



Children-led environmental communication fosters their own and parents' conservation behavior

Jianchi Tian^{a,b}, Yuanchao Gong^{a,b}, Yang Li^c, Yan Sun^{a,b}, Xuefeng Chen^{a,b,*}

^a Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Beijing 100101, China

^b Department of Psychology, University of Chinese Academy of Sciences, Beijing 100049, China

^c School of Business, Beijing Technology and Business University, Beijing 100048, China

ARTICLE INFO

Editor: Prof. Pasquale Marcello Falcone

Keywords:

Children-led environmental communication

Children

Parents

Climate change education

Conservation behavior

ABSTRACT

Carbon neutrality is one effective way to mitigate climate change, and it requires the efforts of all sectors of society. Researchers have developed several communication strategies to encourage climate collective action, but they have mainly focused on adults. We propose children-led environmental communication is a productive pathway for promoting collective action. The present study, using a total of 458 matched household-level survey data and qualitative data from eight children, explored the role of children-led environmental communication. The results show that: (1) Children-led environmental communication facilitates their own climate change worry which in turn leads to conservation behaviors. (2) For parents with little literacy of carbon neutrality, their climate change worry is positively predicted by environmental communication led by their children which also leads to conservation behaviors. (3) Climate change education promotes children-led environmental communication by increasing carbon neutrality knowledge. In conclusion, children-led environmental communication is driven by climate change education, which in turn promotes conservation behavior in children as well as in their parents. We suggest that educators and communicators could consider children-led environmental communication as a new breakthrough in promoting collective action to mitigate climate change.

1. Introduction

Climate change has become a common problem facing the world. If the 1.5 °C goal of the Paris Agreement is to be met, carbon neutrality will have to be achieved by around 2050 (Intergovernment Panel on Climate Change, 2018). To reduce carbon emissions, individuals' behaviors such as efficient use of energy and resources in the residential sector and opting for public transport are considered as effective ways (United Nations Environment Programme, 2020; Mi et al., 2021). Accordingly, researchers developed several communication strategies to encourage mitigation behavior (Lawson et al., 2018). Empirical evidence shows that climate change communication typically changes people's perceptions of climate change as well as mitigation behaviors (Goldberg et al., 2019; Goldberg et al., 2022).

In existing research, climate change communication is defined as a conversation or discussion between individuals about climate change (Goldberg et al., 2019; Swim et al., 2018). However, adults usually take the lead in climate change communication at the household level, and children being a passive and marginal position in the communication

process are often overlooked by communicators. We believed it is essential that children can also play a leading role in communication. In this study, *children-led environmental communication* is defined as the communication initiated by children with parents, peers or teachers about environmental topics. It is a very promising strategy to nudge household conservation behaviors in two ways. First, according to self-determine theory (Ryan and Deci, 2017), the initiative in children-led environmental communication reflects children's intrinsic motivation that helps them to actively engage in communication, which further contributes to positive downstream effects such as the internalization of environmental information and changes in their own conservation behaviors. Second, because parents are more likely to trust information from their children (Lawson et al., 2018; Sameroff, 1975; Wang et al., 2022), children-led environmental communication is a suitable way to change their parents' conservation behaviors. Therefore, parents may shift their own views when children proactively communicate environmental information to them.

There are several limitations in previous research on climate change communication. First, previous research mainly explored the effect of communication on adults' perceptions of climate change and behaviors.

* Corresponding author at: Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Beijing 100101, China.

E-mail address: chenxf@psych.ac.cn (X. Chen).

<https://doi.org/10.1016/j.spc.2023.10.006>

Received 20 April 2023; Received in revised form 25 September 2023; Accepted 6 October 2023

Available online 9 October 2023

2352-5509/© 2023 Institution of Chemical Engineers. Published by Elsevier Ltd. All rights reserved.

Nomenclature	
NNOCCI	National Network for Ocean and Climate Change Institutions
T1	Time 1
T2	Time 2
SE	Standard Error
CI	Confidence interval

Actually, most researchers only measure communication by asking adults whether they discussed climate change with family (e.g., Ballew et al., 2019; Goldberg et al., 2019; Goldberg et al., 2022), without considering the role of children's initiative (Stevenson et al., 2016; Wang et al., 2022). Hence, there is a lack of research exploring whether and how children-led environmental communication affects their own behavior. Second, researchers have realized that adults are influenced by entrenched worldviews and political leanings, and that children are usually not interfered with by political leanings and worldviews and can stimulate adults to rethink and accept climate change information (Cohen, 2003; Lawson et al., 2018; Wang et al., 2022). Yet, limited research considers the role of children-led environmental communication on parents. This is surprising, considering that communication pathways led by children are uniquely positioned to combat inherent adult perceptions of climate change. Third, it is worth noting that research on promoting people to engage in communication is emerging. Recent studies found some interventions, such as educational activities, that are able to enhance adult's willingness to discuss climate change with others (e.g., Geiger and Swim, 2016; Geiger et al., 2017a). The impact of these educational activities on adult discussion is often explained by researchers using social learning theory, impression management and the spiral of silence theory. For children, schooling is a key part of shaping their perceptions and behaviors, which makes it possible for children to initiate discussions about environmental topics. However, given the lack of consideration of initiative in communication in existing research, no studies have explored the impact of education on children-led environmental communication based on self-determination theory. Hence, there is still a huge gap to explore how education fosters children to proactively communicate environmental information with others.

To fill these gaps, we seek to address three fundamental questions in children-led environmental communication: Does children-led environmental communication influence their own conservation behaviors? Does children-led environmental communication have a spillover effect on their parents' conservation behaviors and why? Does climate change education influence children-led environmental communication? We conducted a survey of 440 children and their parents (one parent in each household) in China, over a nine-month interval. We asked children at Time 1 (T1) about conservation behaviors, environmental communication, and collected their demographic information. Considering that communication does not work immediately, after 9 months (Time 2, T2), we therefore asked their parents about their climate change worry, conservation behaviors, literacy of carbon neutrality, and their demographic information (including age, sex, monthly income, and education level). To further validate the role of children-led environmental communication, we conducted face-to-face interviews by inviting eight children in a Beijing middle school, and obtained their qualitative data. Based on these sample data, the results showed that children-led environmental communication had a significant and positive effect on their own conservation behaviors by the mediation of climate change worry; children-led environmental communication significantly and positively predicted parents' conservation behaviors by the mediation of parents' climate change worry. Further exploration found that climate change education had a significant and positive effect on children-led

environmental communication by the mediation of carbon neutrality knowledge. The research framework is shown in Fig. 1.

Our research contributes to the existing literature in three ways. First, the current study found a significant effect of children-led environmental communication on children's conservation behaviors and a key mediator (climate change worry). These findings fill a gap in the climate change communication literature and provides a strong basis for understanding the role of children-led environmental communication. Second, based on our matched family-level data, we found that children-led environmental communication and conservation behavior predict parental climate change worry and conservation behaviors across time. These findings demonstrate robust and positive spillover effects of children's proactive participation in environmental communication, and thus provide new directions for theoretical development of climate change communication. Finally, for the first time, the current work demonstrates that climate change education influences children-led environmental communication through knowledge, suggesting a pathway by climate change education facilitates children-led environmental communication.

2. Literature review and theoretic foundation

In Section 2, we conduct a literature review and examine the existing theories on children-led environmental communication. We propose a framework that explores the influence of children-led environmental communication on both their own conservation behaviors and those of their parents, as well as the factors that affect children-led environmental communication, particularly climate change education. This section's framework consists of three main components: (1) the relationship between children-led environmental communication and conservation behaviors, (2) the spillover effects of children-led environmental communication, and (3) the impact of climate change education on children-led environmental communication.

