Game Design to Learn about Climate Change: Middle School Girls' Experiences with Systems Thinking

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Abstract:

Computing has been a foundational tool in the development of scientific understanding of current and future impacts of climate change, the most important socio-scientific issue facing society today (IPCC, 2013; Field et al., 2012). Science practices, such as modeling and abstraction, are critical to understanding complex systems dynamics integral to understanding climate science, and are critical components of science literacy, featuring prominently in the new Next Generation Science Standards (Achieve, 2013). Game design can be particularly effective in teaching about systems thinking (Salen, 2007; Liu & Hmelo-Silver, 2009; Puttick et al., 2014, GlassLab, 2014), since game design is a species of model building, one of the central scientific practices advocated by the NGSS (Achieve, 2013). However, much is still to be learned about game design as a way to engage young people in learning science or math, and, rarer still, in model building (e.g., Reppening et al., 2010; Tucker-Raymond et al., 2012).

Introduction

This study describes outcomes from a qualitative research study that was designed to explore the affordances of game design in Scratch, a free object-oriented programming environment, in supporting young people to learn about climate change. We report outcomes related to knowledge building about systems and climate change, self-efficacy, environmental values, and attitudes about climate change.

The NGSS identify anthropogenic climate change as essential to education, and explicitly address it at middle and high school levels (Achieve, 2013). In part because of the complexity of climate science, education about climate change is challenging. The cognitive and perceptual challenges to learning are well known (e.g., Hestness et al., 2013; Holthuis et al., 2011; Grotzer & Lincoln 2007; McCaffrey & Buhr 2008; Herbert, 2005). Understanding climate change requires an understanding of complex earth systems (Orion & Ault, 2007; Sell et al., 2006; McNeal et al., 2014). An extensive research literature shows that middle and high school students find climate change-related concepts such as the greenhouse effect, Earth's energy budget, system dynamics, and relationships within and across subsystems difficult to master (Daniel et al., 2004; Shepardson et al., 2009; Punter et al., 2011; Jakobsson et al., 2009; Assaraf & Orion, 2005; Penner, 2000). Furthermore, familiarity with key science practices like modeling (Pluta et al. 2011, Schwarz & White 2005), and the dialectic of scientific discovery (Kuhn & Reiser 2006, Kuhn 2005), are necessary elements of the scientific literacy needed to understand this complex topic.

Initiatives that use game design for young learners have steadily increased in the past decade with the advent of graphical programming environments such as Alice and Scratch, created to engage children in learning computer literacy. In particular, game creation as an introduction to programming and computational thinking has proved to be highly engaging at both middle and high school levels (e.g., Aydin, 2005; Reppening et al., 2008,2010; Lee et al., 2011; Werner et al., 2012). Resnick et al. (2009) and Denner et al. (2001) argue that learning computational thinking is more accessible to a wider range of audiences through game design learning environments.

The innovative learning experience we describe in this paper consisted of a 4-day summer workshop in which 6 middle school girls were tasked with designing a game to teach others about climate change. The experience was carefully constructed so that girls were able to engage in a make and inquire cycle of game design into a systems perspective on climate change.

Rationale for the workshop design

Given the demonstrated affordances of game design in supporting computational thinking, many aspects of which are akin to systems thinking, we were interested in the possible use of game design in Scratch to support the kinds of systems thinking necessary to understand climate change. Furthermore, building on a participatory pedagogy promised to create a powerful learning space for middle school students.

Students understanding of systems thinking

Systems thinking approaches are fundamental for addressing climate change. Sabelli (2006), Songer et al. (2009) and others have argued that understanding complex systems is a critical component of science literacy. Practices related to understanding complex systems, such as modeling and abstraction, are critical components of science literacy too, and feature prominently in new NGSS standards (Achieve, 2013).

Research reveals that middle school students can readily identify components of systems (e.g., Hmelo-Silver et al., 2000; Penner, 2000; Hmelo-Silver & Pfeffer, 2004). While researchers have found that the dynamics of systems—e.g., feedback loops—are harder concepts for both middle and high school students to access (e.g., Wilensky & Jacobson, 2014; Wilensky & Abrahamson, 2005; Assaraf et al., 2013; Goh et al., 2012), the work of Hmelo-Silver, Wilensky, Klopfer, Yoon and others shows that, "little of the conceptual power embodied in the rapidly developing perspectives and tools of complex systems has informed most people's educational experience" (Wilensky & Jacobson, 2014, p. 321). This is certainly true of education at the middle school level.

Furthermore, given the complexity of climate science, it is perhaps not surprising that education researchers and curriculum designers have historically adopted a "deficit" approach to student learning and understanding about the topic. However, we consider the problem of climate science education from the perspective of what assets middle school students bring to this area upon which they can build.

Participatory pedagogies as culturally relevant pedagogies

We recognize learning as a constructive and cultural process that a) draws on the values, practices, and histories of learners and their communities (Bell et al, 2009; Nasir et al., 2006) and b) emphasizes the intellectual resources of young people as knowledge producers (e.g., Tucker-Raymond et al., 2012). Children's identities, or how they and others conceive of them as certain kinds of people, may be more than ever tied to their experiences with a multidimensional media culture rather than ethnic, institutional, or geographic affiliations, although those dimensions of self and identity continue to be relevant (Dolby & Rizvi, 2007; McCarthy et al., 2003). Much of this participation and identity formation is part of what Jenkins (2008) and others call a "participatory culture" (Halverson, 2009; Kafai & Peppler, 2011; Tucker-Raymond et al., 2012).

