a learning context in which an abstract concept maps onto a more intuitive substrate. For example, Papert used "turtles," small mobile robots that could be programmed to move and trace trajectories with an attached pen, as a model for teaching concepts in programming and planar geometry. Models need not be physical objects (Papert argued that the activity of programming itself was an excellent model for learning combinatorics); their critical feature is that they reduce abstraction and increase the learner's ability to playfully explore the desired content. Our pedagogical orientation in Karunatree follows Papert's example. As we will see shortly, Karunatree uses the grounded metaphor of seed planting as a way of modeling distributed causal reasoning in a relatable way.

Within the span of childhood, prior work in formal learning environments suggests the range of 10- to 15-years (5th to 10th grade) as the most appropriate developmental window for our goals. Children at earlier ages are capable of grasping the beginnings of system thinking (e.g., learning to recognize pair wise connections between nodes in a causal network), but they find more distributed kinds of network relationships difficult (Assaraf & Orion, 2010a). By middle school, contrastingly, students are capable of reasoning about a full range of network dynamics when supported by appropriate learning exercises (Assaraf & Orion, 2005; 2010b; Draper, 1992; Penner, 2000). Just as importantly, we also note that the middle school age range is a critical one for children's consolidation of their personal identity (Whitmire, 2000). The adage that "it's easier to avoid a bad habit than to break one" rings true here: if we want to help children grow into adults who make and value sound decisions about complex global issues, this is the age at which we need to act.

### The Systems Thinking Hierarchical Model

Having settled on an audience, we next needed to consider the specific pedagogical approach that Karunatree would use to teach environmental systems thinking. What can prior work tell us about how children's understanding of distributed causal networks first arises? Education researchers have found that when middle school students first begin to consider distributed causal systems, their comprehension typically proceeds via a well-defined succession of stages. Assaraf and Orion (2005) identify three such stages, the collection of which they refer to as the *Systems Thinking Hierarchical* (STH) model. The STH model's stages are:

1) **Analysis of system components.** Children's first approximation of systems thinking consists of simply being able to identify and enumerate the components and processes that make up a distributed causal network.

2) **Synthesis of system characteristics.** As children grow comfortable with these network building blocks they begin to be able to describe pair wise relationships between directly interacting components. Pair wise relationships then gradually give way to a more general understanding of network dynamics, and the ability to work out how changes in one component of the system will ripple outwards to effect other directly and indirectly connected components.

3) **Implementation.** Finally, in what Assaraf and Orion call the implementation phase, children begin to understand distributed networks well enough to make useful generalizations about their behavior (e.g. recognizing positive feedback loops as a generalizable feature), and to make predictive and retrospective inferences.

The ordering of the stages in the STH model is believed to be invariant, with each preceding stage establishing the knowledge and context that is necessary for the next to arise.

### Pedagogical Approaches to STH Learning

Within the framework of the STH model, what kinds of learning activities help children progress through earlier stages of systems thinking to the full implementation stage? Here we will focus on two general kinds of pedagogical activity that have been shown to be effective.

#### *Knowledge integration activities*

Knowledge integration or "reflection" activities such as (a) writing about what one is learning, (b) drawing or creating other visual representations of what is being learned, and (c) visiting real world locations where abstract system processes can be seen "in action" appear to be critical for reaching the highest level of the STH model (Assaraf & Orion, 2005; Bagno & Eylon, 1997; Kali, Orion, & Elon, 2003). In some cases it has been found that most of children's learning actually occurs during these sorts of integration activities rather than during the original presentation of the teaching content itself. For example, Kali, Orion, & Eylon (2003) found only minimal improvements in seventh graders system thinking after teaching a unit that focused on the rock cycle as an example of a distributed causal network. However, after a field trip that provided students with an opportunity to observe what they had been taught in a real world setting, systems thinking was substantially enhanced.

One interpretation of the importance of these integration activities focuses on their promotion of metacognition, an activity that has been shown to catalyze shifts towards higher levels of the STH model in other contexts (Assaraf & Orion, 2010b). Alternatively, integration activities may also help by establishing contexts for grounded generalizations, which we will now discuss.

