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Research Article

9-10-Year-Old Children's Understanding of Climate Change

Mijung Kim[1], **Qingna Jin**[2, *]

[1]Faculty of Education, University of Alberta, Edmonton, Canada
[2]Department of Education, Cape Breton University, Sydney, Canada

Abstract

Recognizing the need to educate young students about climate change, there is ongoing debate regarding the appropriate age and pedagogical approaches for its introduction. Scholars differ in their views on whether to postpone climate change education until higher grade levels due to concerns about children's cognitive and emotional readiness or to advocate for earlier involvement as a means of fostering civic engagement. To contribute on this discussion, this small-scale case study engaged 7 Grade 3-4 students to explore their perspectives and understandings about climate change. Over a two-month period, these students actively engaged in five one-hour sessions focused on climate-related topics, including weather, climate, and greenhouse effects. Group conversations and drawing activities were employed to foster an environment where the children could freely express their perspectives and experiences. The collected data included both students' drawings and video recordings capturing session activities and group interactions. The children in this study demonstrated critical awareness and concerns about climate change. They also expressed diverse conceptual understandings spanning from misconceptions and evolving ideas to sophisticated insights rooted in their experiences. Based on the findings, efforts are made to comprehend whether and how discussions about climate change can be initiated with Grade 3-4 students. The research concludes by highlighting the need for more comprehensive studies to investigate age-appropriate K-6 approaches and curriculum that address both the cognitive and emotional aspects of climate change education.

Keywords

Climate Change Education, Young Children, Qualitative Case Study

1. Introduction

1.1. Climate Change Education

In recent years, frequent climate crises such as wildfires, flooding, and droughts have increased concerns and questions about climate change in society and the calls for climate change education in schools [1, 2]. In Alberta, Canada, the number of wildfires fueled by severe heat and drought has recently increased, leading to loss of habitats, destruction of forests, air pollution, and health concerns [3]. A recent survey poll conducted by a youth group shows the majority of youth (74%) in Alberta worried about their future due to climate change [4]. This concern is not a local anomaly; it resonates with youth across the globe as climate anxiety and dissatisfaction with government responses are widespread within young population across the world [5–7].

While the imperative to educate the younger generation about

*Corresponding author: qingna_jin@cbu.ca (Qingna Jin)

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climate change is clear, the 'how' remains a contentious issue. Various challenges in teaching climate change in schools have been reported. One of the challenges is that there is no school subject or curriculum focusing on the environment or climate; thus, climate change is usually integrated and taught in other subjects such as science or social studies. Yet, its approach is often neglected or peripheral due to the heavy focus on disciplinary contents and curriculum outcomes [8–10]. Especially in science classrooms, the science concepts of climate change such as global warming gasses, greenhouse effect, weather and climate, etc. have been mainly focused to meet the curricular outcomes [11]. A recent literature review of climate change education has shown that, 40 out of 49 studies focused on the conceptual knowledge of climate change (17 on content knowledge alone and 23 on the combination of knowledge and attitudes and/or behaviors) [12]. Another systematic review study also highlighted the prevailing focus on scientific knowledge and conceptual understanding as the main goal of climate change education within school settings [13]. As students' knowledge has been emphasized, researchers questioned the relationship between disciplinary conceptual knowledge and actions, and various findings have been reported. For instance, a study found that students with more adequate scientific knowledge expressed social activism more frequently and their expression of activism developed after the instruction of scientific knowledge of climate change [14]. On the other hand, other researchers explain that scientific knowledge alone cannot be a driving force for decision making or actions, especially in the context of complex socioscientific and environmental issues [10, 15–17]. The deficit model of teaching climate change cannot bring desirable outcomes of decision making and actions or ignite meaningful changes [18]. The interrelation between the knowledge of climate change and pro-environmental attitudes is complex and not always causally related [19].

Teachers' perception, knowledge and beliefs are another challenge in climate change education. A study has reported that the majority of science teachers believe in the need for climate change education [20]. Nevertheless, various obstacles such as insufficient knowledge, lack of resources, personal belief (e.g., do not believe in scientific consensus on climate change), and fear of community backlash often deter them from teaching climate change effectively [1, 9, 18, 21–23]. When they implement it, some teachers focus on scientific concepts of climate change as the curriculum is content-focused [24] or some teachers view sociocultural and ethical concerns related to climate change are not science but social studies, thus should not be addressed in science classrooms [25].