Young people collaborate in many ways in creating educational games, drawing on multiple resources, including asking other students and teachers opinions, help in completing a procedure, including accurate scientific content, and using other students' games for inspiration and ideas (Baytak & Land, 2010). In short, a *participatory* approach to science education using game design allows young people to shape content and collaboratively solve problems (Jenkins, 2008). Participatory pedagogies are thus culturally relevant pedagogies that address students' identities based in their dynamic and multifaceted interactions with media culture, and help academically marginalized students succeed in more traditionally academic settings (Alvermann, 2001; Morrell, 2004; Halverson, 2008).

Learning from game design

Much attention has focused on what students learn about *programming* from game design in collaborative participatory learning environments (e.g. Adams & Webster 2012; Maloney et al. 2010, Monroy-Hernandez & Resnick 2008; Resnick et al. 2009). Much less prevalent are programs that teach *content from core subjects* through computer game design (Kafai, 1994; 2014). In Tucker-Raymond's work, high school and middle school students made games that taught about mathematics including coordinate planes, geometry, linear functions, and STEM career awareness, among other topics (Tucker-Raymond et al., 2012).

Furthermore, game design can be particularly effective in teaching about systems thinking (Salen, 2007; Liu & Hmelo-Silver, 2009; Puttick et al., 2014, GlassLab, 2014), since game design is a species of model building, one of the central scientific practices advocated by the NGSS (Achieve, 2013). Learning outcomes attributable to the expressive power of model building are clearly described by Clement and Rea-Ramirez (2008): these include explicitness, iterative design-analysis-revision from learners, incorporating input and output elements, and flow, among other things. Game design requires all these virtues. Much is still to be learned about game design as a way to engage young people in learning science or math, and, rarer still, in model building (e.g., Reppening et al., 2010; Tucker-Raymond et al., 2012).

With the theoretical framework above, and our prior experience in mind, we conjecture that a learning experience that builds on the strong complementary synergies and common elements among computational thinking features (Brennan & Resnick, 2012), systems thinking and essential climate concepts will contribute to a rich and engaging learning environment, aligned with standards (Fig. 1):

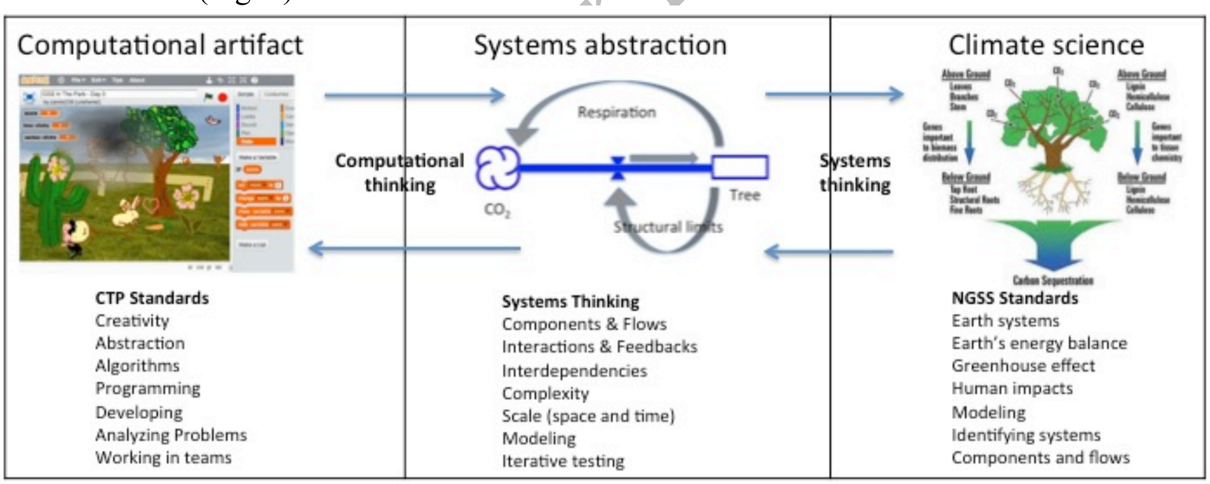

Fig. 1. Complementary synergies, common elements, and alignment with current standards in our theoretical framework. The systems abstraction (middle) and climate science representation (right) were chosen with reference to the system represented in a climate science game created by a middle school student in a TERC workshop (left). The game was designed to educate other students about the capacity of plants to sequester carbon dioxide.

In this study, we address the overarching research question:

- In what ways do students leverage the affordances of game design and systems thinking to learn about climate change?

Workshop Design

The program was a free four-day intensive game design and climate change workshop for middle school girls that, the second pilot of a workshop focused on the use of Scratch game design to teach about climate change. In the workshop, five girls used the object-oriented programming environment, Scratch, to create games based on a make and inquire cycle of game design into a systems perspective on climate change. Specifically, students engaged in computational practices such as modeling, abstraction, management of complexity, and creative design, as well as iterative testing and debugging, as they designed their games.

The program ran six hours a day the week after school ended for the summer in July 2014. Total contact time was 24 hours. The workshop was mostly held in a conference room at the offices of the researchers. There were laptop computers for each student and a room computer with a projector. Students also took a trip to a local wetland reserve and a city park under construction to consider what, if any, systems they could observe. Learning configurations varied. Girls worked alone when programming their games, but came together to discuss the science topics and during the week to show their progress to the whole group. Girls gave a final presentation to a group consisting of family and community members.