#### *Establishing grounded generalizations*

When we think of the term "generalization" we think of a movement towards abstraction—the reduction of noisy specific instances to a pure logical formalism. When it comes to systems thinking however, Goldstone and Wilensky (2008) have argued that what they call grounded generalizations may be more productive than formalisms in helping children and adults to extend their knowledge of causal networks. As they put it, "The problem with formalisms is that, even when they have been acquired, it is difficult to recognize when the formalism is applicable to a situation, and so spontaneous transfer is unlikely" (p. 500). Goldstone and Wilensky's research shows that systems thinking principles are easier to transfer when they are learned in what might be called "minimal context," i.e., as part of a specific example that has been judiciously selected so as to minimize extraneous detail.

While Goldstone and Wilensky are focused on the cognitive importance of grounded generalizations, another feature of this concept that bears mentioning has to do with motivation. Hmelo-Silver and colleagues have argued that teaching children systems thinking skills in the abstract is very difficult simply because they see the topic, removed from any context, as dry and unrelatable (Hmelo-Silver & Azevedo, 2006). Grounded generalizations can help to situate systems thinking in contexts that have more vibrancy and relevance, thus increasing children's motivation to focus on the learning task.

#### *The Karunatree Approach*

Drawing inspiration from these findings, the Karunatree system is organized around two distinct components:

1) An interactive lesson plan or activity that introduces children to the structure of a distributed causal network in the environment, and establishes anchoring reference points for grounded generalization. In order to maximize the flexibility of the system, this introductory component is not actually built into Karunatree's web application itself. Instead, individual educators or ISE professionals can use their own lessons and activities as the launching pad for introducing children to Karunatree. As an illustrative example, we will briefly describe a lesson plan that we

developed to help middle schoolers learn about the environmental effects of palm oil production in Sumatra.

2) Once children have begun to explore the structure of a particular causal network, Karunatree's Google Earth-based web application allows them to integrate their new environmental knowledge and begin translating it into meaningful action. As we will see, Karunatree uses multimedia art projects and the intuitive metaphor of seed planting as a novel mechanism for encouraging meaningful knowledge integration.

In the next section we will examine each of these components in greater detail.

## SYSTEM OVERVIEW

### Introducing a Causal Network

Karunatree is designed to begin with educator supplied lessons or activities that introduce children to the structure of particular environmental causal networks. While the format and content of these lessons is not our principle focus in this paper, we will briefly describe a series of classroom activities that we designed to introduce middle-school-aged children to the rainforests of Sumatra: one of the richest and most unique ecosystems on Earth.

Sumatran rainforests currently exist under the shadow of serious threats from international industries such as the palm oil trade. Palm oil is a ubiquitous ingredient in foods, personal care products, and cosmetics that we use everyday. Palm oil itself is not intrinsically bad or harmful, and actually has the potential to be a highly sustainable crop. In Sumatra, however, the problem is that palm oil is derived from sprawling oil palm plantations that are systematically supplanting native rainforests. The plantations have a devastating effect on biodiversity and habitat density (Fitzherbert et al., 2008), and are linked to a dense array of second-order harms like greenhouse gas emission and chronic lung disease in native populations (Uryu et al., 2008). The pedagogical goal of our test bed "mini-curriculum" was both to familiarize children with these primary environmental challenges, and (importantly) to help them conceptualize them as a causal network.