With the diverse findings on the relationship among knowledge, decision making and actions, the challenges of teaching climate change, and anxieties that children face, researchers have emphasized the necessity for a more holistic redesign of how this crucial topic is taught, as it is not only disciplinary subject knowledge but also personal emotions and socio-cultural values that impact environmental actions [26–28]. It is critical to understand the complexity of one's knowledge, emotions, experiences and values in reasoning and decision-making about climate change.

1.2. Climate Change for Grade 3-4 Students

The age appropriateness of climate change education has been discussed. Pedagogical perspectives have traditionally skewed towards introducing climate change in upper elementary grades and higher levels. For instance, a recent review study showed that the majority of the studies on climate change in K-12 school systems focused on Grade 5, Grade 6 and higher levels [12]. Students' developmental intellectual maturity and emotional readiness have been discussed to explain this tendency, that is, students in Grade 5 are cognitively and emotionally ready to learn about climate change [29–30]. It has been explained that when children were asked to understand abstract issues beyond their cognitive abilities, they might develop anxiety, fear, or phobia toward nature [31]. Children below age 12 may not be at appropriate stages of cognitive development for the magnitudes of time and pace of climate compared to their everyday experiences [30]. The concepts of climate change can be too abstract and mental rather than concrete and tangible for these young children below age 12. This notion has also been reflected in the organization of science curriculum. In the Next Generation Science Standards [32], the greenhouse effect, climate change and its effects are explicitly included in Grades 6-12, clearly omitted in K-5 Grades [33]. Also, in the new science curriculum in Alberta, Canada [34], specific learning outcomes of climate change are listed in Grade 5 and 6.

This raises pedagogical questions regarding the importance of addressing climate change with students below Grade 5 and whether they are cognitively and emotionally ready to engage in discussions about this topic. As aforementioned, traditional climate change education has mainly focused on science content knowledge, with students' cognitive abilities considered pivotal for effective learning. It is important to question what possibilities there are to address climate change with younger students. Researchers claimed that children at early ages already encounter information on climate change through various information sources, books, mass media, etc. in their everyday lives [10, 35]. They start to develop and share questions, concerns, and anxieties about climate change [36, 37]; thus, when and how to address knowledge, concerns, and urgency of climate change with children has become a pedagogical question for teachers in elementary classrooms [31, 38]. If introduced in earlier grades of science classrooms, what would constitute an age-appropriate approach? How can discussions about climate change be tailored for Grade 3-4 students?

In this small-scale case study, 7 Grade 3-4 students were invited to share what perspectives and understanding they have in terms of climate change. Derived from the study findings, efforts are directed towards comprehending the potential methods of addressing climate change with Grade 3-4 students.

2. Research Process

2.1. Participants

For this study, participants were recruited from the local Alberta community through an informal, word-of-mouth approach. The study was promoted within the social networks, specifically targeting parents with children in Grades 3 and 4. While over 15 parents expressed interest in participating, seven students – three from Grade 3 and four from Grade 4 – were ultimately selected based on a first-come, first-served criterion. This selection approach was driven by limitations in available resources and the desire to ensure in-depth interactions, as well as robust data collection and analysis.

2.2. Learning Activities

Throughout two months, five one-hour sessions were organized with the student participants to facilitate discussions and learning about climate change. The initiation involved the topic of weather and temperature, encouraging students to share their everyday weather experiences and learn temperature measurement. The second session concentrated on understanding temperature change and global warming, utilizing a greenhouse model to illustrate the temperature increase. Subsequent sessions delved deeper into temperature change and global warming by analyzing various visual materials related to the causes and impacts of climate change. The fourth session continually focused on the greenhouse effect and global warming, prompting discussions about the causes and effects depicted in visual materials. To enhance engagement, students were also encouraged to express their ideas about climate change through drawings. In the final session, students had the opportunity to share their drawings, thoughts, and views on climate change. Table 1 includes more details about these activities.