The two researchers acted as facilitators - Puttick led most of the discussions on climate change, while Tucker-Raymond provided most of the support for game design and programming. By participating in the workshop, participants and their parents consented to participation in the research. Participant pseudonyms are used.

Below, we present a short description of the activities. On day one, we told the girls that we were working on a project to encourage energy conservation and think about the energy choices people make. We sought to connect how energy choices connected to climate change. We explicitly told them that their job was to create a game that would help other young people make these connections. The participants were introduced to Scratch and signed up with an account. There were varying degrees of familiarity with Scratch beforehand, ranging from no to 2 years' programming experience. Participants were shown the movement blocks, an example of how to construct a simple code in scratch to make a sprite move, and then explored the program.

The middle of the first day was given to the field trip to a local wetlands reserve. The group walked around the paths making observations that they documented with cameras and sketchbooks. This was followed by a group conversation about the possible relationships between the reserve and climate change. We introduced the idea of systems by asking girls what connections they could see among the various components of the reserve, how the reserve might connect to humans and how those relationships might be connected to climate change.

In the afternoon, girls engaged in a preliminary group concept mapping activity. The mapping activity was to provide a visual learning tool for the girls to make and see connections about climate systems. The guiding questions included the following topics: a) What climate change is and what causes it, b) what consumes energy and what conservation efforts might be, and c) how energy is connected to climate change, and d) how the girls' own actions were connected to climate change. The concept map was done on the conference room whiteboard, and preserved for revisiting and elaborating each day of the workshop. Participants then watched an animated video that introduced climate change from a systems perspective, specifically a perspective that linked human consumption patterns to Earth systems: (https://www.youtube.com/watch?v=FKq8DixcbyQ).

They were shown a couple of different kind of games including a platform game and a [X type] game about climate change that one of the facilitators had made. Finally, they were shown some game design storyboards, with examples, to begin to sketch an idea for a game about climate change. They were encouraged to begin their games by designing a sprite or a background, which they all did, quickly abandoning the storyboard templates.

During days 2 and 3, the girls spent most of the day programming, with Tucker-Raymond providing technical support. Girls stopped to explain their games to others each day. Facilitators also circulated, and by the middle of day 2, were encouraging the girls to think explicitly about systems in their games. They also engaged in a group discussion to elaborate the concept map in the middle of each day, constructing and renegotiating the map focused on systems and incorporating new content as they learned on their own through web research the content that was explicitly necessary for their own games.

On day 4 participants spent the majority of the day programming, and debugging. The last hour of the day consisted of presentations to family and community members, followed by free play of the girls' games.

Research design and methods

Participants

Participants were recruited through outreach and flyers to school districts, parent listservs and other youth serving, STEM promoting organizations through which PIs had contacts, including for instance, Science Club for Girls, a regional organization that was the primary point of contact for four of the five girls. The participants were rising 6^{th}, 7^{th}, and 8^{th} graders, each from a different school. Two girls had no Scratch experience, one had learned Scratch 8 months previously, and two had more than a year's familiarity with the program. When asked what drew them to the workshop, two of the girls listed learning or using Scratch as the reason, while one cited the science connection, and one cited the idea of "making a game to help the earth." To protect their identities, we asked all girls to choose pseudonyms; these are used in this paper.

Data sources

Interviews: We conducted semi-structured interviews of each girl in the afternoon of Day3 to gain a more nuanced understanding of their experience. We asked them to describe what their game was about and how it worked, to talk about any systems that might be in their game, and how they thought the game was related to global warming. Interviews were 35-40 minutes in duration. They were recorded using Silverback software to be able to align participant comments with actions they may have made on the computer.

Concept mapping: A daily group discussion was held to generate and then continue to develop a group concept map. These discussions were videotaped. Videotapes were logged and themes were generated using the logs and the end-of-day representations and changes from each concept map.

Think alouds and user testing: At least once each day, in pairs girls tested each other's games and thought aloud about their progress and challenges. These think-alouds and user testing episodes were recorded using Silverback usability testing software. Copies of girls' games were saved and archived at the end of each day.

Final presentation: Parents, guardians, family and friends, as well as selected TERC staff, were invited to attend the last session of the workshop. A total of 16 guests attended as the girls described their games, gave details about systems and trade-offs in their games, as well as how their games were related to global warming. These presentations were videotaped.

Surveys: Girls completed a brief (5 minute) pre/post survey. The survey included 23 multiple-choice questions, and 7 constructed response questions. Questions were designed to assess the following constructs: knowledge about climate change, personal actions with respect to climate change, environmental values related to trade-offs, attitudes about global warming, and self-efficacy with respect to creating games. We also collected demographic information and histories of experience and knowledge about programming, and perceptions of the workshop experience.

Where available items were adapted from validated instruments. Items for taking action with respect to climate change were adapted from the CHEAKS instrument (Leeming et al. 1995). Knowledge about the relative contributions of various sources to greenhouse gas emissions, and attitudes about trade-offs related to addressing climate change were taken from a survey of public attitudes towards energy and the environment in Great Britain (Curry et al., 2005), and general attitudes about global warming from the Six America's survey of the Yale Project on Climate Change Communication (Leiserowitz et al., 2011). Since two of these surveys were designed for adult audiences, we tested the survey with a focus group of four girls, and adapted the items based on their comprehension of some of the vocabulary and item sentence structure. Content was validated by expert review.