In approaching this task we wanted to begin with a piece of the Sumatran causal network that children could relate to emotionally. Thus, our lessons initially focused on the effect that clearing forestland for palm oil production has on native wildlife. Through classroom discussions and an interactive board game, we encouraged children to consider the plight of endangered species such as Sumatran Tigers and Elephants, and to extrapolate the effects that shrinking habitat areas would have on their survival. From this "zoomed in" perspective the clearing of the forest was portrayed as a cause (a first node in the ecosystem's causal network), one whose effect is the loss of habitat and suffering in the forest's former inhabitants (Fig. 1a)

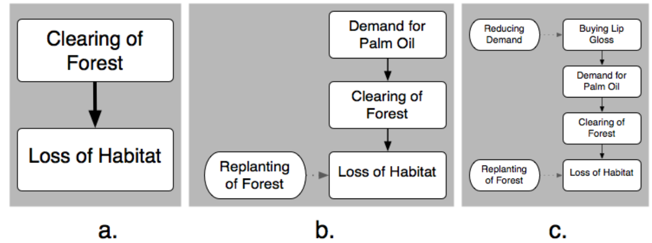


**Figure 1: (a.) shows the simplest, most "zoomed-in" version of the causal network: a simple cause-and-effect relationship. (b.) shows additional complexity, including a possible intervention (Replanting of Forest). (c) is more complex still, with a second intervention (Reducing Demand) "upstream" in the chain of causality.**

But what force caused the forest to be cleared in the first place? Subsequent lessons helped children to literally "take a step back" by revealing more context. Children were gradually introduced to the idea that the clear cutting of the rainforest was not *only* a cause but *also* an effect: an outcome of overseas demand for palm oil (Fig. 1b). Incorporating this new information into their understanding, the children began to be able to integrate knowledge across causal perspectives. They began to see that many events, like the clearing of the forest, are intermediate points in distributed webs of causation. This understanding, in turn, began to refine children's sense of where effective interventions might be staged. They began to understand, for example, that it would not be enough to simply replant the forest, undoing the most obvious, proximal cause of the animal's suffering (Fig. 1b); instead effective intervention would need to occur "upstream", addressing higher order levels of causation (Fig. 1c).

Our lessons eventually culminated with another "human-scale" perspective that children could easily relate to: namely the perspective from the local shopping mall, where cosmetics containing rainforest palm oil are sold. Thus, over the course of our seven-hour curriculum, children were introduced to all the components of a distributed causal network that links the seemingly harmless consumer activity of buying palm-oil-containing lip gloss to an unfolding environmental crisis half-a-world away.

This brief account has obviously glossed over many classroom details, so let's quickly summarize the take-away point that is important for our purposes here: the Karunatree experience begins with introducing middle-school-aged children to an important environmental system (in this case the Sumatran rainforests), and encouraging them to conceptualize that system as a distributed causal network. By leaving this curriculum layer quite general, we believe that educators will be able to apply Karunatree's core web application to a wide variety of environmental learning topics.

### The Core Web Application

As children begin to think about the distributed causal networks that are operating in critical ecosystems such as

Sumatra, Karunatree's core web application offers them a novel means of integrating and reflecting on that knowledge. Our particular knowledge integration activity is driven by the simple physical metaphor of planting seeds. Specifically, Karunatree invites environmental learners to create "seedlings": creative, science-based media projects that seek to spread awareness about important environmental issues.


**Figure 2: The Karunatree web application's homepage, showing a manipulable 3D globe with the location of previously planted seedlings indicated by green leaf icons.**


**Fig. 3: A seedling detail page.**

*Seedling Creation (Offline Component)*

Children create seedlings through the following (offline) process. Having understood a problem such as non-sustainable palm oil cultivation, children first form a hypothesis about how that problem might be addressed. For example, after our Sumatra mini-curriculum, a child might decide that reducing demand for cosmetics products containing rainforest palm oil would be an effective starting point for reducing habitat destruction in that region. In essence, the first step in the seedling process asks children to identify the most promising point of intervention within an ecosystem's causal network and to formulate a specific plan for influencing it.

Once a potential intervention has been formulated, the child creates the seedling itself: a science-based media project (e.g., photograph, drawing, video, audio recording, or other multimedia product) designed to achieve the intervention's effect by educating a logically appropriate audience. Continuing our Sumatra example, an effective seedling might be a collage depicting the connection between cosmetics like lip-gloss and rainforest depletion. Presenting this seedling to an audience of adult cosmetics consumers could be a useful way of raising awareness and beginning to motivate meaningful change. Children engage with the issue of audience selection by choosing a real-world location in which to "plant" (i.e. geolocate) their completed seedling.

