Testing a Curriculum Designed to Build Students' Understanding of Action at an Attentional Distance

Maleka Donaldson Gramling, S. Lynneth Solis, Katarzyna M. Derbiszewska, Daniel Oh, M. Shane Tutwiler, and Tina Grotzer
Harvard University

SUBJECT/ PROBLEM: The newly adopted Next Generation Science Standards (Achieve, 2013) include Cause and Effect as one of "seven cross-cutting concepts that are meant to give students an organizational structure to understand the world" (p. 1). The Cause and Effect standards aim to connect core ideas across disciplines and grade bands, including "communicating and discussing solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment" (grades K-2), honing the ability to "routinely identify and test cause and effect relationships and use them to explain change" (grades 3-5), and helping students understand that "cause and effect relationships may be used to predict phenomena in natural and designed systems" (grades 6-8). In order to thoroughly address these standards, it will be very important for science educators to teach students the concept of action at a distance—that causes and effects can be separated in space and time such that it can be difficult to see the connection between them. In certain instances, causes and effects can be separated both in physical and attentional space—a concept referred to as "action at an attentional distance" (Grotzer & Solis, forthcoming; Solis, Derbiszewska, & Grotzer, 2014). Causal knowledge is typically developed from discerning co-variation relationships, knowledge of causal mechanisms, or testimony from others (Grotzer & Tutwiler, 2014) (which can come in the form of instruction). The concept of action at an attentional distance, however, refers to special cases where causes and effects are in different attentional frames, which makes the detection of the causal connection through co-variation difficult (Grotzer & Solis, forthcoming). Students typically struggle to grasp action-at-an-attentional distance phenomena, presenting a design challenge for science educators who desire to develop curricula that support the recognition of causes and effects that are separated by physical and temporal distances. In the present study, we developed and tested a curricular intervention designed to help students understand and attend to action at an attentional distance by leveraging students' prior knowledge and real life experiences.

Spatial discontinuity between causes and effects is a feature of many scientific concepts (Grotzer, 2012). This is particularly common amongst those situated in the environmental and ecological sciences, from issues concerning the protection of watersheds to impacts on species such as polar bears in the Arctic. Despite the prevalence and importance of understanding action at a distance in science, developmental research has demonstrated that it is a difficult concept to grasp (e.g., Sobel & Buchanan, 2009; Spelke, Phillips, & Woodward, 1995). Similar findings are emerging regarding students' ability to reason about action at an attentional distance. When learners reason about causal phenomena, it often seems most intuitive and efficient for them to look for local causes to explain events in science. As a result, students tend to pay the most attention to causes that are closest to an observed effect. Grotzer and Solis (forthcoming) conducted a microgenetic study with students (n = 10) in second, fourth, and sixth grades in an ethnically and economically diverse school. Students in all three grades tended to give local explanations to scenarios presented that placed the cause and effect in the same attentional space

and, commonly, in direct contact. This pattern of responses existed across both environmental and social domains and when reasoning from effect to cause or cause to effect. Further evidence of students' difficulty in interpreting action at an attentional distance can be found in the science education literature. This work suggests that students find it difficult to learn scientific phenomena that involve spatial and/or attentional gaps (Grotzer, Kamarainen, Tutwiler, Metcalf, & Dede, 2013; Driver, Leach, Scott & Wood-Robinson, 1994). For instance, students may experience difficulty dispelling the idea that plants get nutrition directly from the soil rather than the more complex process of photosynthesis (e.g., Barker & Carr, 1989). Bar, Zinn and Rubin (1997) found that students looked for a medium, such as air, to support and connect forces acting from afar, as in the case of gravity, but that after a pedagogical intervention, they could revise their existing model to allow for action at a distance to occur without the need of supporting forces.