Table 1. *Topics and session activities.*

Topics	Session Activities
Weather, temperature	Session #01 1. Sharing experiences of everyday weather. 2. Sharing ideas about what temperature, weather, and climate mean. 3. Learning how to measure temperature.
Greenhouse effect, temperature change, global warming	Session #02 4. Exploring the model of greenhouse and temperature increase. 5. Introducing students the visual cards related to climate change. Session #03 6. Inquiry activity: Knowing one of greenhouse gasses: Carbon dioxide. 7. Discussing visual materials related to climate change: Which card(s) do you think is/are related to climate change? Why? Session #04 8. Discussing visual materials related to climate change (causes and effects of global warming) 9. Drawing your ideas: What do I want to share about global warming with my siblings/friends? Session #05 10. Sharing your drawings and thoughts on global warming with others.

2.3. Data Collection and Analysis

Qualitative data were collected during the study. Each session was video recorded to capture the students' talk, actions, and interactions. Two video cameras were set up, one for each table where the students sat. Children's drawing and writing throughout the sessions were also collected. The data interpretation followed the steps of thematic coding [39, 40]. The two researchers separately viewed the video data and children's drawing and writing to understand how children experienced and understood climate change related ideas (open coding). The two researchers shared initial coding to compare similarities and differences in interpretation. Then, the data were collectively reviewed to identify similarities and differences and resolve any discrepancies. The main themes of the study findings were finalized through collective review and discussion (axial coding). To

delve deeper into children's understanding, data explicitly demonstrating the themes were selected, and the ideas expressed by children through their talk, drawing, and writing were examined (selective coding).

3. Findings

Throughout the study, children engaged in various activities sharing their experiences and understandings about climate change. They explained, drew, discussed, and interacted with classroom materials to learn about climate change and express their thoughts and insights on this complex issue. In this section, the key findings that emerged from the observation and analysis of the students' work are outlined. To ensure the anonymity of student participants, all their names have been replaced with pseudonyms.

3.1. Children's Awareness and Concerns About Climate Change

It was evident that students in this study were well aware of the notion of climate change. For instance, a student Jared remarked that he knew climate change was an ongoing phenomenon which "is happening every year, every month and every day." Moreover, students expressed their awareness of anthropogenic influences and genuine emotions concerning global warming and climate change. During the first session focused on weather, the following conversation took place.

Researcher: What do you know about the weather?

Nate: Global warming

Mike: Ya! That's actually a problem in ourselves because we actually made global warming. I don't want to talk about it.

Researcher: Why don't you want to talk about it?

Mike: Because global warming is destroying animals, it's gonna, maybe, kill penguins….

Nate: Progressively.

Mike: Ya, I know, it will actually.

After acknowledging that climate change was caused by human beings, Mike expressed his reluctance to discuss the topic, and his voice conveyed a clear sense of disappointment and sadness. This emotional tone indicated that the topic of global warming evoked strong feelings within him. Nate in the group also demonstrated his understanding and shared concerns about the impacts of global warming on animals and the potential for species extinction. Their comprehension went beyond mere awareness of the issue. They displayed a genuine empathy for the well-being of animals and expressed worry about the consequences of global warming on their lives.

Children's concerns and emotions regarding climate change were also shown through their drawings. Children depicted in their drawings the rising Earth temperatures and portrayed the potential impacts of global warming on both animals and humans. In Gina's drawing (Figure 1), she portrayed the collapse of fish populations, the increasing size of the sun, and the shrinking size of a tree and an animal figure symbolizing the negative consequences of climate change. When asked about her drawing, Gina provided further explanation:

There is the sun, and animals are surviving. For this one [pointing to the right part], the land will dry up and the fish will die…. [pointing to the left] This fox is really happy because all the fishes are alive, and it is not sweating that much. For this one [moving finger to the right] it [the fox] is sweating a lot, and all the fishes are dead. It is sad! Really sad!