The fact that all of the above steps can be accomplished offline is intentional, as it helps to make Karunatree's core learning activity accessible even in classrooms and environments without immediate internet access (e.g., at our pilot location, described in the next section). Once seedlings are created, however, their full value is realized by uploading them to Karunatree's online web application.

*Seedling Curation and Distribution (Online Component)*

Accessible from any modern web browser, Karunatree's online component is based on a freely explorable 3D model of the Earth built using the Google Earth API. Figure 2 shows the web app's homepage with its prominent 3D globe; the locations of previously planted seedlings are indicated by the green leaf icons dotted across the virtual terrain.

Using the standard Google Earth controls (e.g., pan, zoom, tilt; visible to the right of the globe) users can explore the globe to find seedlings that are relevant to their geographic region. A dropdown search box on the right ("Search for Seedlings" also allows users to search for seedlings related to specific issues using keywords (e.g. "elephants").

Clicking a seedling on the globe interface opens that seedling's details page, of which Fig. 3 provides an example. Most prominently, the details page includes a large image of the seedling project itself, in this case a collage depicting tubes of lipstick raining from a canopy of oil palm trees. Immediately below the project is the work's title, along with a listing of the artists (children) that created it.[1]

Note that we use the "artist" appellation throughout the system as a way of empowering children to take themselves

[1] To protect children's privacy, Karunatree never displays the full names or contact details of users; system usernames (first name plus last initial) are displayed only for children who returned signed parental consent forms.

and their creations seriously. Relatedly, clicking on any artist's name opens a user page where all of that child's seedlings are catalogued. By giving children their own distinct online portfolios in this way, we hoped to convey the sentiment that seedlings were more than just short-term "assignments." Rather, we hoped that children would treat their seedlings as meaningful pieces of public work, curating their seedling portfolios much as professional photographers carefully manage their Flickr photostreams.

Returning to Fig. 3, immediately below the title and artists listing is the Artist's Statement area. Serving the same function as placards in a museum, the Artist's Statement area allows children to upload text or auditory commentary to accompany and explain their work. Creating these Artist's Statements is an important knowledge integration activity for children, and it also helps adults to properly interpret projects in cases where the child's artistic skills lean towards the abstract. Adults and children can also respond to Artist's Statements, leaving comments to encourage the creator in their efforts and (ideally) to indicate something that they learned from viewing the seedling. This feedback mechanism is an important element of our design, as it again reinforces the message that seedlings are not classroom assignments, disconnected from social context. Seedlings are meant to be public educational artifacts, and the responses area allows children to experience the satisfaction of helping others to learn more about the environment. The multi-modal nature of seedlings and Artist's Statements also encourages children to work across media to present their message, an important 21st century media literacy skill (Partnership for 21st Century Skills, 2004).

Finally, each seedling details page also includes a palette of various social functions (the gray buttons to the right of the project view). Pageviews and "boosts" (e.g. likes) are tracked as another way of helping children to gather positive feedback on their work. A tweet function also helps make it easy for others to distribute the address of seedlings that they particularly enjoy. A planned transplant function will eventually allow registered users to "plant clippings" or copy favorite seedlings to other relevant locations.

## EVALUATING KARUNATREE

Having described Karunatree's conceptual underpinnings and system design, we can now turn to questions of evaluation. Our evaluation was conducted in partnership with Girls, Inc. of Orange County (GIOC): an educational non-profit dedicated to educating and empowering girls from traditionally disadvantaged backgrounds. In the summer of 2010, Karunatree was used as the science education component of GIOC's Eureka! summer day camp in Costa Mesa, CA. Over the course of the four-week camp program, Eureka! participants learned about the Sumatran rainforests, created Karuna seedlings to reflect on their new knowledge, and completed program evaluation surveys.