2.1. Children-led environmental communication and conservation behaviors

Initiative holds a central position in self-determination theory and reflects an individual's intrinsic motivation (Ryan and Deci, 2017). In

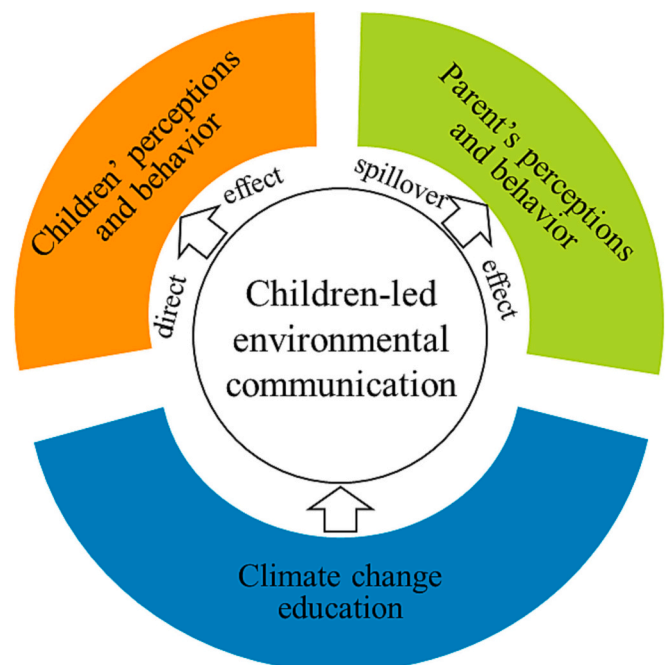


Fig. 1. The framework of the current research.

this theory, intrinsic motivation represents a highly autonomous and self-driven state for individuals, emphasizing the pivotal role of initiative in engaging in various activities. For example, in the context of school learning, the quality of learning is usually better for students with high intrinsic motivation. Conversely, extrinsic motivation entails engaging in behaviors driven by external factors such as compliance, rewards, or punishments, which often results in lower performance compared to intrinsic motivation (Ryan and Deci, 2017). To illustrate, students primarily motivated by extrinsic factors may experience diminished learning outcomes during passive learning, and they may even be at risk for behavioral problems or dropping out of school (Ryan and Deci, 2013, 2016).

Applied to environmental communication, self-determination theory highlights the positive impact of the intrinsic motivation in the communication initiator on individual performance (Ryan and Deci, 2017). Within families, parents commonly take the lead in initiating conversations, leaving children in passive roles and subject to external pressures to participate in discussions. Consequently, these non-self-determining factors suggest that children may lack autonomy and exhibit externally driven motivation in engaging in environmental discussions, which may not yield positive behavioral outcomes from these conversations. In contrast, when children take the initiative in discussing climate change topics with their parents, this self-directed behavior contributes to favorable downstream effects.

We contend that when children proactively engage in conversations about climate change, their self-driven engagement yields positive outcomes, including enhanced climate change worry and increased personal climate actions. From the perspective of climate change communication theory (Ballantyne, 2016), interpersonal environmental communication shapes people's perceptions of climate change, which is one of the keys to influencing behaviors. For example, Goldberg et al. (2019), based on the panel data, found that interpersonal environmental communication effectively raised climate change worry. As climate change worry results from people engaging with the topic of climate change and being troubled by the consequences of climate change, it is likely to motivate individuals to take personal climate action to mitigate climate change (Bouman et al., 2020).

However, children-led environmental communication has long been overlooked by communicators. Most research on the role of climate change communication tends to focus on general discussions among adult populations, neglecting the significance of initiative and children in communication. Consequently, there are limited studies that have addressed the positive downstream effects (e.g., increased climate change worry promotes conservation behavior) of children-led environmental communication. Therefore, based on the above inferences, we propose the following hypotheses.

H1. Children-led environmental communication is able to promote their own conservation behavior.

H2. Climate change worry mediates the effect of children-led environmental communication on conservation behavior.

2.2. The spillover effects of children-led environmental communication

The spillover effect of communication can be explained by socialization theory. According to socialization theory, parents as the primary socialization factor exert the greatest influence on children and adolescents. Most research on socialization focuses on children's learning outcomes during interactions with their parents. These outcomes are thought to be likely to result from communication within the family (Grønhoj and Thøgersen, 2009). Empirical studies found that environmental communication in family contributes to the adoption of pro-environmental behaviors by family members. For example, married-couples promote each other's pro-environmental behaviors (Goldberg et al., 2022; Hung and Bayrak, 2019); parents foster their children's climate change perceptions and behaviors (Jia and Yu, 2021; Mead

et al., 2012; Valdez et al., 2017).

Recently, a growing body of environmental research focuses on reverse intergenerational effects (Lawson et al., 2018; Wang et al., 2022; Žukauskienė et al., 2021), and it is supported by the bidirectional theory of parent-child relationships (for example, Bell, 1968; Sameroff, 1975). Spiteri (2020) found that parents reported that they were often receptive to requests from children and willing to engage in recycling behaviors. Ultimately, the results of the interviews showed that some children extended the participation of the community in the act of recycling (Spiteri, 2020). An interview with Chinese families also showed that children shared environmental topics with their parents and believed they influenced their parents, while parents acknowledged that they were influenced by their children to actively participate in pro-environmental behaviors (Deng et al., 2022). The results of these qualitative multiple case studies across different cultural contexts reveal that children-led environmental communication has a real impact on parents' pro-environmental attitudes and behaviors.

An empirical study focusing on parent-child intergenerational learning showed that climate change communication elevated parental climate change worry (Lawson et al., 2019a). In another study conducted by Lawson et al. (2019b), educational sessions focusing on intergenerational learning were conducted. The results revealed that children's communication about climate change with their parents increased parental worries regarding climate change within an education-driven context. Especially in the family context, children are a source of climate change information from close social networks (compared to less close social networks) (Žukauskienė et al., 2021), and they are more likely to motivate parents to accept information (for similar views see Goldberg et al., 2019; Lawson et al., 2018; Wang et al., 2022). Therefore, it is reasonable to assume that child-parent communication elicits parental climate change worry, which provides a route of spillover effects from children-led environmental communication to parent's conservation behaviors.

In addition, the characteristics of parents may moderate the spillover effect of children-led environmental communication. For example, parents with different levels of climate change literacy may be influenced differently by children-led environmental communication, as knowledge is a driver of public concern about climate change (Shi et al., 2016). Further, for parents who lack knowledge about climate change mitigation such as carbon neutrality, the information they receive come more predominantly from communication with their children (Žukauskienė et al., 2021), and their climate change worry may be altered as a result. Ultimately, parents' climate change worry arising from their communication with their children will motivate them to take further action. Considering that there is limited knowledge about the spillover effect of children-led environmental communication, the present study aims to prove the following hypothesis based on matched household-level data.

H3. For parents with little literacy of climate change mitigation, children-led environmental communication increases parental climate change worry, thus increasing parental conservation behaviors; for parents with relatively high literacy of climate change mitigation, children-led environmental communication is less likely to increase parental climate change worry, increasing parental conservation behaviors.