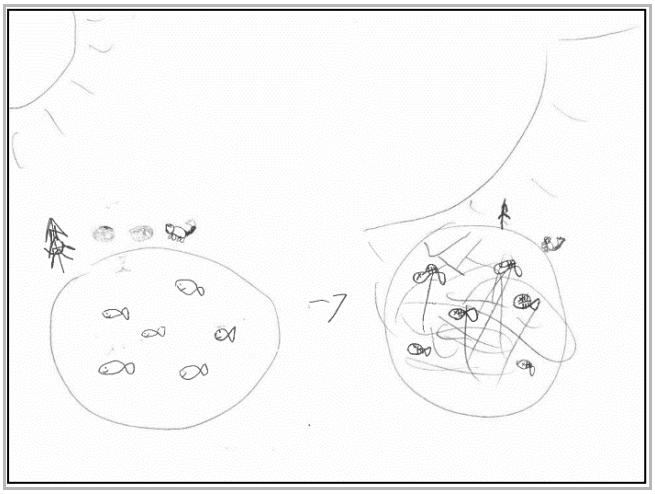

Figure 1. *Gina's drawing about climate change.*

Gina's drawing and explanation demonstrated her awareness of climate change and its impact i.e., the temperature of the earth is increasing leading to significant consequences for living beings on the planet. She also expressed her worry and sadness toward climate change.

Jane's drawing (Figure 2) depicted dark smoke emerging from buildings and cars, symbolizing the contributions of human activities to global warming. Both the human beings and animals in her drawing were covered with tears and sweat, highlighting the intense heat and discomfort caused by rising temperatures. Together with the visual elements, Jane's written words, "it is so hot that people and animals die," communicated a profound sense of distress and concern for the well-being of all living beings affected by global warming.

Nate drew a polar bear (Figure 3) sweating on a green field and explained that "global warming is changing landscapes." He also expressed his feelings, stating, "It is sad! It is sad to see a polar bear sweating on greenery because of global warming. It is sad. … But saving polar bears, saving our planet is never too late!'' The sense of sadness was evident; however, Nate also highlighted his hope and belief in the urgency of taking actions to address climate change and protect the environment and the Earth.

Figure 2. *Jane's drawing about climate change.*

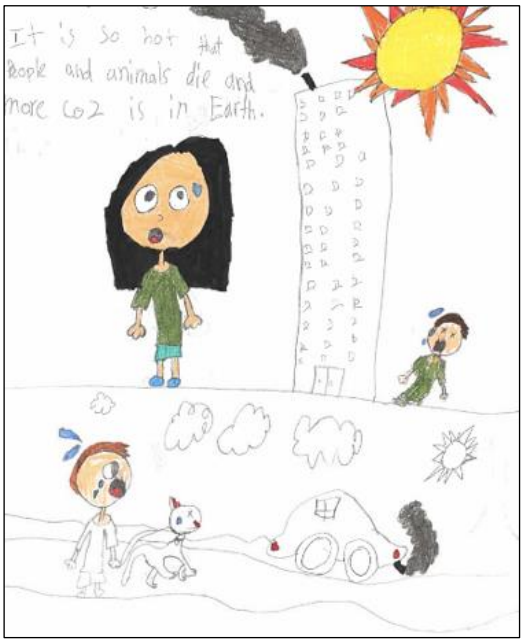

Figure 3. *Nate's drawing about climate change.*

Children in this study demonstrated their critical awareness of human being's role in climate change and emotional reactions towards global warming and climate change through conversations with peers and their drawings. Their emotional responses revealed their worries about the negative impacts on both human beings and animals caused by climate change. Notably, despite their young age, these children displayed a sense of urgency and beliefs in the need for action to address and mitigate the challenges posed by climate change. Their hopeful and determined outlook emphasizes the importance of empowering the future generation to take an active role in environmental stewardship.

3.2. Diversity of Children's Conceptual Understanding

In addition to demonstrating critical awareness and emotions towards climate change, children exhibited a diverse degree of conceptual understanding of climate change. In this section, the description begins with children's misconceptions and sophisticated insights, representing the two ends of the spectrum of their conceptual understanding to show the complexity of children's understandings about climate change. Following that, the exploration focuses on their evolving ideas, which was predominant in the observation, as well as how they collectively constructed and refined their ideas through collaborative efforts.