### Materials & Methods

#### *Participants*

Participants in our evaluation were 69 girls enrolled in the Eureka! summer day camp, ranging in age from 11- to 15-years-old (mean age: 12 years, 10 mos; standard deviation: 11 mos). The majority of the girls were Hispanic (68%) and were entering either the 8th (29%) or 9th (35%) grade in the fall.

#### *Program*

Our evaluation period consisted of seven 60-minute sessions distributed across the four weeks of the camp. During sessions 1, 2, 4, and 6, participants completed the mini-curriculum on the Sumatran rainforests described in the previous section. In sessions 3, 5, and 7, the girls created seedling projects to help convey what they were learning to others. The girls were responsible for crafting their seedlings, writing or recording accompanying artists' statements, and for selecting appropriate "planting" locations using the web application's globe interface. Due to time constraints and limited onsite network access, the investigators performed the job of actually photographing and uploading the projects to the Karunatree web server.

#### *Measurement Tool*

A pre-survey was administered to the girls before the beginning of our first program session, and a post-survey was administered at the conclusion of the last session. The pre-survey consisted of 28 Likert-type statements with a five-point scale for agreement/disagreement (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree), several questions about computer use habits, and a demographic inventory. The post-survey included the original 28 Likert statements, as well as a new section containing Likert-type questions about the experience of the workshop and several short answer questions.

### Seedling Content Analysis

Before evaluating the quantitative data generated by our pre- and post-measures, let's first consider the seedling projects that participants created. Here we provide a brief content analysis of three of the approximately fifty seedlings crafted during the Eureka! program, an exercise we hope will provide some useful insights into the strengths and weaknesses of Karunatree's educational approach.

#### *"The Real Palm Oil"*

Figure 3 presents a first example seedling titled "The Real Palm Oil." The seedling, which can be viewed online at <link omitted for blind review>, was described as follows in the audio Artists' Statement recorded by its three creators:

"This seedling has palm trees dripping with lip stick, in which palm oil is a main component. We made this artwork because we wanted make-up buyers to become more aware that palm oil is in most cosmetics. Palm oil is not harmful, but if grown in an unsustained [*sic*] way it can hurt the entire ecosystem. So, to all make-up buyers and department store frequents [*sic*]: take responsibility for your purchases; take a look at the big picture."

The seedling's creators chose to "plant" it at the location of a local Sephora Cosmetics store in Orange County, reasoning that this would be a logical place to reach adults in a good position to act on this knowledge.

The content of this seedling suggests that the children involved have learned important lessons about rainforest conservation in Sumatra. Perhaps more importantly, their planting of the seedling at a nearby consumer outlet that is plausibly linked to the problem represents a high-level understanding of the relevant causal network.

### *"The Sumatran Jungle"*

The artists who created the seedling shown in Figure 4, "The Sumatran Jungle," took a 3D approach to the creation of their work. On the left side is a representation of rainforest land, with trees and elephants, and on the right is plantation land with a farmer and his rows of crops.

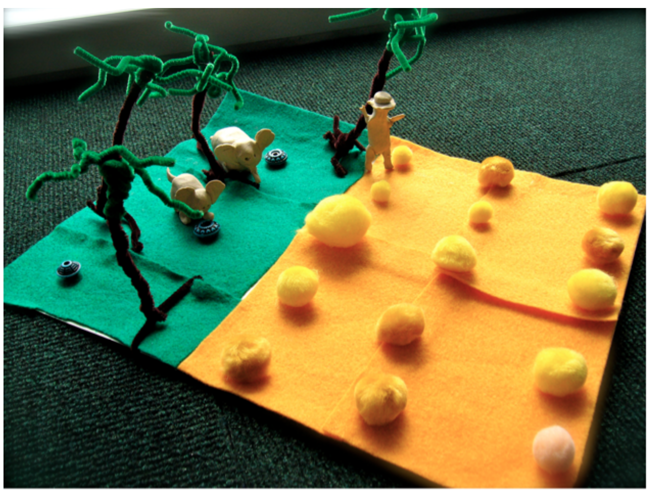

**Figure 4: This seedling, titled "The Sumatran Jungle," addresses the tension between human activities and those of other species such as elephants.**

The Artists' Statement for this seedling was as follows:

"Our jungle is half-and-half with forest land and plantation land. We made this art work because we want everyone to know that the land should be equal for the farmers and the forest animals."