2.3. Climate change education and children-led environmental communication

Education may have great potential to foster children's proactive communication, as a sound educational approach is an important path to develop students' autonomy by knowledge (Ryan and Deci, 2017) and children's knowledge has been identified by researchers as an important factor in breaking climate silence (i.e., not engaging in environmental communication) (Geiger and Swim, 2016; Goldberg et al., 2019; Swim

et al., 2018). While communication scholars gradually focused on how to contribute to climate change discussions in recent years, one possible explanation is that (Geiger and Swim, 2016), according to the spiral of silence theory, if people mistakenly believe that they are in conflict with the views of the majority of other people, they will be reluctant to engage in climate information dissemination. Especially, since the topic of climate change is controversial, they believe that their views may not be popular with others. Other evidence also shows that U.S. adults report more knowledge about climate change when they participate in educational programs aimed at increasing their knowledge (Geiger et al., 2017b). Importantly, climate change knowledge improved their self-efficacy and response efficacy to engage in climate change discussions, which led to an increase in the discussion of climate-change related topics (Geiger et al., 2017a).

It is universally accepted that education as one of the effective interventions provides students with knowledge (Barraza et al., 2003; Monroe et al., 2017). Applied to climate change, climate change education aims to enrich students' knowledge of climate change through the addition of climate change to curriculum guides (Monroe et al., 2017). Empirical studies have found that climate change education increases students' knowledge about climate science (Flora et al., 2014; Karpudewan and Mohd Ali Khan, 2017; Tolppanen et al., 2022). For example, in the United States, a leadership training program on climate change education led by the National Network for Ocean and Climate Change Institutions (NNOCCI) is designed to increase knowledge about climate change. Swim et al. (2017) found that visitors who participated in climate change education at nature-based museums participating NNOCCI reported more knowledge compared to non-visitors.

However, climate change education researchers have begun to question the weak link between knowledge, attitudes and behaviors to engage with climate change (e.g., Monroe et al., 2017; Rousell and Cutter-Mackenzie-Knowles, 2020). In addition, existing research has also neglected proactivity in environmental communication, and the topic of knowledge influencing children's proactive engagement in environmental communication based on self-determination theory has not been examined. Therefore, there is a strong need to test the effectiveness of climate change education and whether it affects students' proactive climate change communication. If carbon neutrality education increases students' carbon neutrality knowledge, children may be more willing to proactively engage in environmental communication. Therefore, we propose the following hypothesis.

H4. Climate change education has a positive indirect effect on the frequency of children-led environmental communication through knowledge.

3. Methods

In Section 3, we provide an overview of the reasons and procedures for data collection, as well as the measurements for key variables. In Subsection 3.1, we provide a detailed explanation for selecting Beijing as a representative region in our study, and describe the process of collecting household-level data and socio-demographic information from participants. Additionally, we provide a description of the purpose of the qualitative interview and information about the interviewees. In Subsection 3.2, we outline the measurements for key variables, which include children-led environmental communication, climate change worry, conservation behaviors, climate change education, children's knowledge about carbon neutrality, parental literacy of carbon neutrality, and control variables.

3.1. Data collection

We used Beijing as the study site. Beijing is one of the most populous and educated cities in China, and it ranks first among Chinese provinces and cities in GDP per capita (2022). It is a leader in China in all aspects of

the economy and education. However, despite its advancements, Beijing's energy consumption continues to trend upward. Fortunately, in line with the Chinese government's goal of carbon neutrality, the Beijing Municipal People's Government has introduced policies and programs to promote carbon peaking and carbon neutrality in the areas of energy, science and technology, and education. For example, the local government of Beijing has launched the Beijing Green Development and Carbon Neutral Campaign, which includes activities like the Beijing Green Living Season and the Carbon Inclusion Service for Resident Households. These efforts incentivize residential households to adopt low-carbon behaviors through financial incentives from the consumption side. Importantly, carbon-neutral education is also being implemented by the local government in Beijing. It serves as an effective tool that extends beyond individual consumers and can impact entire households. Some middle schools in Beijing have gradually incorporated carbon neutral education into their education system. For example, middle schools in Beijing encouraged students to engage in activities such as producing handwritten newspapers, donating used goods, and participating in popular science fairs and talks, all centered around the concept of low-carbon practices (Zhang et al., 2022). Therefore, we chose Beijing as a representative region to study the impact of children-led environmental communication on the conservation behavior of children and their parents. We hope that targeted climate change education will promote climate change mitigation behavior among various groups, such as youth and middle-aged adults.

In November 2021, we contacted over a dozen classroom teachers in several Beijing middle schools and informed them that we hoped to learn about students' knowledge and attitudes towards carbon neutrality. After obtaining students' consent, the classroom teachers sent the questionnaire (please see the supplementary information below) developed by us to their students. In the end, we collected 723 questionnaires at time 1 (T1). In general, communication does not work immediately, given that it requires the long-term engagement of people to change their perceptions and behaviors (Markowitz and Guckian, 2018). Therefore, to assess the robustness of the effect of children-led environmental communication, we surveyed their father or mother after nine months (notated as Time 2, T2), and collected a total of 458 matched household-level data, with a response rate of 63.34 %. After excluding missing cases for key variables (excluding socio-demographic variables) as well as invalid cases (a total of 3.93 %), the final valid sample was 440. The demographic distribution of children and parents is shown in Table 1.

To further validate the effectiveness of children-led environmental communication and climate change education, we conducted qualitative data collection in June 2023 at a middle school in Beijing. Convenience sampling was used to select participants for the study. A total of eight children (males = 2, females = 6; mean age = 13.25, standard deviation = 0.46) were invited to participate in structured face-to-face interviews. During the interviews, we posed two question themes to both the children: (1) whether their involvement in climate change education influences their own knowledge and the initiative of discussions. (2) whether the initiated discussions of climate change with their parents influences their parents' attitudes and behaviors. The specific questions posed in the interviews can be found in Appendix A Table A1. The results of these interviews allow us to further qualitatively assess the causal relationships between these variables.

Additionally, we invited the parents (mean age = 43, standard deviation = 2) of these children to complete an online questionnaire survey. Specifically, we designed an online questionnaire and instructed these children to take home printed QR codes for their parents to use in completing the questionnaire. However, only six out of eight parents responded to the survey, including two males and four females. In the questionnaire (as shown in Table A2), we asked parents to determine whether their children had proactively discussed carbon-neutral related topics with them and whether this had influenced their attitudes and behaviors.

Table 1
Socio-demographic information of the participants.

Characteristic Socio-demographic	Descriptions	Children (Number)	Descriptions	Parents (Number)
Sex	Male	216	Male	95
	Female	218	Female	345
	Missing	6		
Age (years old)	12	187	30–40	117
	13	179	41–45	215
	14	62	>45	108
	Missing	12		
School	A	126		
	B	33		
	C	281		
Education level	–	–	Junior high school and below	26
	–	–	High school/ junior college	71
	–	–	Bachelor's degree/college	280
	–	–	Graduate students	63
	–	–	Under 3000	35
Income (Yuan/ Month)	–	–	3000–5999	74
	–	–	6000–9999	123
	–	–	10,000–29,999	152
	–	–	30,000 and above	56
	–	–		

Note: We excluded all missing values in our statistical analysis. Specifically, in the correlation analysis, we used 440 valid samples to exclude missing cases for key variables; In the linear regression analysis, we further excluded missing cases for socio-demographic variables to control for the influence of socio-demographic variables.