3.2.1. Misconceptions, as Well as Sophisticated Insights About Climate Change

During the research sessions, some misconceptions and misunderstandings were observed in children's explanations, which was not surprising. In this study, it was observed that children had diverse interpretations of the term "climate change." For instance, Gina expressed that climate change can refer to "the world gets warmer or colder." Daniel mentioned "climate change happens every year, it can start from warm to cold, and then [cold to] warm again." Another student attempted to differentiate climate change from global warming, noting that "global warming is getting warmer and warmer, but climate change can be either temperature going up or down." Also, regarding how to address climate change, Jared said "the only thing that can make it [the Earth] cool is the moon." These conversations highlight the challenges that children face in comprehending the time scale of climate change and differentiating it from daily changes in weather. The children encountered challenges to grasp the distinction between short-term weather changes and long-term temperature trends associated with climate change. They had heard, experienced, and read about the Earth's temperature changing over time, which led them to consider the possibility of getting colder again. Their attempts to reconcile their everyday experiences, such as getting cooler at night when the moon is visible, indicate their efforts to make sense of the concept of climate change based on their own observations and understanding. These experiences, although not directly related to climate change, may influence their interpretation and conceptualization of the phenomenon.

While holding misconceptions, students on the other hand also displayed some sophisticated ideas related to climate change. It was fascinating to witness their deeper understanding of the topic, considering their limited exposure to formal education on the subject. One area where children exhibited their sophistication was in their explanations of the 3R approach (reduce, reuse, recycle) as a means to address climate change. During a discussion on this topic, one student demonstrated their insightful thoughts on reducing and recycling. The conversation among the children unfolded as

follows:

Jared: This is what you can do, first, … grab the recycle stuff to recycle …

Nate: … landfill is something you cannot recycle, so the best is to reduce what we use … The first thing is to reduce the use, then the last is to recycle … because that is the last we can do.

…

Nate: Recycle is bad

Jared: No, it is good.

Nate: Recycling is bad, because the only way to recycle is to use a machine, and then it takes a long time. Maybe in North America, you have to ship it to Asia, and then you have to take a plane, a truck, maybe a ship to get there, and all of these things will create CO_2 (Carbon Dioxide) which is bad … also, the incinerator … to burn the recycled … when you burn it, there is CO_2 again.

Nate understood the complex relationship of recycling to climate change and further environmental issues internationally. His understanding of the 3R approach, specifically recycling and reducing, demonstrated their critical analysis of the environmental implications of human actions. He not only acknowledged the significance of waste reduction but also recognized the potential limitations of relying solely on recycling. While the 3R concept is promoted in climate change conversations, reducing and reusing are more effective than recycling, leading to less consumption and reduced waste. However, recycling is more commonly seen and practiced in everyday lives. Merely putting recyclable wastes such as water bottles or biodegradable containers into the recycling bins, people think that's an environmentally friendly action. However, the consequences of using many recyclable materials daily, even when unnecessary, or the effectiveness of recycling programs are not much questioned. The Grade 4 student's critical perspectives and questions about recycling were encouraging.

3.2.2. Conceptual Development in Progress

Over the course of the sessions, it was evident that the children's conceptions were continually evolving. They actively synthesizing their everyday experiences to formulate evolving ideas about climate change. They articulated and shared with each other ideas such as "the earth is getting warmer", "it impacts lives on Earth", and "some human actions make this worse." They were striving to make sense of how all these separate notions were interrelated. They were in the process of constructing and developing their understandings about climate change to construct a coherent understanding of climate change – even if these conceptual ideas were incomplete. For example, in a card-sorting activity where children were prompted to choose visual cards associated with climate change and explain their selections, it was clear that they could identify connections between various phenomena—like wildfires, droughts, deforestation, and endangered species—and climate change. Nonetheless, they struggled to articulate how these elements were interrelated. Take Anna as a case in point: she picked a card that showed a wildfire and identified it as related to climate change. Yet, when asked to explain her reasoning, she responded with uncertainty, saying "I don't know, but they are related … [thinking for a few seconds] maybe, the fire will have lots of CO_2, and that is related to climate change … there might be more." Anna recognized the connection between wildfires and climate change, noting one aspect of their relationship: wildfires release a large amount of CO_2 into the atmosphere, which contributes to global warming. Anna's comprehension of the interplay between climate change and wildfire was limited; yet, opened up her ongoing journey of understanding these complex relationships. Likewise, another participant, Jane, a Grade 3 student, selected two visual cards, one showing endangered animals and the other depicting industrial areas, and said that "they are related to global warming, … but I cannot explain why."