This seedling raises a number of interesting issues regarding the creation of media interventions. The display of low-tech media (felt, clay, and pipe cleaners) via a high-tech delivery mechanism helps to personalize the environmental issues at hand. Many web sites that seek to persuade people to engage in environmentally sound behavior run the risk of blending in to the vast scope of the internet; by enabling viewers of the seedling media to feel a personal connection to the child artists, Karunatree may help encourage greater impact than would be achievable with more "sterile" content.

The idea that land should be "half-and-half" between farmers and forest points to a valuable premise—that there must be sharing between human and non-human species—but demonstrates the weakness of shallow engagement with these ideas. Half-and-half is an arbitrary allocation, and lacks an awareness of the subtleties of many environmental issues. More subtly, the seedling media itself appears to show more of a two-to-one split, with the forest getting the smaller part of the bargain. While the core idea of sharing is sound, this seedling points to the need for greater engagement with the particulars of various environmental issues, especially when seedlings may be so precisely targeted at certain audiences.

### *"Colorful Elephant"*

Finally, a seedling aptly titled "Colorful Elephant" illustrates an interesting failure mode for the seedling creation activity. While the artists have succeeded in making a work that is visually striking and quite beautiful, the lack of meaningful content or actionable suggestions renders the seedling less effective.

**Figure 5: A beautiful but low-content seedling.**

The seedling's Artists' Statement, "Don't let beautiful elephants go extinct!," provides little for viewers to go on for changing their behavior or perspective. The ability to target specific audiences leads to the need for seedlings to be rich in content that pertains to the particular contexts that caused those audiences to be selected.

The full library of pilot seedlings can be browsed at <link omitted for blind review> (the free Google Earth browser plug-in is required). While the projects themselves span a wide range of artistic abilities, the underlying theme is generally one of increased understanding of and identification with the problems occurring in Sumatra's rainforests. Further, we found that the children generally found the process of creating the seedlings to be very enjoyable, and were willing to expend considerable effort planning and executing their creations. As one participant put it, she liked how the process of creating seedlings "let us be in charge and show [adults] what we think about Sumatra."

### Quantitative Results

To understand the girls' experiences more fully, we conducted a quantitative analysis of our pre- and post-workshop participant surveys.

#### *Analysis*

Factor analysis was used to combine 20 of the 28 Likert scale questions included on both the pre- and post-survey into five constructs: learning attitude, teaching confidence, self-efficacy, identity, and attitude toward group work. A score for each construct was then calculated for each survey by averaging the scores of the questions that loaded onto that construct. The remaining 8 Likert scale questions on both the pre- and post-surveys (pertaining to content knowledge) were analyzed individually, as were the Likert items regarding the workshop experience that were included only on the post-survey. Sign tests were used to evaluate changes between the pre- and post-surveys.

#### *Results*

The surveys indicated that the girls generally enjoyed the workshop, with 73% of participants agreeing with the statement "This workshop was fun" (compared to 3% disagreement). An even greater percentage of girls (85%) agreed that they had learned something over the course of the four-week program. Additionally, 71% agreed that the workshop made them more interested in the environment, and 64% agreed that this workshop made them more interested in helping others learn about the environment. Finally, 60% would recommend this workshop to friends. When asked to choose what they considered to be the best thing about the workshop, roughly half of the girls chose creating the seedlings while half chose the interactive board game that was used in several instructional sessions to help portray the Sumatran causal network.