3.2. Measurements of key variables

3.2.1. Children-led environmental communication

We used a question to ask students whether the description of environmental communication matched their actual situation (0 = very unlikely, 10 = very likely) at T1, i.e., “I would take the initiative to discuss low-carbon environmental knowledge with my classmates, teachers, or family”. This question was adapted from a survey by the Yale University Climate Change Communication Project (Ballew et al., 2019).

3.2.2. Climate change worry

We used four questions to measure climate change worry at T1. The measure was adapted from the study by Lawson et al. (2019b). The four questions included, “How worried are you about climate change? (0 = not worried at all, 10 = very worried)”; “How much do you think climate change will affect the following areas? (0 = very little, 10 = very much) a. Global; b. China; c. The region where you live”. In the child sample, the Cronbach's alpha coefficient for these four questions was 0.752; in the parent sample, the Cronbach's alpha coefficient for these four questions was 0.860, indicating that the four questions had a good reliability. We calculated the average value of the participants' scores on four questions, which represented climate change worry.

3.2.3. Conservation behavior

We used four items adapted from the study by Han et al. (2022) to measure conservation behavior. Respondents were asked to judge whether the descriptions of behaviors were consistent with their usual habits (0 = not at all, 10 = very much). The four descriptions included “Every time I leave a room, I turn off the lights”, “I save electricity by removing the plug from the plugboard immediately after charging my phone or other electronics while at home”, “I can use air conditioners or heaters in an energy-conserving way, for example, the temperature of air conditioners is not set lower than 26 degrees Celsius in summer, and

windows are not opened frequently in winter to reduce unnecessary energy waste” and “I manage to reduce water consumption when taking a shower (e.g. turning off the showerhead when applying the shampoo)”. In the child sample at T1, the Cronbach's alpha coefficient for these four questions was 0.757; in the parent sample at T2, the Cronbach's alpha coefficient for these four questions was 0.778, indicating that the four questions had a good reliability. We calculated the average value of the participants' scores on four items, which represented conservation behavior.

3.2.4. Climate change education

At T1, we asked students about the status quo of climate change education in their schools, with four questions. “Has your school carried out handwritten newspaper production activities on energy conservation, low-carbon environmental protection, etc.”; “Has your school organized donation activities for used items”; “Has your school provided the opportunity to participate in science fairs on carbon neutrality, low carbon environmental protection and other themes?”; “Has your school organized lectures in popularizing knowledge on carbon neutrality, energy conservation, emission reduction, low-carbon environmental protection and so on?”. Students were asked to answer ‘yes’, ‘no’ or ‘don't know’. Only items with a ‘yes’ answer were scored as 1 point. Ultimately, the sum of the four questions represented the level of students' participation in climate change education. The validity of these four questions has been tested by existing research (Zhang et al., 2022).

3.2.5. Children's knowledge about carbon neutrality

Nine questions were developed to measure students' knowledge of carbon neutrality. Students were asked to determine whether the description of carbon neutrality was correct at T1. Only items that were answered correctly were scored as 1 point. The final sum of the nine questions represented the level of carbon neutrality knowledge. The nine questions included “Clothes produce carbon emissions during the manufacturing process”, “Food purchased at home (e.g., meat, vegetables, fruits, snacks, etc.) does not produce carbon emissions during production, transportation, etc.”, “Consumption of paper is not related to carbon emissions”, “Carbon emissions in daily life can be reduced by planting trees”, “Coal generation produces a lot of carbon emissions”, “The steel industry is not related to carbon emissions”, “Frequent air travel generates large amounts of carbon emissions”, “Long-distance travel by car generates large amounts of carbon emissions”, and “Compared to fuel cars, new energy vehicles will not play a role in reducing carbon emissions”.

3.2.6. Parental literacy of carbon neutrality

We provided parents with a description of carbon neutrality and asked them if they had heard of carbon neutrality at T2. Parents were asked to answer ‘yes’ or ‘no’. The description of carbon neutrality was as follows:

“Carbon” means carbon dioxide, and “neutrality” means that all carbon dioxide or other greenhouse gases emitted by companies, groups, and individuals are offset by energy conservation, reforestation, etc. This process is called carbon neutrality.

The concepts related to carbon neutrality include carbon emissions, low-carbon products, and low-carbon environmental behaviors. Carbon emissions refer to the process of carbon dioxide, methane and other greenhouse gas emissions; “low-carbon” refers to lower greenhouse gas emissions. Therefore, low-carbon products refer to products with energy-saving and emission-reducing effects (e.g., energy-saving home appliances); low-carbon environmental behaviors refer behaviors that reduce carbon emissions and protect the environment in life (e.g., choosing low-carbon travel).

3.2.7. Control variables

We measured and included in the regression model demographic, and social contextual control variables to better isolate the influence of children-led environmental communication. For example, we measured the children's school, sex, and age, as well as the parents' sex, age, monthly income, and education level. In addition, previous research has indicated that digital social media tools and other resources can play a crucial role in acquiring information and influencing children's attitudes and behaviors towards climate change (Parry et al., 2022). Therefore, to exclude these factors that interfere with the impact of education, we assessed children's proactive information acquisition by using a question that asked students whether the description of proactive information acquisition matched their actual situation (0 = very unlikely, 10 = very likely). For example, while I am at home or on vacation, I will proactively browse through various channels (e.g., Weibo, WeChat, Shake, Bilibili, newspapers, books, etc.) for information about low-carbon environmental protection or carbon neutrality. The question is adapted from the study by Tian et al. (2022).

4. Results

4.1. The statistical descriptions and correlations among key variables

We calculated statistical correlations between the key variables, as shown in Table 2. The results showed that children-led environmental communication was positively associated with their own climate change worry and conservation behavior as well as their parents' climate change worry and conservation behavior. In addition, climate change education, children's knowledge and children-led environmental communication have a significant positive correlation with each other.

4.2. Children-led environmental communication fosters their own conservation behavior by the mediation of climate change worry

In order to fully assess the impact of children-led environmental communication on their own conservation behavior by climate change worry, we constructed a model using multiple linear regression analysis. In Model 1, to demonstrate the effect of children-led environmental communication, we constructed a controlled model by coding sex (0 = female, 1 = male), school a (0 = no, 1 = yes), school b (0 = no, 1 = yes) as dichotomous dummy independent variables, and age and children-led environmental communication as continuous variables. Next, Model 2 added children's climate change worry to Model 1 to test the explanation power of children's climate change worry. The results were shown in Table 3.

As can be seen in Table 3, Model 1 is established ($F = 19.923, p < 0.001$). Specifically, socio-demographic variables have no significant effect on children's conservation behavior. Children-led environmental communication, however, has a significant and positive effect on children's conservation behavior (standardized $\beta = 0.441$, standard error (SE) = 0.026, $p < 0.001$), which validated hypothesis 1.

In Model 2 ($F = 18.74, p < 0.001$), after the inclusion of children's climate change worry, the standardized regression coefficient β for children-led environmental communication reduces 0.021. The result indicates children's climate change worry may be a mediator. Next, we tested the mediating effect of children's climate change worry using the PROCESS macro model. We selected model 4 and conducted a bootstrap at the 95 % confidence interval from 5000 bootstrap samples (Hayes, 2013). As shown in Fig. 2, the indirect effect of children's climate change worry is significant and positive ($\beta = 0.021$; SE = 0.012; 95 % confidence interval (CI) = [0.003, 0.048]), even after controlling for children's socio-demographic variables. These results, validating hypothesis 2, suggest that children who are more proactively involved in environmental communication will be more worried about climate change and more likely to engage in conservation behaviors.