Children in this study demonstrated some ideas of multiple interconnected factors involved in climate change, yet, they were unable to articulate them fully. This limitation is understandable given the complexity of climate change. Children's understanding of the interconnected factors, albeit limited, suggests a developing understanding of the complexity of climate change. Jane, shared during the sessions that "I did not know much about climate change, but I am interested in learning more about it." As the sessions progressed with their enthusiasm, a steady and gradual development of children's understanding, interests, and emotional engagement was observed, especially through collaborative efforts. The following episode illustrates students collaboratively constructed and refined a collective representation of the greenhouse effect, highlighting both the natural processes that regulate the Earth's climate and the impact of human actions on altering this balance.

Nate took the lead by illustrating his comprehension on the whiteboard. He depicted the Earth's surface and the upper boundary of the troposphere as two circles, along with a chimney symbolizing CO_2 emission from industrial activities. Nate explained, "This is the Earth and the atmosphere ... This is the industrial area which releases more smoke, containing CO_2 that is being emitted into the atmosphere." Building upon Nate's drawing, Jared wanted to contribute and drew the Sun as the "heat source" (Figure 4b). He then added arrows to represent solar radiation reaching the Earth's surface, some of which were absorbed and reflected back into the atmosphere, ultimately becoming "trapped within the atmosphere" (Figure 4c). As Jared made this addition, Daniel noticed the representation of cars was missing and mentioned their contribution to the greenhouse effect "also cars, with cars, there will be more [solar radiation] trapped in the atmosphere". Inspired by Daniel's comment, Jared included a car emitting CO_2 as another source of greenhouse gas (Figure 4d).

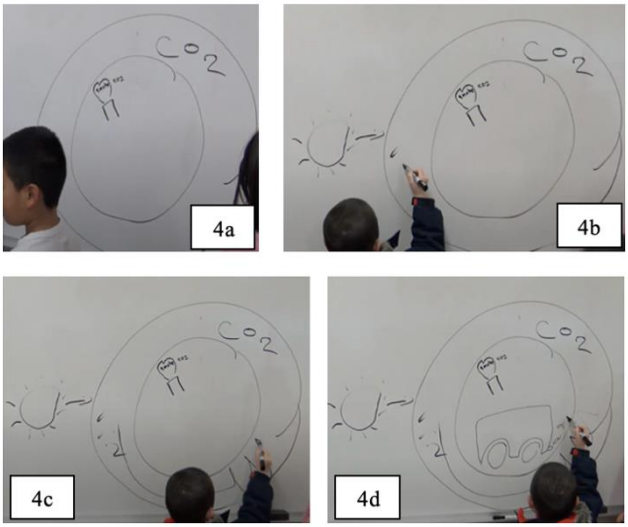

Figure 4. *Children's collective drawing.*

Through this collaborative process, the children created a collective explanation of the greenhouse mechanism, incorporating key components such as incoming solar radiation, absorption and reflection, greenhouse gasses (specifically CO_2), and the generation of thermal energy. Their drawings and discussions demonstrated an understanding of both the natural greenhouse effect and the enhanced greenhouse effect resulting from human activities. Their comprehension of how human activities have enhanced the greenhouse effect and contributed to global warming highlights their growing awareness of the complexities of climate change.

4. Discussion

Children in this study exhibited a keen awareness of and concerns about climate change. They also demonstrated a range of conceptual understandings about the issue, spanning from misconceptions, evolving ideas to sophisticated insights. A noteworthy observation was the important role of collaborative engagement in visualization with peers in advancing and refining their evolving understandings. While misconceptions were identified among children in this study, they were observed as alternative ideas subject to change over time. Many researchers have noted that misconceptions or erroneous explanations about climate change are prevalent among high school and university students, as well as adults [41, 42]. Therefore, the identified misconceptions shouldn't be a factor against teaching children about climate change; they instead emphasize the need to explore effective and appropriate ways of introducing and engaging children in climate change education.

Amidst the ongoing debate concerning when to introduce climate change topics in elementary classrooms, questions have been raised about younger students' cognitive and emotional capacity to comprehend the complexity of the issue. Some researchers advocate postponing climate change education until Grade 5 or higher, contending that younger children lack the necessary cognitive and emotional maturity to tackle these intricate topics [29, 30]. However, findings from this study indicate that students in Grades 3-4 can engage meaningfully with climate change issues, suggesting that with well-designed instructional supports and pedagogical strategies, early engagement in climate change discourse could be beneficial for younger learners.