Unfortunately, a comparison of the pre- and post-survey data indicates that, while the girls tended to enjoy their experience, their attitude toward and knowledge about environmental science did not positively change as a result of participating. Of the five constructs measured, only teaching confidence showed a statistically significant positive shift. Similarly, of the eight content knowledge statements measured on the survey, only one ("Whenever we buy things, we are influencing the environment" *(True)*) showed a significant positive change. More troublingly, we found statistically significant *negative* changes in three of the other content statements: (a) "Ecosystems consist of plants and animals. Humans aren't part of ecosystems" *(False)*, b) "Sometimes one cause can have many effects" *(True)*, and c) "An effect always has exactly one cause" *(False)*. Children actually performed significantly *worse* on these items after the workshop than they did at its outset.

## DISCUSSION

Karunatree attempted to address a difficult but pressingly important problem: how can we prepare the next generation with the knowledge and cognitive skill set that will be needed to achieve greater environmental sustainability? In a manner that is perhaps consistent with the scale of the challenge, the efforts reported here represent imperfect progress.

To begin with the positive: our quantitative and qualitative results both suggest that Karunatree's seedling metaphor and its Google Earth-based web application are an effective way of kindling and supporting children's interest in the environment. Over the course of the four-week program, the majority of participants reported that they had grown more interested in environmental issues like rainforest conservation, as well as in helping others to better understand them. The majority of children also believed (at least subjectively) that they had come away from the workshop with more environmental knowledge than they started with.

Unfortunately, while our system performed well in terms of establishing interest, it was markedly unsuccessful in terms of promoting children's measurable knowledge, either of causal networks in general or the environment in particular. Indeed, rather dishearteningly, we actually observed significant declines on 3 out of 8 knowledge measures. What is striking about these declines is that the measured content items did not pertain to highly specific or involved concepts. Rather, as the items referenced in the prior section make clear, we measured declines even for very general factual statements of the sort that are foundational to understanding causal networks (e.g. "An effect always has exactly one cause" *(False)*, "Sometimes one cause can have many different effects" *(True)*). Ultimately then, as a mechanism for conveying content knowledge, the current system must be judged unsuccessful.

Why did Karunatree fail? We believe that one important culprit was attempting to accomplish too many educational objectives in too narrow a window of time. In retrospect, it is clear that the seven hours allotted for our workshop at GIOC were insufficient to both *a)* introduce children to the basic behaviors of causal networks, and *b)* to have them map those concepts onto a complex natural system. While our approach was solidly justified by educational research (e.g. grounded generalization, Goldstone & Wilensky, 2008), our findings seem to argue that separating the network from its concrete manifestation—at least in the short timeframe we had to work within—might have been a better approach. In future iterations of this project we will seek to embed the Karunatree experience in a context with broader scope than a 7-hour program, so that we may help students to develop a more detailed understanding of the causal phenomena at work A longer program will also give us time to help to foster the spread of seedlings and to study the characteristics of their dispersal.

Another weak link in our design was the fact that we were not able to pre-pilot or refine our Sumatra mini-curriculum before deploying it at GIOC. While some of our activities worked very well (i.e. the interactive boardgame) others, most notably classroom-based activities involving short lecture-format presentations, were unpopular with students. Further tuning of the curriculum layer would clearly be helpful in the future.

## CONCLUSIONS

The Karunatree project encountered mixed success, fostering positive interest and engagement from the students involved but failing to promote significant learning on an array of content measures. Nevertheless, both the successes and failures of this project may provide guidance for future efforts of this kind. We hope that other researchers will build on this example and join the effort to help people learn about complex causal systems, and to use ICTs to do so when it is appropriate.

While Karunatree was not as successful as we might have hoped, we remain convinced that the project's core goal — helping children to master effective systems thinking—is critical to the long-term success of our species and the ecosystems in which we live. We envision a world in which people, governments, and institutions will think broadly about their place in the world, and the way in which their actions will influence the future. To enable whole populations to learn about causal network dynamics and the issues they inform, we must develop new paradigms for exploring these topics. We hope that Karunatree's successes and failures will help to provide useful insights on how to make progress in this critical domain.

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