4.3. Children-led environmental communication has a spillover effect on parental conservation behavior

According to socialization theory, parents may also change their own attitudes and behaviors as a result of observing children's behavior in their daily lives. Our analysis showed that children's conservation behavior T1 positively predicted parental conservation behavior T2 (standardized $\beta = 0.131$, SE = 0.274, $p < 0.05$) and parental climate change worry (standardized $\beta = 0.156$, SE = 0.035, $p < 0.01$). Therefore, we controlled the influence of children's conservation behavior T1 to fully assess the impact of children-led environmental communication T1 on parental conservation behavior T2 by parental climate change worry T2.

First, we constructed a model using multiple linear regression analysis. As shown in Table 4, we found children-led environmental communication has a significant predictive effect on parental climate change worry T2. Importantly, we found a significant interaction between children-led environmental communication T1 and parental literacy of carbon neutrality T2 on parental climate change worry T2 (standardized $\beta = -0.321$, SE = 0.379, $p < 0.05$), even after controlling for parental and children socio-demographic variables, children's conservation behavior T1, children-led environmental communication T1 and parental literacy of carbon neutrality T2. These results indicate that although children-led environmental communication can directly influence their parental climate change worry, the moderating effect of parental literacy of carbon neutrality needs to be considered.

Next, we tested the indirect effect of parental climate change worry using the PROCESS macro model. We selected model 7 and conducted a bootstrap at the 95 % confidence interval from 5000 bootstrap samples (Hayes, 2013). As shown in Table 5 and Fig. 3, the indirect effect of parental climate change worry is significant and positive ($\beta = 0.04$; SE = 0.021; 95 % CI = [0.005, 0.088]) for parents without literacy of carbon neutrality at T2, even after controlling for parental and children socio-demographic variables, children conservation behavior T1. However, the indirect effect of parental climate change worry is not significant ($\beta = 0.006$; SE = 0.008; 95 % CI = [-0.009, 0.021]) for parents with literacy of carbon neutrality, even after controlling for parental and children socio-demographic variables, children conservation behavior T1. These results, validating hypothesis 3, suggest that for parents without literacy of carbon neutrality, the increase in their children's engagement with environmental communication raises their level of climate change worry, which makes them more likely to engage in conservation behaviors.

4.4. Climate change education fosters children to engage with environmental communication via the mediation of knowledge

Considering that other sources of information may influence knowledge, we used the stepwise method proposed by Baron and Kenny (1986) to test the indirect effect of climate change education on children-led environmental communication through knowledge. First, we aim to demonstrate that carbon neutrality knowledge is influenced by climate change education after controlling that students are likely to actively acquire knowledge from other sources. Therefore, in Model 4, we constructed a controlled model by coding sex (0 = female, 1 = male), school a (0 = no, 1 = yes), school b (0 = no, 1 = yes) as dichotomous dummy independent variables, and age and proactive information acquisition as continuous variables. Next, Model 5 added climate change education to Model 4 to compare the importance of climate change education and control variables on knowledge. The results were shown in Table 6.

As can be seen in Table 6, Model 4 is established ($F = 5.8, p < 0.001$). Specifically, socio-demographic variables have no significant effect on carbon neutrality knowledge. Proactive information acquisition from various channels, however, has a significant and positive effect on carbon neutrality knowledge (standardized $\beta = 0.204$, SE = 0.029, $p <$

Table 2
The correlations between the key variables.

	Mean (Standard Deviation)	1	2	3	4	5	6	7
1.Children-led environmental communication T1	6.02 (3.44)	–						
2.Children's climate change worry T1	7.40 (1.95)	0.147**	–					
3.Children's conservation behavior T1	8.09 (2.02)	0.452**	0.212**	–				
4.Parental climate change worry T2	8.63 (1.40)	0.139**	0.107*	0.159**	–			
5.Parental conservation behavior T2	8.92 (1.36)	0.134**	0.069	0.238**	0.329**	–		
6.Climate change education T1	1.51 (1.31)	0.227**	–0.003	0.198**	0.072	0.101*	–	
7.Children's carbon neutrality knowledge T1	6.49 (2.11)	0.154**	0.135**	0.179**	0.011	0.155**	0.252**	–

* $p < 0.05$.
** $p < 0.01$.

Table 3
The effect of children-led environmental communication on their own conservation behavior.

Predictive variable	Model 1			Model 2		
	Standardized β	Standard Error	t	Standardized β	Standard Error	t
Sex	0.075	0.177	1.684	0.071	0.175	1.615
Age	0.015	0.138	0.307	0.018	0.136	0.381
School a	0.013	0.369	0.159	0.021	0.365	0.255
School b	–0.046	0.353	–0.535	–0.036	0.349	–0.421
Children-led environmental communication	0.441	0.026	9.813***	0.42	0.026	9.361***
Children's climate change worry				0.144	0.045	3.24***
R ²	0.197			0.217		
F	19.923***			18.74***		

Note: Outcome variable: children's conservation behavior.
*** $p < 0.001$.

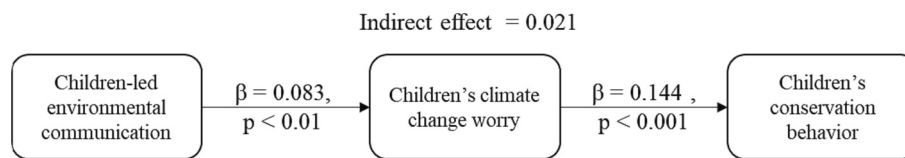


Fig. 2. The indirect effect of children-led environmental communication on their own conservation behaviors.

0.001). More importantly, in Model 5 ($F = 8.089$, $p < 0.001$), after the inclusion of climate change education, the standardized regression coefficient β for climate change education (standardized $\beta = 0.202$, $SE = 0.076$, $p < 0.001$) is greater than for proactive information acquisition (standardized $\beta = 0.168$, $SE = 0.029$, $p < 0.001$). The result indicates that although students can enrich their knowledge via proactive information acquisition from various channels when they are at home or during holidays, climate change education is still their main source of knowledge acquisition.

Next, we test whether carbon neutrality knowledge further influences children's engagement with environmental communication. We found carbon neutrality knowledge has a significant and positive effect on environmental communication (standardized $\beta = 0.124$, $SE = 0.08$, $p = 0.011$). Besides, after controlling for carbon neutrality knowledge, climate change education still has a significant and positive effect on environmental communication (standardized $\beta = 0.196$, $SE = 0.127$, $p < 0.001$). Based on Baron and Kenny (1986), the indirect effect of climate change education is significant (indirect effect = 0.025), as shown in Fig. 4. The result means that climate change education has an impact on environmental communication by the mediation of carbon neutrality knowledge, which validated hypothesis 4. That is, the more carbon neutral education children receive, the more their carbon neutral knowledge will increase and thus they will be more likely to actively engage in environmental communication.

4.5. Repeated validation of qualitative data by interviews

To validate the credibility of our quantitative findings, we conducted

follow-up interviews to assess the impact of children-led climate change communication on children's climate change concerns and conservation behaviors, whether climate change education could enhance children's knowledge of carbon neutrality and their ability to engage in children-led environmental communication, and whether children-led climate change communication could stimulate parents' concerns about climate change and their adoption of conservation behaviors. A total of eight children participated in face-to-face interviews, all of whom confirmed their involvement in climate change education activities related to carbon neutrality. Specifically,¹ five of them mentioned their participation in a low-carbon-themed handwriting activity, while three reported attending science talks focused on low-carbon topics. Furthermore, one child participated in a used goods donation activity. Importantly, all participants expressed that engaging in climate change education activities increased their understanding and knowledge of carbon neutrality. Notably, one child also stated that their interest in climate change had grown as a result of these activities.