Intervention studies like the one conducted by Bar, Zinn, and Rubin (1997) have also shown that instruction can help students to reason about causes and effects separated in space. The microgenetic study discussed above, for example, provided insights into students' ability to reason about action at an attentional distance in certain cases (Grotzer & Solis, forthcoming). Students demonstrated the ability to formulate distant responses, especially when aided by their prior knowledge and experience, familiarity with the context, and construction of narratives and analogies. For example, when presented with a scenario where trees within a two-mile radius in a forest had died, students referred to their knowledge of global warming and acid rain (two examples of action at an attentional distance) to come up with potential explanations for what had caused the trees to die. The more knowledge and experiences students had to draw from, the more prone they were to think of potential causes and effects beyond the immediate attentional space, especially in contexts that were familiar, such as technology, social interactions, and scientific concepts learned in school. While prior knowledge was generally important, prior knowledge of mechanisms was especially powerful in moving students from local to distant explanations.

Helping students realize that causality can act at a distance and that it can be especially difficult to perceive when causes and effects are set in different attentional frames may help them to understand why it is hard to notice, maintain a focus on, and address certain environmental issues. It may also help students to recognize that causal relationships can be more complex than they realize. With these challenges in mind and given that students have shown the ability to reason about action at an attentional distance in certain circumstances, we set out to design and test a curricular intervention to help students understand and attend to this complex causal pattern. The goal of the intervention was to increase students' sensitivity to the spatial gaps that may influence complex causal events in ecosystems science. During the lessons, students engaged in activities that directed their attention to the role of distal causes and effects in a variety of real-world, science phenomena. Also, through the use of case studies and student-generated examples, the curriculum built on students' existing knowledge and reasoning to deepen understanding of spatial discontinuity in causal events.

The curriculum for teaching middle school students to reason about action at an attentional distance was developed and pilot-tested in Spring of 2013 (Grotzer, Derbiszewska, Donaldson Gramling, & Solis, 2013). A quasi-experimental design study was carried out with a diverse

population of low SES sixth-graders (n = 46). Students participated in the curricular intervention and took pre- and post-assessments. The results (Donaldson Gramling, Solis, Derbiszewska, & Grotzer, 2014)[1] underscored the importance of the endeavor revealing that 75% of the students' responses on the pretest were spatially local and any pre- to post-test differences were subtle (with 63% of the post-test responses focused locally). This pilot resulted in changes to the curriculum including more opportunities 1) to explicitly discuss what made the causal patterns difficult to discern and attend to and 2) to apply it to diverse cases to encourage transfer. The curriculum was then tested in a larger study of 6th graders during the 2013-2014 school year, and the results from this second study are reported here. Results showed that while students' perceived importance of local causes remained high and stable from pre-test to post-test, the ratings of importance for distal causes were notably higher on the post-test.

DESIGN/PROCEDURE: Participants included 14 sixth grade classes (n = 325 students) of seven teachers in public and private schools. In order to maximize our ability to generalize the findings, the classes included a diverse range of SES levels and school settings (Table 1). The sample included low SES urban students, high SES urban students, as well as rural students in a mixed SES school. Sessions were videotaped and audiotaped.

Table 1. *Teacher and student level demographic characteristics of study sample (n=325 students with seven teachers)*

Teacher-level characteristics	N	%
School setting		
Urban	2	29%
Suburban	5	61%
School type		
Public	2	29%
Private	5	61%
Student-level characteristics	**N**	**%**
Gender		
Male	172	53%
Female	153	47%
Free/Reduced Price Lunch eligible?		
Yes	40	12%
No	285	88%

Intervention: The Causal Learning in the Classroom (CLiC) curricular intervention included a module comprised of four lessons designed to help increase student awareness and understanding of the influence of distance between causes and effects (Figure 1).

[1] Presented at 2014 NARST Annual International Conference.