Scholars have emphasized the importance of early civic engagement by involving young students in environment- and climate-related conversations [43, 44]. However, the same study also illuminates teachers' apprehensions regarding the developmental appropriateness of introducing climate change issues. Specifically, teachers advocated for setting age restrictions, particularly on activist actions like local campaigns or legal demonstrations, advising that such involvement be delayed until ages 11-13 [43]. This caution mirrors broader educational concerns about exposing young children to complex or emotionally charged topics. Some teachers believe that the innocence of childhood should be protected from complex societal issues [45]. Introducing sensitive topics may emotionally or psychologically burden young learners, leading teachers to omit such subjects from their curriculum [45]. Climate crisis is one of the topics that might elicit concerns from teachers, who may choose to sidestep the issue to protect childhood innocence and to prevent causing tension among children, families, and communities. Nevertheless, the research prompts a reconsideration of the advisability of this protective stance. Children in this study exhibited both cognitive understanding and emotional responses to climate change. Specifically, through their drawings, they empathetically portrayed animals suffering from the consequences of climate change, showing concern for loss of habitats and extinction. This resonates with findings from another study, where children aged 9-10 expressed strong emotions, including anger towards adults for contributing to climate change, and concern for the well-being of animals [46]. Given that children are already forming their own perspectives on climate change through various mediums, avoiding these topics may hinder, rather than help, children's learning and understanding of the world [26].

Discussions with students revolved around responsibilities and actions to foster hope and optimistic attitudes toward climate change. However, due to time constraints, delving deeply into these critical conversations was not possible, leaving pondering on how to address the anxieties young children may experience about climate change. This raises further questions about how to effectively engage students in both intellectual and emotional dialogues within the elementary classroom setting. These reflections lead us to recognize that the current focus of climate change education primarily centers on the scientific legitimacy of its causes and effects, neglecting the emotional, ethical, and actionable dimensions. Despite a weak or no-coalition between scientific knowledge and pro-environmental attitudes and behaviors [47], the prevailing educational approach remains largely content-centric, pressuring teachers to "cover" curriculum requirements. This

constraint is felt as early as preschool, where teachers encounter barriers to talking about the environment due to the responsibilities of school curriculum [48, 49]. Such concerns are certainly not unique to preschool and resonate across the K-12 spectrum. Acknowledging many challenges that teachers encounter in climate change education (e.g., a lack of time and support, curriculum constraints), research underlines the pivotal role that classroom teachers play in shaping positive narratives and outcomes related to climate change and sustainability [50]. Committed teachers find innovative ways to integrate the urgency of climate issues with students' existing knowledge, emotions, and experiences, thereby crafting more comprehensive and effective educational approaches [26].

5. Conclusion

In conclusion, this study highlights the capability of Grade 3-4 students to engage meaningfully with climate change, challenging notions of postponing climate change education until later grades and emphasizing the importance of early engagement with climate change discourse. Findings from this study encourage educators to reconsider protective stances, recognizing that children, even as young as 9-10, are actively shaping their perspectives on climate change through various mediums. Avoiding these conversations may hinder their learning and understanding of the world.

Children in this study, through sharing their rich knowledge, experiences, and emotions, prompt reflection on how they situate themselves within the larger narrative of climate change. The findings suggest that educators should not overlook the intricate interplay of students' experiences, emotions, and understandings when discussing climate change in the classroom setting. Future studies will be essential to explore effective ways of addressing the complexity of children's cognitive and emotional understandings of climate change and developing age-appropriate climate change education across K-6 levels.

Ethics Approval and Consent to Participate

This research has been granted ethics approval by the University of Alberta. All the student participants and their parents have provided consent by signing assent and consent forms.

Abbreviations

CO_2: Carbon Dioxide
3R: Reduce, Reuse, Recycle

Author Contribution

Mijung Kim, the first author of this paper and PI of the project, led this research study. Two authors, Mijung Kim and Qingna Jin, worked collaboratively on all stages of the writing process.

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Conflicts of Interest

The authors declare no conflicts of interest.

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