Significantly, all participants indicated that they actively shared information about these activities with their parents and engaged in discussions on low-carbon topics such as carbon emissions, global warming, sewage, and air pollution. One child mentioned that their parents showed willingness to listen to their thoughts on these matters. They also suggested that these extensive discussions have raised their worries about climate change and prompted them to become more

¹ Some of the children in our study participated in more than one type of climate change education activity.

Table 4
The effect of children-led environmental communication on parents' climate change worry.

Predictive variables	Model 3		
	Standardized β	SE	t
Parent sex	0.041	1.519	0.840
Parent age	-0.018	0.165	-0.356
Income a	-0.229	0.014	-3.105**
Income b	-0.034	0.216	-0.475
Income c	-0.111	0.264	-1.711
Income d	-0.116	0.338	-1.527
Education a	-0.004	0.235	-0.065
Education b	-0.002	0.393	-0.022
Education c	-0.092	0.210	-1.237
Children sex	0.093	0.281	1.947
Children age	-0.027	0.134	-0.510
School a	0.089	0.104	0.973
School b	0.147	0.280	1.551
Children conservation behavior T1	0.131	0.274	2.453*
Children-led environmental communication T1	0.340	0.037	2.579**
Parental literacy of carbon neutrality T2	0.118	0.054	1.346
Children-led environmental communication T1 \times Parental literacy of carbon neutrality T2	-0.321	0.379	-2.103*
R ²	0.100		
F	2.628***		

Note: Outcome variable: parents' climate change worry T2. Parent sex: 0 = female, 1 = male. Income a: 0 = no, 1 = under 3000 RMB/Month. Income b: 0 = no, 1 = 3000–5999 RMB/Month. Income c: 0 = no, 1 = 6000–9999 RMB/Month. Income d: 0 = no, 1 = 10,000–29,999 RMB/Month. Education a: 0 = no, 1 = junior high school and below. Education b: 0 = no, high school / junior college. Education c: 0 = no, 1 = bachelor's degree/college. Children sex: 0 = female, 1 = male. School a: 0 = no, 1 = yes. School b: 0 = no, 1 = yes. Parental literacy of carbon neutrality T2: 0 = without, 1 = with.

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$

Table 5
The indirect effect of parents' climate change worry for parents with different literacy of carbon neutrality.

Parental literacy of carbon neutrality	The indirect effect of parental climate change worry	SE	lower limit confidence interval	upper limit confidence interval
Without literacy	0.043	0.021	0.005	0.088
With literacy	0.006	0.008	-0.009	0.021

involved in conservation behaviors. Moreover, all participants believed that these discussions also influenced their parents' perceptions and behaviors concerning climate change. Half of them (4 out of 8) reported

observing an increase in their parents' adoption of green travel practices or purchase of low-carbon food items in their daily lives following the discussions. Regarding resource and energy conservation behaviors, all participants noticed improvements in their parents' habits. For instance, the majority (5 out of 8) mentioned that their parents now practice multipurpose water usage, turn off lights when not needed, or regulate air conditioning temperature promptly.

For the parents, a structured questionnaire was employed to investigate their attitudes and behaviors. All parents confirmed their children's participation in and communication about these climate change education activities. Crucially, they reported that their children initiated discussions on carbon neutrality-related topics with them. The majority (5 out of 6) of parents expressed that these discussions influenced their own worries about climate change. Furthermore, all parents reported that their children influenced their resource and energy conservation behaviors, such as water and electricity conservation.

In summary, the results of qualitative data indicate that children-led environmental communication has the potential to influence children's climate change worry and conservation behaviors. It is facilitated by climate change education, which enhances their knowledge of carbon neutrality. Furthermore, it also has the ability to impact parents' climate change worry and their adoption of conservation behaviors.

5. Discussions

The present study, based on matched household-level data, explored in detail how children-led environmental communication influences their own conservation behavior and spillovers to their parents' conservation behavior, and how children-led environmental communication is influenced by climate change education.

First, we found that children-led environmental communication was effective in elevating their own climate change worry, and therefore increasing their conservation behavior. Our results, consistent with previous research, indicate interpersonal communication is an effective factor for behavior and attitude change (Ballantyne, 2016). Importantly, these findings highlight the importance of children's initiative in communication. For example, people who believed that climate change is occurring do not necessarily worry about climate change (Van der Linden, 2017). However, we found children-led environmental communication is able to boost internal perceptions of climate change (e.g., climate change worry). We speculate that intrinsic motivation, characterized by curiosity and interest, is central to environmental communication, which explains the effect of children-led environmental communication. Children who take the initiative to engage in environmental communication may be more willing to deeply process information, which reinforces their understanding of climate change (e.g., climate change worry).

Second, we found children-led environmental communication predicted parents' conservation behavior across time, suggesting a robust and positive spillover effect of children-led environmental communication. This finding proves a bidirectional socialization between

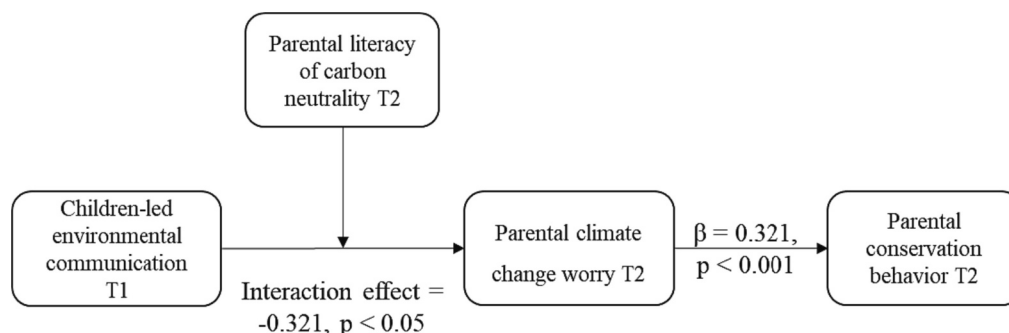


Fig. 3. The interaction effect of children-led environmental communication and parents' literacy of carbon neutrality on parental conservation behavior.

Table 6
The effect of climate change education on knowledge.

Predictive variable	Model 4			Model 5		
	Standardized β	SE	t	Standardized β	SE	t
Sex	-0.055	0.197	-1.165	-0.059	0.193	-1.277
Age	0.084	0.154	1.611	0.083	0.151	1.62
School a	-0.104	0.413	-1.145	-0.081	0.405	-0.916
School b	-0.038	0.400	-0.413	-0.030	0.392	-0.335
Proactive information acquisition	0.204	0.029	4.292***	0.168	0.029	3.546***
Climate change education				0.202	0.076	4.282***
R ²	0.065			0.091		
F	5.800***			8.089***		

Note: Outcome variable: carbon neutrality knowledge.