Figure 1. *Sample Pages from CLiC Curriculum, Module 1*

These carefully developed activities were designed based on prior work concerning how students reason about action at an attentional distance (Grotzer & Solis, forthcoming; Solis, Derbiszewska, & Grotzer, 2014). The lessons introduced students to the idea in a number of ways that made the concept more salient and helped them connect it to observations in their communities and daily lives (see Appendix A). Lesson activities included:

- prompts from the teacher to access prior knowledge and experiences relevant to the topic
- brainstorming and discussing examples from everyday life and current events in which causes and effects do not touch
- exploring case studies concerning the geographic reach of recent natural disasters like floods, tsunamis, and earthquakes
- examining primary source materials about a local watershed land dispute

Students were asked to interact with the curriculum primarily through whole-class, small group, and partner discussions. Looking across many different scenarios and examples, students were prompted to explicitly consider and share their thoughts related to the working of action at a distance—specifically, why it is hard to realize that a causal relationship exists when causes and effects are separated in space and why we should be alert to such possibilities. For example, in the final lesson, students were asked to apply learnings from prior experiences to develop strategies to address environmental issues related to climate change. Students considered advertising and legislation that connects our individual actions to the fate of the polar bear habitat and developed ways to remind others in their community about their role in distal effects. The curriculum leveraged students' ability to reason about causal mechanisms when they are made obvious to them. These activities highlighted the connections between the text-based presentations of how ecosystems work, and real-life happenings that students may observe in the news or in their own community.

Pre and Post Assessments: In order to assess students' levels of action at an attentional distance reasoning, students were given the Action at a Distance and Change over Time (ADCT) Inventory. This written assessment was developed in order to measure the extent to which

students' believe distal causes (both spatial and temporal) are important when trying to explain proximal ecological effects (Grotzer, Derbiszewska, Donaldson Gramling, Solis, Thompson, Tutwiler, 2014). On the ADCT Inventory, students were presented with three different scenarios from nature (bees dying, declining health of trees, fish dying in a pond). For each scenario, students were first presented with a simple description of the widespread, ecological pattern. Then, in an open ended format, they were prompted to provide likely explanations for the event. And finally, students were asked to use a four-point, Likert-style scale to rate the importance (response anchors: not important, a little important, pretty important, or very important) of examining evidence at various spatial or temporal distances from the effect. For example, to help explain why evergreen trees in an area might be getting weaker, students were asked how important it was to study the area within a few hundred feet of the trees or study the entire region within hundreds of miles of the trees. Similar questions were asked for each of the three scenarios. The assessment was administered just before the start of the curricular intervention and repeated in the day(s) immediately following the fourth lesson. Responses to the Likert-type items related to spatial distances are the focus of the present analysis.

FINDINGS AND ANALYSIS: The analysis of students' responses on the perceived importance of attending to action at an attentional distance when addressing ecological puzzles shows promising results.

To examine potential changes in students' ratings of importance of looking for action at an attentional distance, we created two composite scores for the Likert-scale responses. The first one, *LOCAL*, is the sum of scores on six individual items, two from each of the 3 scenarios, that inquired about students' perceived importance of local causes (e.g., direct contact such as the area touching the trees; or in the vicinity such as within a few hundred feet of the trees). The other composite, *DISTAL*, was a similar six-item composite of questions that inquired about students' perceived importance of distal causes (e.g., midrange distal such as within a few miles of the trees; or far-range distal such as hundreds of miles from the trees). The score on each individual item ranged from between one to four, with a maximum possible overall score of 24 for each composite. Both the *LOCAL* and *DISTAL* composites were normally distributed and had good inter-item reliability (Figure 2)

