Examining the Social Aspect of Climate Change through Mathematics

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Abstract - **We designed an instructional module that seamlessly integrates mathematics, environmental science, and technology to help students think critically about climate change. The results from a design experiment in a sixth-grade classroom show that our tasks not only enhanced students' covariational reasoning in mathematics but also helped students identify the different traits of climate change they encounter every day in the news media.**

Index Terms – Climate Change, Covariational Reasoning, NetLogo, Social Justice.

INTRODUCTION

For years, researchers have emphasized the role of literacy for developing critical consciousness [1, 2] among students. Researchers such as Gutstein [3] and Stinson, Bidwell, and Powell [4] stressed upon the role of mathematics to help students understand numerical data and ask basic, relevant questions so that they develop a deeper understanding about underlying sociopolitical issues, such as unemployment rate and racial profiling. Acknowledging the role of mathematics for addressing the social aspect of climate change, Abtahi, Gotze, Steffensen, Hauge, and Barwell [5] questioned the "ethical and moral responsibilities" (p. 2) of mathematics educators to familiarize students with issues regarding the environmental and social aspects of climate change. They argued that, if teachers assume their ethical responsibilities and incorporate climate change into their mathematics instruction, then that would facilitate students' ability to identify the role of mathematics in climate change and prepare future decision makers to affect change for the betterment of the climate. Similarly, Karrow, Khan, and Fleener [6] discussed the severity of climatic issues and argued that mathematics education should "concern itself with the development of the individual, in relation with our Planetary Ecosystem" (p. 9). Following the path laid by the research above, this study focuses on the topic of climate change to leverage on the power of mathematics for educating our next generation about the impact of the exploitation of the natural environment and its profound impacts on our global society.

CLIMATE CHANGE: A SOCIAL ISSUE

The climate around us is rapidly changing and many scientists claim that the change in climate is "attributed directly or indirectly to human activity" [7]. We often do not realize, but our simple acts of choosing household items, electronics, appliances, and transportation impact our environmental conditions [8]. Due to human activities, the global greenhouse gas emission rate is increasing by .5 to 1% every year [7] and if this trend continues, then there might be a global rise of temperature between 2 and 5 degrees Celsius in next few decades [10]. As a consequence, "the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted" (p. 5).

Though climate change is a threat to the entire humanity, the rapidly changing climate brings down its effect on poor people disproportionately. The poor, instead of being the minor consumers of the available resources [11; 12], are more likely to endure the harmful effects of environmental hazards. In spite of the current threats to the environment, the rich section of society can ensure their children healthier lives with clean air and non-polluted water supplies while the people belonging to the lower economic strata of society are less able to avoid environmental hazards such as motor vehicle exhaust, industrial pollution, and power generation [12]. Hence, climate change is an issue of social justice, which like any other social issue can be better interpreted and addressed through mathematics.

THE MATHEMATICS OF CLIMATE CHANGE

To explore the mathematics embedded in issues related to climate change, our attention was drawn to research on covariational relationships, which involve coordinating two quantities as the values of those quantities change [13]. A student may reason covariationally when they envision two quantities, example, air temperature and height of sea level, varying simultaneously [14]. Reasoning covariationally, such as arguing that the height of sea level increases as the air temperature increases, can be the basis on which functional thinking can be developed in the later years of schooling [13].

In real life, most of the essential information about climate available in the news media, advertisements, weather reports, and journals are in the form of graphs or pictures. But the reading of graphs and their interpretation can be challenging for many students and adults too [15, 16]. Students often focus on the shapes of the graphs, overlooking the underlying covariational relationships between the factors represented [16]. Consequently, in this study we utilized the power of technology to adapt and develop three mathematical modeling simulations in NetLogo to investigate if the dynamic simulations help students reason covariationally and develop within students a critical consciousness about climate change.

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Aiming to engage students with covariational reasoning and graphing to understand climate change, our goal was to investigate:

1. What types of tasks and tools may be used for developing students' critical thinking about climate change through covariational reasoning and graphing?
2. What is the nature of students' thinking about climate change as they engage with these tasks and tools?