Video of programming activities. For the most part, this video captures the overall environment, but does little to add to understanding of individual students' stances and learning toward climate change, systems, or game design. There were some moments of dialogue between students or staff and students that were logged and used to check, add to, confirm, or disconfirm interview, group discussion, and presentation data. Participant-observer notes from the researchers provided additional data and directions for analysis.

Data analysis

Transcripts from interviews and conversations as well as logs of video data were imported into dedoose. We used a grounded theory approach (Glaser & Strauss 1967) to analyze data. We generated a preliminary set of pre-determined (etic) codes based on principles in our theoretical framework including climate science content, game design, and systems thinking (Miles and Huberman 1994, Maxwell 1996) to categorize our data along dimensions prescribed by the six categories shown in Table 1. At the same time, we paid attention to new patterns and ideas from the participants as they emerged (Creswell, 2009), generating emic codes as we identified new themes, for example distinguishing between own and others' actions that mitigate climate change or that contribute to climate change.

Coding category	Code
Science	Systems thinking (feedback, cycling, input/output, human connections), Global warming, other science)
Game	As analog to environmental issue, as teaching tool, structure, playability, aesthetics, use of metaphor, programming skill level, use of systems thinking in programming
Trade-offs	As analogy to real world, in game making (related to playability, or to aesthetics), emergent understanding of
Attitudes	Attitudes toward science, the environment, programming
Socio-ecological/human connections	Ethics/morals, psychology, behavior that contributes to climate change (own or others'), behavior that mitigates climate change (own, others')

Table 1.

A more detailed presentation of the coding scheme is shown in Appendix 2.

Results

Results presented here are ongoing and emergent. Data were analyzed along the five dimensions in the coding table. We then organized those codes into three broader findings: a) analogies to science content in the games, b) game design experience, and c) evidence of systems thinking, including socio-ecological connections. After presenting results related to these broader findings categories, we briefly present results from the survey and the concept mapping activities.

Analogies to Science Content

All of the participants appropriated the workshop goals and made games related to environmental issues so that they could teach others, or at least make them aware, of climate change. All games introduced information to the player that explicitly stated a particular problem with climate change. For some, information was in the directions to the game. For others, it was introduced as information before game play.

Riley's game included different ways of mitigating climate change at three different levels. The first involved capturing methane emissions from cows in the first level of the game, identifying carbon sinks in a second level, and identifying recyclable waste in a third. Twilly also included a game about capturing cow methane, the goal of Ricky's game was to capture CO_2 from a factory, and Hippo and Victoria's games included using trees and other green plants to mitigate CO_2 production. Some of the game play was more realistic in relation to analogies to systems (plant trees to process of CO_2; different plants have different capacities for processing CO_2) while some was less concrete about the real world counter-part, for example, clicking away puffs of CO_2 or methane.

Victoria's game included planting trees:

Well, it trades oxygen for carbon dioxide, the trees do. Yeah and the person, the character putting down the seeds takes up the space with trees for having cleaner air, so it could be used for buildings. Instead of using it for buildings the person plants trees for cleaner air. (interview)

The concept was an emphasis of our Day One afternoon trip to the nature reserve and a topic of conversation we explicitly addressed with participants.

All games reflected an emphasis on the human player, as an agent mitigating contributing factors to climate change. One student included a bee as an avatar that plants seeds that eventually grow to trees. Although not a perfect analogy, Victoria did represent the role of pollinators as interactants with plants and contributors in the ecosystem. All other participants used the pointer as the on screen agent making the player the direct agent for climate change mitigation.

The games were also analogous to time as a factor in climate change as well. Three of the games (Riley, Hippo, Ricky) pointed to the production of greenhouse gasses as an ongoing phenomena, without end. Those games only ended when time ran out. A timer is a common feature of computer game play but is also analogous to the time left for the Earth if human behavior does not change. Ricky stated:

Basically, my game relates to global warming because factories, they produce a lot of carbon dioxide and they make pollution, and they pollute the air, and polluting the air causes greenhouse gasses to trap all that heat and creates global warming…And it shows how in real life you need to have like a certain amount in order to actually help. You know, you can't just turn off the light once and then it'll be fine, its like you need to do it constantly. (Interview)

These constructs (production, mitigation, time, feedback loops) are all aspects of systems thinking as they relate to climate change.

Game Design Experience

All of the participants were coded talking about their games as tools to teach about causes and mitigating factors of climate change. Some were more explicit about this than others. For instance, Riley accounts for 10 of the 30 coding instances while Twilly only accounts for one. This is true of Twilly across categories however, as she was not interviewed.

For instance, Riley's reasons for including a classification game about carbon sinks in her game was to inform others about a topic they potentially knew less about:

I don't think a lot of people know about carbon sinks and we're chopping them down a lot and also in the video it was talking about how they're taking away all our carbon sinks and there's few left to take out the greenhouse gases. So I was thinking if people knew about them more then maybe they would stop and think about what they did if they took out the carbon sinks.