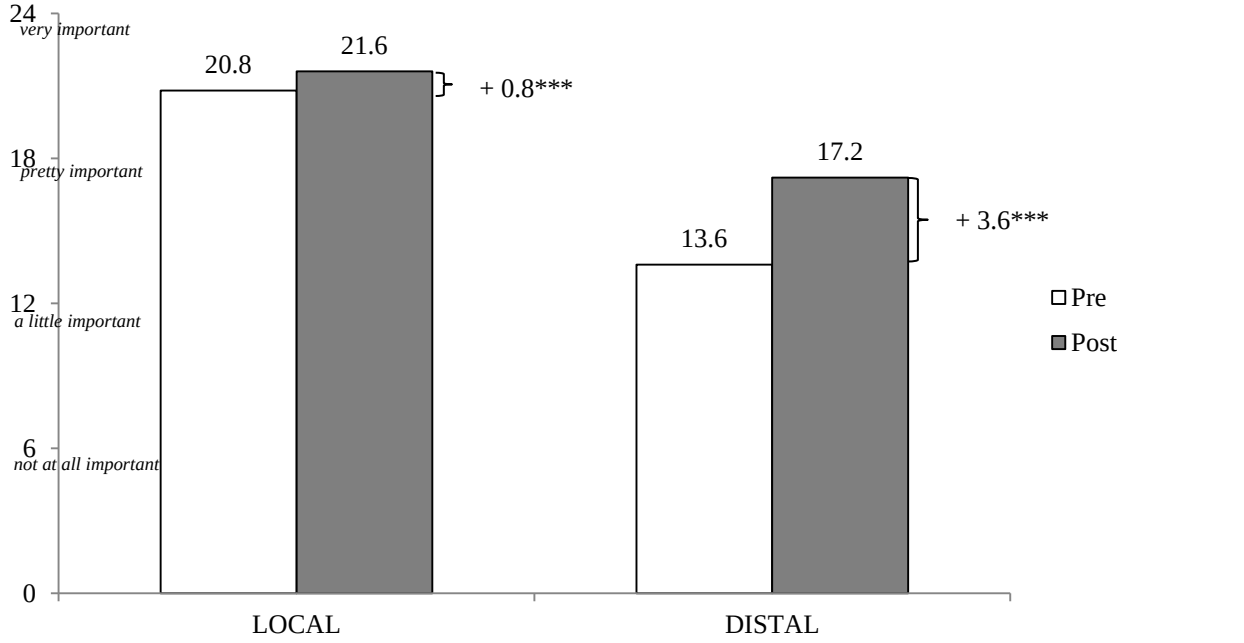
Figure 2. Inter-item reliability (Cronbach's alpha) for *LOCAL* and *DISTAL* composite scores, pre-test and post-test (n=325)

	Pre-assessment	Post-assessment
LOCAL	0.6890	0.8261
DISTAL	0.7202	0.9033

Examination of mean pre- and post-assessment composite scores (Figure 3) revealed that the *LOCAL* importance ratings showed a small 4% change after the intervention (X_{PRE} = 20.8, X_{POST} = 21.6, difference of +0.8 points). The mean pre- and post- scores both correspond with the "pretty important" to "very important" range of scores. There were more substantial changes on the *DISTAL* measure. As compared to *LOCAL*, the mean DISTAL composite score was lower on the pre-test (X_{PRE} = 13.6). When compared to the *DISTAL* pre-test, on average, students had 27% higher *DISTAL* post-test scores (X_{POST} = 17.2, difference of +3.6 points), reflective of higher

ratings of perceived importance after the intervention. This change in mean score corresponds with a shift in *DISTAL* ratings from just above the "a little important" range toward the lower bound of the "pretty important" range.

Figure 3. Pre- and post-test mean scores for *LOCAL* and *DISTAL* student ratings of importance.



*p<0.001****

Clustering of students by pre-existing groups violates core assumptions of the t-test of mean differences, and may lead to biased findings if detectable intra-class correlations are present. Employing techniques suggested by Tutwiler & Chen (in preparation), we developed a gain score by subtracting the pre from the post scores, then used an unconditional means multi-level model (a model with no predictors at level one or level two) to test the hypothesis that the population average gain score across students and teachers was zero. We found that the small, average *LOCAL* gain score and the comparatively larger, average *DISTAL* gain score were both statistically significant ($p<0.001$), and therefore rejected the null hypothesis that their true value was zero.