METHOD

The primary methodology used in this study was the design experiment [18]. We engineered particular forms of learning in naturalistic settings and studied the impact of those forms of learning in the given context. The design experiment was conducted in two sixth-grade classrooms from an urban school in the northeastern part of the United States, located in a mixed and diverse area, highly inhibited by a Hispanic or Latino population (39.95%, according to 2010 Census). According to the Partnership for Assessment of Readiness for College and Careers (PARCC), the two schools we considered were low performing schools where a very low percentage of students either met or exceeded school-wide expectations on the PARCC Assessment. These performance reports indicate an alarming trend which suggests that these underrepresented and economically disadvantaged students desperately need an educational intervention to be prepared for the higher grades.

To develop our tasks and analyze students' covariational reasoning, we used the Mental Action framework developed by Carlson et. al [17]. This constructivist framework describes a progression in students' covariational reasoning while interpreting graphs. Table 1 presents an adaptation of the Mental Action of Covariational Framework table developed by Carlson et al. [17] where in the third column we include the questions that we developed to complement the simulations and prompt the participating students to attain different levels of covariational reasoning. The third column also presents some possible student responses for each level of reasoning. According to Table 1, the development of covariational reasoning begins with identifying a change between two given quantities, followed by a focus on the direction of the change, then a focus on the changes at discrete points, and finally on the changes in between those points.

We leveraged the power of technology for illustrating the relationships dynamically, aiming for students to recognize how the change in one factor influences the values of other factors [19]. We modified an existing simulation and developed two new simulations on NetLogo [20], an agent-based modeling tool, to enable students to model complex environmental phenomena and concepts. In the following section we describe the three simulations we used and the investigations (tasks) that we designed to accompany those simulations. We also discuss how these tasks helped students to reason covariationally and develop an in-depth understanding of the climatic condition of the earth.

TABLE 1: MENTAL ACTION OF COVARIATIONAL FRAMEWORK BY CARLSON ET AL. [17]

Mental Action	Description of Mental Action	Probing Questions and Possible Student Responses
Mental Action 1 (MA 1)	Coordinating the value of one variable with changes in the other.	What happens to the value of air temperature as you change the value of carbon dioxide? e.g. *As the amount of carbon dioxide changes, the value of air temperature also changes.*
Mental Action 2 (MA 2)	Coordinating the direction of change of one variable with changes in the other variable.	How does the value of air temperature change as we increase the value of carbon dioxide? e.g. *As the value of carbon dioxide increases, the value of global air temperature also increases.*
Mental Action 3 (MA 3)	Coordinating the amount of change of one variable with changes in the other variable.	How does the value of air temperature change when the amount of carbon dioxide increases from 200 to 300 units? e.g. *As the value of carbon dioxide changes from 200 to 300 units, air temperature increases from 44 to 48 degree Celsius.*
Mental Action 4 (MA 4)	Coordinating the average rate-of-change of the function with uniform increments of change in the input variable.	What can you say about the change in the value of air temperature for each interval of carbon dioxide? e.g. *For every interval change of carbon dioxide, air temperature increases by 5 degrees or higher.*
Mental Action 5 (MA 5)	Coordinating the instantaneous rate of change of the function with continuous changes in the independent variable for the entire domain of the function.	How did the value of air temperature change for the entire change in carbon dioxide? e.g. *The change in the air temperature with respect to carbon dioxide is increasing.*

RESULTS

Investigation I

For the first investigation, we used an existing NetLogo simulation called the Climate Change (Figure 1). The Climate Change simulation represents a model of energy flow in the earth and its atmosphere, particularly heat energy. When sunlight falls on the earth's surface it either gets reflected in the atmosphere or is absorbed by the earth. The absorbed particles are infrared rays and they are represented as red dots in the simulation. The red dots randomly move around the earth and the simulation shows the change in air temperature as the amount of infrared rays increases.