Riley also hoped that when people know more about the topic of carbon sinks they would take action. In her final presentation she stated:

> *Its related to global warming because its teaching kids like how not to like how what state our world is in and what we have to do to prevent more from happening… I hope people learn that they need to do their part to help the environment because we all need to help because the environment is getting worse and we have to step up and do something.*

However, she does not didactically tell the player to take action and protect carbon sinks, or eat less meat. She focuses on what the problems, as she sees them, are. In this sense, Riley adopts a "knowledge is power" stance in which those who know can, and should, by means of moral imperative, exert their agency:

> *And it was cool how cows, you learned, use 20% of methane pollution, so I thought it would be a good thing to inform people about. So I decided to do it. Use it.*

The video the group watched was the main source of Riley's content in her first two games, catching cow farts and classifying carbon sinks. In both cases, Riley seems to focus on topics that she herself learned about in the video. As she says in the above excerpt, she thought it was cool when she learned that cows "use" [produce] 20% of methane in the atmosphere. Riley is not necessarily teaching to the big ideas of climate change but to those concepts that struck a chord with her personally. This is a tension in our design as we wanted projects to be personally compelling to participants and at the same time wanted them to come away with a systems perspective on climate issues. In the future, we believe that an intentional effort to locate participants' individual games as a network of connected ideas will make the systems aspect of the teaching and learning more transparent.

In many of the games, the teaching was done explicitly through text as an introduction to the games rather than learning through the playing of games themselves. For instance, Riley's introduction screen to the Carbon Sinks game includes a definition of a carbon sink and why it is important:

> Carbon sinks are objects that take green house gases out of the atmosphere. Look at the descriptions in the following pictures and decide which object in each pair is a carbon sink. You'll have 30 seconds.

In this game, the player learns what a carbon sink is from the introductory screen language. She also learns examples of a carbon sink from playing the game. Less explicit are the ways in which carbon sinks are connected systematically to mitigating the effects of climate change.

Victoria also, more didactically and with more detail, used textually based introduction screens to convey information about climate change. For instance, while her game was about planting trees to act as sinks for carbon dioxide, she included information about carbon dioxide on an introduction screen:

> So this is facts about carbon dioxide. It says an average 20 gallons of carbon dioxide is brought in for every gallon of gas a car uses. And it tells more facts. [clicks to next screen] and it tells about how trees take in carbon dioxide and not let heat get trapped in [clicks to next screen and reads instructions].

Victoria had so much information to include that she needed multiple explicit, didactic screens to convey it. During the game, the players plant trees and carbon dioxide bubbles disappear yet there is no text or verbal information that accompanies the game play other than play instructions. In these ways the participants' games might be classified as containing at least two parts: a) an information/learning section, and b) an engagement/play section.

Unlike Riley, Victoria did make explicit that she wanted players to know about systems aspects of climate change. In her final presentation, Victoria stated:

> *And I hope people learn from this game that carbon dioxide is a major cause of global warming and planting trees helps.*

Like Riley and Victoria, Hippo hoped that her game would compel people to act on climate change based on the information that they learned in the game. Hippo, however, was more concerned than others about the limits of the earth's ecosystem and human kind's expectations of those limits:

> *I hope people learn from this game that the plants have a limit of the carbon dioxide they can absorb, just like in real life. So from this angle people learn that they can't just like put their burden on the plants, its not enough.*

This focus also reflects her multiple expressions over the course of the week of anxiety over the "burden" people were continuing to place on plants and its unsustainability for a healthy world. Riley was also anxious about what can be done to mitigate climate change.

Ricky's game, about how factories produce carbon dioxide and the difficulty of controlling it, was only implicitly connected to systems thinking. She too, however, wanted people to learn from her game, to think about how humans can mitigate climate change:

> *And I chose this particular topic because I don't think people realize how much pollution, from the stuff that you buy, can actually make when they're in factories… I hope that people learn from my game how much pollution factories cause and it just sort of harms the environment.*

Like the others, Twilly wanted to make others' aware of factors contributing to climate change:

> *I hope that they can learn that cows are more than what they seem.*

Twilly's statement points to a theme that crossed all of the games. That is, she wanted to teach others about something that they may take for granted yet are actually much more powerful than they seem and at the same time are also parts of a system of climate change that includes both human contributions and mitigation. In Twilly's case it was that cows, the animals from which we get dairy products and meat, produce methane. So it is not just food that they produce, it is also methane, which can be harmful to the earth. For Ricky, it was that our buying and consumption habits contribute to carbon dioxide production through factory waste and for Hippo, it was that humans assume plants can, or already do, carry our burden indefinitely.
Both Hippo and Victoria expressed concern about the time it took for trees to grow or to convert carbon dioxide. They thought that it could be more realistic. However, neither explicitly expressed concern that this difference would interfere with players' learning.

Systems Thinking

In the interview, there is clear evidence of emergent systems thinking as Riley talks about trees as carbon sinks:

> *I knew that trees absorbed CO_2 I just didn't know they had a real name [carbon sinks]. […] I don't think a lot of people know about carbon sinks and we're chopping them down a lot[…]there's few left to take out the greenhouse gases.*

Prompted by the guiding question we gave to the participants for their final presentations of their games, Riley addresses connectedness as a systems component, saying:

> *There are systems in my game because they are all really connected in the way that they're all talking about the environment and what we can do to help.*

Appropriating this knowledge by naming it represented an important learning experience for Riley. As she took ownership of the idea of carbon sinks, her entire game centered on this new abstract way of thinking about real objects in the world. Recontextualizing "trees" as "carbon sinks" opened a whole new perspective for her about what trees could be in the world. This realization was important enough for her that the task for players that she presented in the second level of her game was to rename objects too. Players must sort representations of real objects as carbon sinks or not carbon sinks, her definition of a carbon sink was anything that contained carbon.