*** $p < 0.001$.

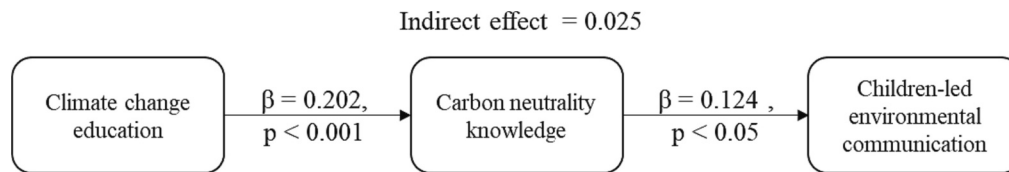


Fig. 4. The indirect effect of climate change education on children-led environmental communication.

children and parents (Grusec and Davidov, 2010), which is quite reliable. On the one hand, we demonstrate the intertemporal effect of children-led environmental communication on parents considering that communication does not work immediately. On the other hand, we came to a net spillover effect of children-led environmental communication, after controlling the influence of children's conservation behavior T1. In addition, we also found that parents' characteristics (i.e., understanding of carbon neutrality) was a key moderating variable. Our results showed that children-led environmental communication only has a positive indirect effect on the conservation behavior of parents without literacy of carbon neutrality. Specifically, for parents without literacy of carbon neutrality, they significantly increased their level of climate change worry and increased their conservation behavior after being influenced by children-led environmental communication. Conversely, for parents with literacy of carbon neutrality, they already had high levels of climate change worry. For example, at T2, there was no significant difference in parents' climate change worry ($M_{\text{aware}} = 8.60$, $SD = 1.39$; $M_{\text{unaware}} = 8.78$, $SD = 1.49$) between parents with literacy of carbon neutrality and those without literacy of carbon neutrality, $p > 0.05$. Thus, the spillover effect of children-led environmental communication has reached a ceiling and cannot further increase the level of climate change worry for parents with literacy of carbon neutrality.

Thirdly, we found that children-led environmental communication is positively influenced by climate change education. Specifically, climate change education increases children's carbon neutrality knowledge, even after controlling for the possibility that children obtain carbon neutrality information from sources other than school education. As children's carbon neutrality knowledge increased, children were more likely to engage in environmental communication. These findings are consistent with previous studies (Geiger et al., 2017a; Geiger et al., 2019). When children have some knowledge of climate change, they perceive themselves as capable of communicating with others. According to self-determination theory (Ryan and Deci, 2017), education supports the development of their knowledge and competence, which will enhance their intrinsic motivation to engage in communication.

Lastly, the qualitative data support and provide compelling evidence for these findings. The children reported their participation in various climate change educational activities, all of which were effective in increasing their knowledge of carbon neutrality. The fact that one child expressed a heightened interest in climate change indicates a positive impact of the educational activities on children's knowledge acquisition.

Moreover, these educational activities sparked extensive discussions among the children and their parents, covering not only global warming caused by carbon emissions but also other environmental issues like water pollution and air pollution. This suggests that targeted educational activities can generate broader discussions encompassing different environmental concerns. Importantly, consistent with our quantitative analysis, these discussions triggered children's worries about climate change and motivated them to adopt conservation behaviors, underscoring the pivotal role of children-led environmental communication. Additionally, the children believed that their discussions would influence their parents, and indeed, they observed behavioral changes in their parents. Likewise, the parents acknowledged being influenced by their children and expressed worries about climate change. These findings align with previous interviews (Spiteri, 2020; Deng et al., 2022) indicating that parents listen to their children's advice and modify their behaviors accordingly.

5.1. Theoretical implications

The current study contributes to current theories threefold. First, we proposed the new concept of children-led environmental communication and discussed how it can be a promising communication strategy to encourage collective action. Previous research only focused on adult's communication and therefore neglected a unique perspective focusing on the role of children and their initiative in climate change communication. On the one hand, initiative as an intrinsic motivation contributes to children's deeper understandings of climate change and their behavior. On the other hand, according to the theory of bidirectional parent-child relationship, children's proactive communication with parents is able to have an effective reverse intergenerational effect on parents. Therefore, current work further enriches the field of climate change communication.

Second, the present study reveals pathways through which children-led environmental communication influences their own conservation behavior. Specifically, climate change worry is a key mediator of the effect of children-led environmental communication on conservation behavior. Also, the current work provides new directions for the development of climate change communication theory from the perspective of spillover effect. In the field of climate change communication, research on the spillover effect is still very limited, as there are many challenges associated with conducting research with children and

in family units (Lawson et al., 2018). For example, collecting data from paired groups of children and their parents requires huge efforts. The present study, based on matched household-level data, found that children-led environmental communication predicted parents' climate change worry and conservation behaviors. These findings provide preliminary evidence for the development of climate change communication theory.

Third, the current work reveals that education is an effective factor in promoting children's proactive participation in environmental communication, and identifies knowledge as a key mediating variable. Our study contributes to the development of climate change education theory and communication theory. First, research on interpersonal communication is just emerging. Most researchers focused on adult populations (e.g., Geiger et al., 2017b). Furthermore, to our knowledge, there is no study examining the role of climate change education on children-led environmental communication. Additionally, most climate change education research has focused on how to promote children's climate change perceptions and actions to mitigate climate change, but limited research has focused on the effects of climate change education on environmental communication. In the present study, we found for the first time that climate change education can indirectly influence children-led environmental communication through increasing knowledge. These findings demonstrate the significance of climate change education across countries and groups, and provide strong evidence for the expansion of education theory and communication theory.

5.2. Practical implications

On the one hand, our study has some implications for climate change communication. First, our studies provide a new sight and evidence highlighting the role of children-led environmental communication. Science communicators need to focus on how children-led environmental communication foster their climate action, considering that children are free from worldviews and political leanings and that they will become policymakers and decision makers in the future. Second, science communicators can change the traditional view (i.e., science communicators are concerned with how to directly intervene with adults in climate change communication). Our findings showed that children-led environmental communication has robust and positive spillover effects on parents change their inherent climate change attitudes and behaviors. These learnings from intergenerational sources provide a new perspective for promoting adult engagement in climate action. Consistent with other researchers (Lawson et al., 2018), children as subjects of communication are more conducive to changes in adults' attitudes and behaviors. Therefore, when other communication strategies are ineffective, science communicators may consider choosing children-led communication strategies to promote adult engagement in climate change mitigation. Third, our findings provide an actionable way (i.e., school education) to promote environmental communication among children. Science communicators can use climate change education as one of the important tools to promote science communication. In addition, science communicators can also take full use of the dividends of the information era to promote climate change communication among children. For example, we found that knowledge, as the individual factor, promotes children's participation in climate change communication, and the source of knowledge is also likely to be from various online media. Therefore, science communicators can develop popular science videos for children through Internet media, which can help children acquire knowledge and help them participate in climate change communication.

On the other hand, our study has some implications for climate change education in schools. First, our findings demonstrate the relevance of climate change education. Climate change education is effective in helping children to recognize and learn about carbon neutrality, which meets the goals of educators. In addition, climate change education can indirectly increase children-led environmental

communication through knowledge, which further extends the role of education. Therefore, we encourage educators to incorporate climate change and carbon neutrality into the curriculum guidelines for subject education. Further, climate change education in this study covers educational activities such as science lectures and exhibitions, and educators can therefore consider diversifying the content of school education. Educators can enrich students' knowledge and develop their skills through a variety of teaching formats. Second, our study also found that climate change education also influences parents, and that this influence is due to the communication of information from children. Children act as a bridge between school and household, facilitating the linking of school and household to address climate change together, which is an important way to achieve collective climate action. Therefore, educators can focus on climate change education based on intergenerational learning, which can help make the role of education more widely promoted. For example, educators can guide and nurture children's habits of discussion with their parents.