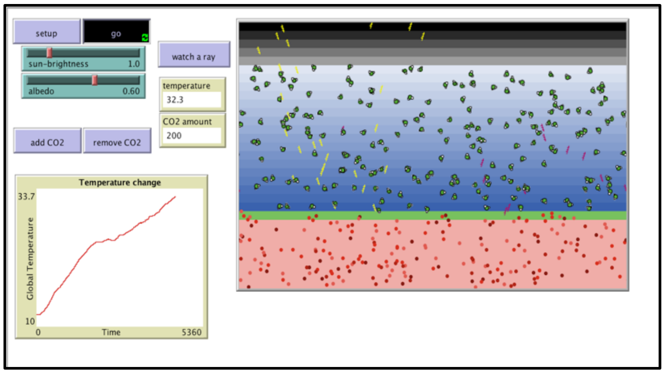

FIGURE 1: CLIMATE CHANGE NETLOGO SIMULATION

The simulation includes two factors of the environment, the albedo of the earth and the amount of carbon dioxide that impacts the atmospheric air temperature. The albedo of the earth, otherwise known as terrestrial albedo, is the measure of the reflective nature of the earth's surface. It is the proportion of the sun's radiation reflected by the surface of the earth. Various elements of the earth, such as the clouds, oceans, deserts, and forests absorb solar radiation and contribute to the global temperature of the planet. Since regions like forests and oceans are darker in color, they have lower albedo and absorb more sun's energy. On the contrary, ice and white clouds have a high albedo and absorb less the sun's energy. All these different albedos from different sections of the earth are averaged out to give the albedo of the planet. The user can manipulate the value of albedo of the earth (from 0 to 1) and observe its effect on the atmospheric temperature. The simulation also allows the user to increase and decrease the amount of carbon dioxide molecules by clicking the add CO_2 and remove CO_2 buttons and investigate how the value of atmospheric temperature changes along with it.

Students were asked to experiment with the simulation and respond to a series of statements pointing to the non-numeric covariational relationships between carbon dioxide, albedo, and air temperature, such as: "If I increase the value of albedo, the air temperature increases/ decreases" or "If I decrease the amount of carbon dioxide, the air temperature increases/ decreases". We then engaged students into a whole class discussion where they reflected on their explorations and articulated the relationships they found between the given quantities. Students' generalizations included statements such as: "the higher the carbon dioxide is, the higher the temperature would be" or "If I increase the value of albedo, the air temperature decreases." These generalizations show that students successfully identified the covariational relationship between carbon dioxide and temperature, as well as the relationship between the value of albedo and air temperature. Students not only identified the varying quantities in the simulation but they were also able to coordinate the direction of change of the two covarying quantities. Such coordination indicates students' reasoning aligned with Carlson et al.'s [17] Mental Action 2 in Table 1.

Subsequently, students were asked to use the simulation to collect data of the values of air temperature for different values of carbon dioxide in a table and plot the ordered pairs (Table 2 and Figure 2). We anticipated that the graphing activity might allow the students to recognize visually the amount and rate of change of air temperature with change in the value of carbon dioxide, in other words to reach Mental Actions 3 and 4 on the Carlson et al. [17] framework.

TABLE 2: TABLE CONTAINING THE VALUES OF AIR TEMPERATURE FOR CORRESPONDING VALUES OF CARBON DIOXIDE.