Further, the affordance of game design has empowered her to go beyond naming two system components that influence carbon flows – trees and humans – and represent the idea of dynamics as trees and humans are players in the cycling of carbon. Trees "take out" greenhouse gases, i.e., carbon dioxide, and humans have a direct impact on the system by removing trees as potential carbon sinks. This is an important move in appropriating a systems point of view, as other researchers have observed (e.g., Hmelo-Silver et al., 2000; Penner, 2000).

Victoria, too, identifies trees as components of the carbon cycling system, though not as carbon sinks, and also includes human action and its impact on carbon cycling in her emergent systems view. She presents this in an informational screen in her game:

> Interview *[Reading] Trees are a big help to reduce carbon dioxide. Like how we breathe in oxygen and breathe out carbon dioxide, trees and plants do the opposite. They inhale carbon dioxide and exhale oxygen. But lots of trees are being cut down. Planting trees is an easy way to help decrease carbon dioxide.*

She elaborates the notion of cycling – a key systems function – as she talks about tree functioning, expressed as "cleaning the air:"

> *Yeah and they release oxygen over and over again that cleans the air and helps stop trapping the head inside the earth. Because the carbon dioxide is what keeps it in along with other gases. Yeah.*

Hippo has a fairly elaborated systems perspective as she describes systems components and systems dynamics at multiple levels, from the chemical level in photosynthesis ("*the system in plants is photosynthesis and almost no // pretty much no animals can do photosynthesis and that helps get the carbon dioxide out of the air and converts it into oxygen")* to the global level in describing the greenhouse effect ("*CO_2 acts like kind of a blanket around the earth that traps the sun's heat there to keep everything warm")*.

As an aside: From a systems perspective, the detailed mechanism of photosynthesis – Hippo's "converting it into oxygen" or Victoria's use of a breathing metaphor to describe inputs and outputs from trees – is irrelevant, even though elsewhere we could go into depth about how these are valuable resources or assets, that could be productively built upon if understanding how photosynthesis works were the learning goal.

She is clear about the role of humans in the whole systems perspective, and describes their role in disrupting the carbon cycle. She understands that limits are important features of systems too:

> *also if you think about deforesting and clearing away forest areas, plant areas and wildlife, the amount of things that can absorb the CO_2 is going down. And also since there is a limit we can't really rely on anyone other than ourselves to stop this.*

Furthermore, she identifies a systems feedback loop that she would have built into her game if she had had the time to do so:

> *I was going to include a a little dude with a chainsaw like about to chop down trees and whatnot, to make it more difficult, I don't know how to do that, but…he was supposed to chop them down to show that we, the trees can't absorb enough and at the same time the trees are being chopped down, which adds to the difficulty which adds to pollution which adds to global warming, so, it all, it all goes to global warming…*

We would argue that both the transformation involved in making the invisible visible, and the transformation involved in taking on a systems perspective <climate change> to create tangible components of the Earth system that can be acted upon by them as game designer and by their intended audience, are powerful acts. Such agency can empower the girls to imagine and potentially transform the systems, the world, and the systems that contribute to and mitigate global warming.

We see all the girls attempting to make invisible things visible. Carbon dioxide, methane, global warming, carbon sinks all become visible as a result of the act of design. For Twilly, cows are more than they seem, for Riley trees are carbon sinks, for Hippo the capacity of different types of plants to take up carbon is made visible in the scoring system of her game.

We also see them all making the human connection to climate change visible as well, in different ways. For example, Twilly's is a personal connection as she represents herself in a tutu in the game with the task of capturing, i.e., mitigating, methane released by cows.

Hippo's, on the other hand, is impersonal. The two central figures sitting together on a fence in her gamescreen are oblivious to their role in global warming, but the visible dark cloud of carbon dioxide floating above their heads represents her sense of urgency about the issue of climate change and human inaction in the face of it. In essence, her screen characters stand in for everyone, as she elaborates in the interview:

> *"If you think about deforesting…the amount of things that can absorb the CO_2 is going down [from deforestation]. And also since there is a limit we can't really rely on anyone other than ourselves to stop this…the people are trading the safety of the planet for their own comfort. W hat I mean by that is people are choosing to ignore it so they're basically pushing away anything that they see that promotes awareness of what's happening, so they're living their lives, not ignorant but in willing ignorance.*

She makes their willful ignorance visible by positioning the characters in the center of the system she has portrayed, and she emphasizes the moral dimension of their inaction by positioning the cloud of CO_2 directly over their heads.

While not represented in her game, Hippo talks in the interview about scales of both space and time, both of which are also essential elements of a systems view, as she elaborates on the socio-ecological and moral aspects of human relationships to global warming:

> *Or an uncertain now, for like, cause like in the Arctic things are melting rapidly, polar bears are going extinct and…*

Essentially she seems to be saying that people's actions and choices have an effect at a distance, that is, we are all connected in one system that has and will have inescapable consequences. She continues:

> *millions of people are saying, "Oh no, I won't make that much of a difference by not driving my car," but they drive their cars and they're all making a massive difference like putting literal tons of CO_2 into the air, which is heating up the planet[…] this is what's going to happen, its not going to happen in 10 billion years, you can't solve this just by throwing away, I mean recycling one plastic bottle. You can't do this just by turning off the lights for one day and then rewarding yourself the next day with a full day of screen time.*

She is acknowledging that the scale of the problem is hard to comprehend, is more immediate than people seem to think, and implies that actions will need to be correspondingly great.