Not surprisingly, the rated importance of investigating potential causes in the local area in direct physical contact and immediately near to the observed effect was high on the pretest and remained so post-intervention. Although the CLiC intervention was designed to expand students' attention beyond the local area, it did not diminish students' perceived importance of proximal causes. In fact, perhaps due to the frequent discussion of causes and effects in nature, it seems to have even enhanced the perceived importance of local causes to a small degree. However, we also found that, on average, ratings of the importance of investigating distant causes were at a substantially higher level after the CLiC intervention. This evidence suggests that providing students with direct instruction about cause and effect at a distance and offering opportunities for discussion, as was done in the CLiC lessons, can help students to more readily consider the importance of evidence located at an attentional distance from an ecological effect.

These findings are promising in terms of how students' thinking about the importance of action at an attentional distance shifted after the intervention. We expect to conduct qualitative analyses of open-ended questions along with more complex modeling of the data set and exploration of other variables such as fidelity of implementation in order to better understand the outcomes.

DISCUSSION: The findings of this study have important implications for the learning and teaching of complex causal mechanisms in ecosystems science. We observed that, on average, after the CLiC curricular intervention, students rated potential causes situated in spatially distant spaces outside of the attentional frame of the effect as being of greater importance as compared to their pre-test scores. We suspect that these gains are a result of the close examination of the workings of action at an attentional distance in the provided case studies from the CLiC curriculum, as well as the encouragement to generate and analyze examples from their own lives. Taking a close look at these cases and discussing at length may help students to realize the immense influence that far away effects can have, while also illustrating how difficult it can be to simultaneously attend to distal causes and local effects.

The ability to understand and attend to causes and effects separated by spatial and attentional distances equips students to glean complex causal phenomena in the world and participate as active agents to ensure more conscious communities and a healthier planet. The CLiC lessons offer a tool for educators to help students build critical thinking and complex causal reasoning skills and for students to become aware of the challenges of attending to distant, yet important, causes that influence their local environment. It also highlights the influence their local behaviors and choices may have on distant neighbors. This research also relates to the cause and effect aspects of the Next Generation Science Standards. Being able to understand action at an attentional distance is critical for making scientifically and morally informed choices on our small planet. Our findings inform the design of science classroom experiences that support students in becoming part of a scientifically literate population.

While the trends in our data are encouraging, there are some limitations to the study, particularly concerning implementation of the curriculum by educators, which can be affected by a host of factors including teaching approaches, student academic readiness, and classroom norms during group discussions. Analysis of classroom video data is the focus of a separate fidelity study examining the question-asking and discussion during classroom discourse, a key feature of the CLiC lessons (Donaldson Gramling, Derbiszewska & Grotzer, 2015). In that study, we hope to get a detailed view of how teachers use CLiC. This can allow us to explore what, if any, additional supports we might offer educators to help them better leverage the benefits of the CLiC intervention.

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APPENDIX A

Summary of Module 1 Activities
Reprinted from Donaldson Gramling, Solis, Derbiszewska, & Grotzer, 2014

Module 1: Becoming Global Thinkers: Thinking about Distant Causes and Effects

Lesson	Title	Main activities
1	Action at a Distance: Thinking Across Spatial Gaps in Science	Brainstorm and share causes and effects in everyday life. Students bring initial thoughts, and teacher draws special attention to non-touching causes and effects. Reflecting on familiar, student generated causal patterns helps students develop a more refined definition of cause and effect.
2	Figuring Out the Connection Between Distant Causes and Effects	In a whole group discussion, students think through the distant effects of real-world events involving action at a distance. By comparing the 2011 flooding of New Orleans and the 2011 earthquake/tsunami in Japan, students gain a deeper understanding of the way causes can have distal impacts.
3	Applications: A Watershed Case Study in Cambridge, MA	In small groups, students relate ideas about distant causes and effects while considering the city's purchase of watershed land from a neighboring town. Students examine primary documents from the actual case and develop arguments for or against the city's decision based on their understanding of distant causes and effects.
4	Applications: How Can What I am Doing Here Hurt the Polar Bears?	Apply lessons learned from prior experiences to thinking about environmental issues related to climate change. Students consider advertising and legislation that connects our individual actions to the fate of the polar bear habitat. They may also develop ways to remind others in their community about their role in distal effects.