Carbon-dioxide	Air Temperature
0	25
100	34
200	44
300	48
400	56

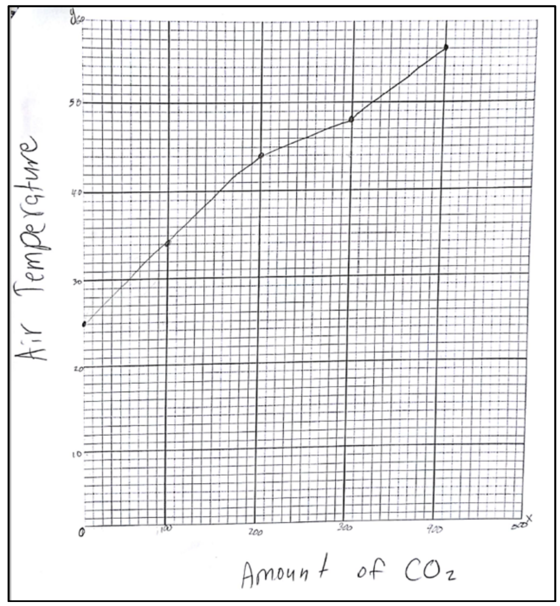

FIGURE 2: GRAPHICAL REPRESENTATION OF THE RELATIONSHIP BETWEEN CARBON DIOXIDE AND AIR TEMPERATURE

The students focused on each interval of carbon dioxide (example, [100-200], [200-300], etc.) and observed the change in the value of air temperature. One of the students, Molly, focused on two such consecutive intervals arguing that "this relationship is different from this relationship." When asked to elaborate her response, she added that "this temperature (temperature at 200 units of CO_2 - temperature at 100 units of CO_2) is 10 degrees higher than this one (temperature at 300 units of CO_2 - temperature at 200 units of CO_2). So, if you find a range, the range would be 10." Adding to Molly's explanation, another student, Kelly, explained that "these points are higher (temperature at 200 units of CO_2 - temperature at 100 units of CO_2), they are more steep. So that means there is higher increase. These means the numbers are further apart."

Students' responses show that their understanding went beyond the direction of change of output due to change in the input and they were able to focus on each interval of carbon dioxide to observe the amount of change in air temperature, aligned to Carlson et al. Mental Action 3 [17].

At this point, students were able to calculate and compare the rate of change of air-temperature for uniform increment of carbon dioxide.

Investigation II

The goal of this study was to help the students identify both the causes and consequences of the greenhouse effect. The impact of the disproportionate increase in the amount of atmospheric carbon dioxide presented in the first simulation helped us address the causal side of the greenhouse effect. To help students learn about the consequences of the greenhouse effect, the second simulation, Sea Level Rise (Figure 3) was developed. While the other existing simulations on sea level rise focused on the satellite map view of flooding, in this study we aimed to make the simulation more intuitive and relevant to middle school students by including various cartoon buildings in different areas of the New York city, Newark, and Kearny [21]. We anticipated that the graphic interface of the simulation would facilitate students in identifying that as the air temperature increases, the height of future sea level also increases, thus displacing people residing in those buildings due to flooding. In this simulation, students could change the value of temperature rise from 0 to 4 degrees Celsius in half degree increments. Each time the value of temperature rise increased by half-degree increments, the height of future sea level also increased by 4 feet.

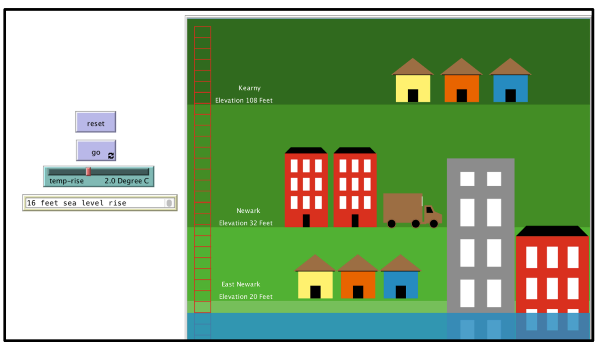

FIGURE 3: SEA LEVEL RISE SIMULATION

After an initial exploration of the simulation, the teacher asked the students to notice what happens when the value of temperature rise increases and students successfully identified that "the higher the temperature..., the higher the sea level and the lower the global temperature, the lower the sea level," a covariational reasoning which aligns to Carlson et al. [17] Mental Action 2. Next, students were asked to use the simulation to collect values of the height of future sea level for corresponding values of the rise of temperature in a table and plot the ordered pairs in a graph depicting the covariational relationship between the concerned quantities (Figure 4). During this activity, Kelly stated, "I know what it is, because I felt a relationship is already on a line." When we asked Kelly to explain her answer, she stated that the relationship will be "on line" or linear because "every time you increase by 0.5 degrees, the sea level rises 4 feet." Kelly's reasoning illustrates a type of covariational reasoning aligned to Carlson et al. [17] Mental Action 3.