Survey

The sample of 5 students was too small to analyze statistically. However, it was possible to discern trends in the data. In part, we wanted to understand what students knew about climate change and possible contributing factors. As such, we asked them to describe the relative impact of various sources for production (e.g., automobiles, factories, breathing and mitigation (e.g., trees, oceans). All participants knew at the outset that burning coal for energy is a problem because it releases carbon dioxide and other pollutants into the air. At the same time, difference between pre and post surveys showed that students were more aware of trees and oceans as potential mitigators of carbon dioxide in the atmosphere and slightly adjusted their perceptions of automobiles, factories, coal burning power plants, home heating, breathing, and farming to generally reflect a better understanding of the relative weight of each of these contributors to climate change.

*Self-efficacy***:** Average gains on a 5-point scale for participants about their feelings toward programming increased, with four of the five participants showing an increase. On average, students gained 1 point on the scale for the statement "I can create games with Scratch that people want to use." They also gained 0.6 points (average) for the statements, "I can create computer games that can help improve communities" and "I can help other people learn about reducing global warming by creating a computer game for them to play." In addition, we asked the girls how they thought they could reduce global warming. Not surprisingly, four of the girls listed actions within their own personal sphere of influence, such as carpooling, buying local, or planting trees. One girl listed actions at an institutional level, saying: "Start organizations, non-profits, and research facilities."

Environmental values related to trade-offs: We asked the girls a series of questions about the priority they would place on "protecting the environment." All of them came into the workshop with a strong pro-environmental stance, agreeing with the statement that "Both the environment and convenience are important, but the environment should come first," and disagreeing with the statements that "Both the environment and comfort are important, but my comfort should come first" and "The highest priority should be given to the happiness of people living right now in my area, even if it hurts the environment here or anywhere else." They changed their rating from neutral to agreeing with the statement that "The highest priority should be given to protecting the environment, even if it costs me or my family more money."

Attitudes about global warming: There was a small gain (0.4) in the average of the girls' perception that global warming would harm them personally, and the average point of time in the future at which they thought it would take effect increased from 27 years to 32 years (the equivalent of a lifetime for a young person!). All of the girls believed that humans can reduce global warming, with three choosing the statement that "its unclear at this point whether we will do what's needed," one that "people aren't willing to change their behavior, so we're not going to," and one that "we are going to do so successfully."

Concept mapping

The concept map that was generated on the first day showed that the girls collectively had fairly comprehensive but superficial knowledge. They could link energy use to the burning of fossil fuels, and its contribution to "global warming," and articulate that global warming was the cause of "climate change." Separately, they linked "greenhouse gases" to global warming. They stated that temperatures change because of climate change, but were less clear about resulting "environmental change." One girl thought that environmental change would result in "animals adapt[ing]" and thought it might also lead to "[other] animals extinct[ion]." The group was also able to identify renewable energy (solar, wind, hydro, biofuels and geothermal) as having a role in mitigating climate change. Another girl stated that nuclear energy could mitigate climate change, but it also generated radiation. The group was not sure about the statement that radiation might be connected to global warming.

On Day 2, they elaborated the concept map in several interesting ways. They integrated humans into the concept map explicitly, by i) adding humans under "animals adapt" and "animals extinct," ii) stating that humans were agents of environmental change in the form of deforestation which contributes to global warming, iii) implicating humans in exacerbating and/or mitigating climate change by their choices of sources of energy, and energy conservation. They also identified methane as a specific greenhouse gas and stated that humans could mitigate its effect by capturing it. Finally, they also identified large-scale farming as a significant source of greenhouse gases through the generation of methane.

On Day 3, they elaborated their statements about how humans exacerbate and could mitigate climate change by their choices of sources of energy, and energy conservation. They listed automobiles, home heating, home uses of electricity (lights, machines, entertainment, water, as well as "buying stuff").

Discussion

Since analysis is ongoing and emergent, synthesis of data with reference to our research questions and knowledge from the field is also emerging at this time.

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Appendix 1. Pre/post Student Survey

1. I have talked with my parents about how to help with environmental problems.
a. very true b. mostly true c. not sure d. mostly false e. very false

2. I will talk with people other than my family (e.g., friends, teachers) about how to help with environmental problems soon.
a. very true b. mostly true c. not sure d. mostly false e. very false

3. To save energy, I turn off lights and/or appliances at home when they are not in use.
a. very true b. mostly true c. not sure d. mostly false e. very false

4. Burning coal for energy is a problem because it:
a. releases carbon dioxide and other pollutants into the air
b. decreases needed acid rain
c. reduces the amount of ozone in the stratosphere
d. is too expensive
e. pollutes the water in aquifers.

5. Many environmental issues (such as energy use) involve difficult trade-offs or choices. Rate the following statements:
(a. agree very much b. agree c. neutral d. disagree e. disagree very much)

i. The highest priority should be given to protecting the environment, even if it costs me or my family more money.
ii. Both the environment and convenience are important, but the environment should come first.
iii. Both the environment and comfort are important, but my comfort should come first.
iv. The highest priority should be given to the happiness of people living right now in my area, even if it hurts the environment here or anywhere else.