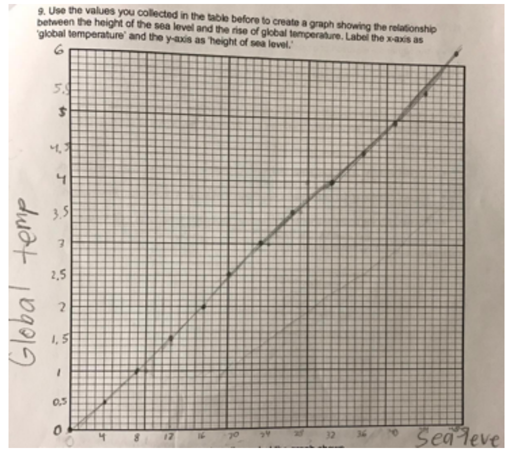

FIGURE 4: GRAPHICAL REPRESENTATION OF TEMPERATURE RISE AND HEIGHT OF FUTURE SEA LEVEL

Investigation III

The first two simulations were developed with the intention to help students identify the different traits and consequences of the greenhouse effect through dynamic mathematical activities. For the third investigation, we developed a new NetLogo simulation, the Carbon Calculator (Figure 5). To develop an equitable society, it is important to develop within students a sense of agency, that is, a belief in themselves as people who can make a difference in the world, as ones who are makers of history. Educators working toward an equitable and unbiased society can help students develop not only a sophisticated understanding of power relations in society but also the belief in themselves as conscious actors in the world [3]. Helping young people develop a sense of personal and social agency is the goal of this next simulation.

The Carbon Calculator simulation allows students to reflect on their own lives and inspect the amount of carbon dioxide they contribute to the environment annually. The user can select some of their daily life activities, such as number of hours they spend watching TV or playing video-games, or the amount of electricity they consume through AC or heater usage, and calculate the total amount of carbon dioxide they produce annually as a result of their current lifestyle. For each of these factors, students can manipulate the number of hours and calculate the total amount of carbon dioxide they emit in a year. For instance, if students watch TV for one hour and switch it off after watching, then the total amount of carbon dioxide added to the atmosphere in one year is 82 Kg. The calculator contains a slider for the TV hours, which the students can manipulate to increase the time watching to up to four hours and calculate the total amount of carbon dioxide added in the atmosphere. To help students engage in different forms of covariational reasoning, both linear and non-linear, we deliberately chose the values of carbon dioxide which would prompt students to plot and identify such relationships between two given quantities.

As students calculated and compared the amount of carbon dioxide they release through their household's regular activities, they made generalizations, such as the double/triple the distance travelled by a car, the double/triple the amount of carbon dioxide released, or the more the number of people

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carpools, the less the amount of carbon dioxide released in the atmosphere.

FIGURE 5: CARBON CALCULATOR NETLOGO SIMULATION

The goal of this activity was not just to help students recognize their contribution to climate change but also to take initiative and build strategies to change their own life-style and reduce carbon emissions. Therefore, after students calculated the amount of carbon dioxide they release based on their activities, we asked them to find ways to minimize the carbon emission by reconsidering some of their choices. Many students mentioned that they often keep chargers plugged in even though no device is connected, or keep their lights or AC on when they do not really need it. For instance, Jimmy commented, "I actually noticed that the AC, is a lot even if you leave it on for an hour. So, it would be smart not to leave it on overnight. I'll do that." The activity not only engaged students in calculating the total amount of carbon dioxide that they emit as a result of their daily activities, but also helped them become aware of the relentless usage of resources which disturb the normal atmospheric condition of the earth. This activity surprised some of the students, who responded with comments such as, "*Even if a TV is plugged in, the video game or X-box is plugged in, it still releases CO_2*". Another student said, "I did not realize that I release that much CO_2."

CONCLUSION

Our study suggests that the integrated curriculum we des_ provided students with a platform to develop their covariational reasoning through the context of climate change. Students investigated how the different quantities such as CO_2, albedo, air temperature, and electricity consumption covary and formed generalizations aligned to the first three Mental Actions of the Carlson et al. [17] framework.

Students' covariational reasoning helped them develop a critical consciousness about the greenhouse effect and suggest ways that they can help minimize the release of carbon dioxide in the atmosphere. This study shows that if schools adopt and implement such integrated curricula, then our students would be better prepared to interpret the data they encounter in their out-of-school lives and think critically about the underlying phenomena of our environment.

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