6. There is growing concern about increasing levels of carbon dioxide (CO2) in the atmosphere. How do you think the following contribute to these levels? Score how much you think the following decrease CO2 (-3), have no impact (0), or increase CO2 (+3).

				Contribution				
Automobiles	-3	-2	-1	0	+1	+2	+3	Not sure
Factories	-3	-2	-1	0	+1	+2	+3	Not sure
Coal burning powerplants	-3	-2	-1	0	+1	+2	+3	Not sure
Home heating	-3	-2	-1	0	+1	+2	+3	Not sure
Breathing	-3	-2	-1	0	+1	+2	+3	Not sure
Nuclear power plants	-3	-2	-1	0	+1	+2	+3	Not sure
Farming	-3	-2	-1	0	+1	+2	+3	Not sure
Trees	-3	-2	-1	0	+1	+2	+3	Not sure
Oceans	-3	-2	-1	0	+1	+2	+3	Not sure

7. How much do you think global warming will harm you personally?
a. Not at all b. Only a little c. A moderate amount d. A great deal e. Don’t know

8. When do you think global warming will start to harm people in the U.S.?
a. They are being harmed now b. In 10 years c. In 25 years d. In 50 years e. Never.

9. Which of the following statements comes closest to your view?
a. Global warming isn't happening.
b. Humans can't reduce global warming, even if it is happening.
c. Humans could reduce global warming, but people aren't willing to change their behavior, so we're not going to.
d. Humans could reduce global warming, but its unclear at this point whether we will do what's needed.
e. Humans can reduce global warming and we are going to do so successfully.

10. I can create games with Scratch that people want to use.
a. agree very much b. agree c. neutral d. disagree e. disagree very much

11. I can create computer games that can help improve communities.
a. agree very much b. agree c. neutral d. disagree e. disagree very much

12. I can help other people learn about reducing global warming by creating a computer game for them to play.
a. agree very much b. agree c. neutral d. disagree e. disagree very much

13. How do you think you can reduce global warming? Please list all of the ways you can think of, if any.

14. What drew you to the workshop?

15a. What was enjoyable about the workshop?
15b.What was hard or frustrating about the workshop?

16. What is a trade-off?

17. What is an example of a system? Draw it here.

18. What new things did you learn about climate change, or anything related to it, this week?

Appendix 2. Coding scheme

Note: Use INT for code that represents our interpretation when the child hasn't explicitly uttered the item.

1. Science	
a. Systems Thinking	Includes components of earth systems
a.1 Feedback	
a.2 Cycling	
a.3 Input, output	
a.4 Connection of humans to earth systems	
b. Global Warming	Includes ideas related to global warming including greenhouse gases, increasing temperatures
c. Other Science	Includes science other than systems thinking or global warming, e.g., photosynthesis,
d. Where in the game (or in talk about the game) is it located?	Game, talk about the game in interview, talk about the game in presentation, talk about the game on silverback recording, talk during discussions
2. Game	
a. Game as an analog to environmental issue… Where does it diverge/converge? Why?	A component of game design or game play is analogous to the environmental issue that is portrayed in the game, e.g., "trees are best at absorbing CO2 so your score goes up by 5 every time you click on it"
b. Game as a teaching tool	Explicit talk about an aspect of the game that relates to the learning goal of the game, or part of the game, or game play
c. Structure	Aspect of the game that relates to how it works, e.g., scoring, clicking on objects
d. Playability	Explicit talk about how an aspect of game design affects the player's experience, or playability
e. Aesthetics	Explicit talk about an aspect of the game that relates to its appearance, aesthetics, e.g., color choice,
f. Metaphor	Use of metaphor in talking about game design, or incorporation of visual metaphor into game itself, e.g., click on snail to buy time in the game
g. Programming skill level	
2g.1	Game design (or talk) displays competence
2g.2	Game design (or talk) displays challenge of programming
h. Systems thinking in computer programming	Uses systems concepts in the context of programming, e.g., feedbacks, inputs and outputs, if…then statements
3. Tradeoffs	
a. In analogy	Action in game represents real world
b. In game making -Playability	Talks about having to make a tradeoff related to the playability of the game, for example with respect to

	younger or older kids
c. In game making -Aesthetics	Talks about making tradeoffs about the aesthetics of the game, e.g., drawing own image vs. importing a sprite or image
d. In real world	Talks about tradeoffs in the context of the real world either societal or of the child, e.g., weighing up pros and cons of choices
e. Emergent	Talk demonstrates emergent understandings of tradeoff
4. Attitudes toward	
a. Science	Expresses positive or negative attitude about own relationship to science
b. Environment	Expresses positive or negative attitude about own relationship to the environment
c. Programming	Expresses positive or negative attitude toward own relationship/skill to programming
5. Socio-ecological/human connections	
a. Ethics/morals	Talks about the ethics associated with being a contributor to climate change
b. Psychology	Talks about the psychological impacts of knowing about climate change, including powerlessness, guilt, not doing enough, etc.
c. Behavior that contributes to climate change	Talks about human actions that contribute to climate change
5c.1	Own actions
5c.2	Others' actions
d. Behavior that mitigates climate change	Talks about human actions that mitigate climate change
5d.1	Own actions
5d.2	Others' actions
6. Sources from which child derives information	
a. Video	Video shown during the workshop
b. Web	Child's own web search
c. Field trip	Field trip during first day of workshop
d. Peers	
e. Adults	