5.3. Limitations

It is crucial to acknowledge the limitations of the present study. Firstly, while we highlight that children-led environmental communication improves household-level conservation behaviors and is influenced by climate change education, our focus is primarily based on the self-determination theory and the spiral of silence theory. However, it is important to note that there are other theories that may also new perspectives on our findings but were not extensively discussed in our study. For instance, the self-regulation theory emphasizes the role of self-efficacy and learning goals in self-regulated learning (Zimmerman et al., 1989), which means children could take the initiative to engage in environmental communication to enhance their understanding of climate change. Similarly, the knowledge, attitudes, and behaviors (KAB) model may also explain the willingness to proactively communicate climate change with parents, particularly after knowledge improvement, by highlighting the significance of knowledge in driving actions (Paço and Lavrador, 2017; Salazar et al., 2022). Exploring these additional theories in future research could contribute to a more comprehensive understanding of the underlying cognitive, affective, and behavioral processes behind children-led environmental communication and its impact on conservation behaviors. Secondly, the results of this study are based on panel data across only nine months, which restricts our ability to determine the long-term stability of the influence of children-led environmental communication on both their own and their parents' conservation behaviors. Therefore, the long-term effect of children-led environmental communication lacks being further examined in our research. Thirdly, although we conducted face-to-face interviews with children to qualitatively assess our hypotheses, there was a lack of manipulation of children-led environmental communication such that the causality may remain weak. Fourthly, while this study highlights the robust spillover effect of children-led environmental communication on parents' climate change worry and conservation behaviors over time, achieving carbon neutrality necessitates broader community participation in mitigating climate change. Given that communication can have spillover effects on people within various groups, such as classmates and colleagues, it is essential to explore these spillover effects among different groups, which have been understudied in the current work. Lastly, this study first identified a positive effect of climate change education on children's participation in environmental communication. However, climate change education alone does not fully account for changes in children-led environmental communication. Other factors, such as the use of digital social media (DSM) tools (Parry et al., 2022) and rewards (Ji et al., 2023), may also motivate their engagement in conversations and discussions on the topic and need to be further explored. Despite controlling for the influence of other sources on children-led environmental communication, our work acknowledges the need for further comprehensive studies aimed at the improvement of

children-led environmental communication through other potential sources.

6. Conclusions

This study proposes a new concept—children-led environmental communication, and demonstrates its influence on household (including children and their parents) conservation behavior with a mediation of climate change worry. Meanwhile, we also find climate change education can boost children-led environmental communication through improving children's climate mitigation knowledge. Overall, children-led environmental communication was found to be viable for boosting household-level conservation behavior. Therefore, we suggest that communicators are encouraged to consider children-led environmental communication as a new strategy to promote climate collective action. In addition, we also suggest that educators are recommended to incorporate climate change education into the education system, which in turn can facilitate children-led environmental communication. However, there are still some limitations that deserve to be explored in future research. These include the absence of examining the support of other theories such as self-regulation theory and KAB model for our findings, the robustness of results over a longer time period, the potential spillover effects among other groups such as classmates, colleagues, and neighbors, and other factors that may drive children-led environmental communication. To address these limitations, future research is suggested to (1) use other theories such as the self-regulation theory and KAB model to explore the cognitive, affective, and behavioral processes

behind children-led environmental communication, (2) employ panel data with a longer time span to explore whether the relationship between education and household behavior remains robust, (3) conduct experimental manipulations of children-led environmental communication to determine causality, (4) adopt an interdisciplinary manner to explore how to promote coordination and cooperation among classmates, colleagues, or neighbors regarding climate change issues and the spillover effects of climate change communication, and (5) investigate additional ways such as DSM tools and rewards that foster children-led environmental communication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The present study was supported by the National Social Science Foundation of China (No. 19ZDA358), the Scientific Foundation of Institute of Psychology, Chinese Academy of Sciences (No. E2CX3315CX) and CAS Engineering Laboratory for Psychological Service (KFJ-PTXM-29). The authors would like to thank the Editors and two anonymous reviewers for their constructive feedback. The authors also thank Mrs. Hang Su for her valuable suggestions on the revised manuscript.

Appendix A

Table A1
Questions for interviews with children.

Questions
1. Have you ever participated in carbon-neutral education activities organized by your school, such as producing handwritten newspapers, science exhibitions, science lectures, donating used items, etc., focusing on topics like climate change, energy conservation, emission reduction, and low-carbon environmental protection?
2. If you have participated, do you believe that engaging in these carbon-neutral education activities has enhanced your understanding of carbon neutrality?
3. Have you informed your parents about these carbon-neutral education activities?
4. If you took part in these carbon-neutral education activities, did you actively engage in discussions with your parents about topics related to carbon neutrality, such as climate change, energy conservation, and low-carbon environmental protection?
5. If you have actively discussed carbon-neutral related topics with your parents, do you think these discussions have influenced your own worries about climate change?
6. How can these discussions influence your own behaviors regarding energy and resource conservation, such as saving water and electricity?
7. If you have actively discussed carbon-neutral related topics with your parents, do you believe these discussions could influence their perspectives and behaviors concerning climate change?
8. Do you think you have the ability to influence your parents' behaviors in conserving resources and energy, for example, through promoting water and electricity conservation?

Note: These questions were adapted from the study by [Deng et al. \(2022\)](#).

Table A2
Questionnaire for parents.

Questions	Response (Number)
1. Have your children ever participated in carbon-neutral education activities organized by your school, such as producing handwritten newspapers, science exhibitions, science lectures, donating used items, etc., focusing on topics like climate change, energy conservation, emission reduction, and low-carbon environmental protection?	Yes (6), No (0), I do not know (0)
2. Have your children informed you about these carbon-neutral education activities?	Yes (6), No (0), I do not know (0)
3. Have your children actively engaged in discussions with you about topics related to carbon neutrality, such as climate change, energy conservation, and low-carbon environmental protection?	Yes (6), No (0), I do not know (0)
4. Have your children's discussions about carbon neutrality raised your worries about climate change?	Yes (5), No (1), I do not know (0)
5. Have your children influenced your behavior in terms of conserving resources and energy, such as saving water and electricity?	Yes (6), No (0), I do not know (0)

Appendix B. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.spc.2023.10.006>.

References

- Ballantyne, A.G., 2016. Climate change communication: what can we learn from communication theory? *Wiley Interdiscip. Rev. Clim. Chang.* 7 (3), 329–344. <https://doi.org/10.1002/wcc.392>.
- Ballew, M.T., Leiserowitz, A., Roser-Renouf, C., Rosenthal, S.A., Kotcher, J.E., Marlon, J. R., Lyon, E., Goldberg, M.H., Maibach, E.W., 2019. Climate change in the american mind: data, tools, and trends. *Environ. Sci. Policy Sustain. Dev.* 61 (3), 4–18. <https://doi.org/10.1080/00139157.2019.1589300>.
- Baron, R.M., Kenny, D.A., 1986. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51 (6), 1173–1182. <https://doi.org/10.1037/0022-3514.51.6.1173>.
- Barraza, L., Duque-aristiza'bal, A., Rebollo, G., 2003. Environmental education: from policy to practice. *Environ. Educ. Res.* 9 (3), 347–357. <https://doi.org/10.1080/135046220303462>.
- Bell, R.Q., 1968. A reinterpretation of the direction of effects in studies of socialization. *Psychol. Rev.* 75 (2), 81–95. <https://doi.org/10.1037/h0025583>.
- Bouman, T., Verschoor, M., Albers, C.J., Böhm, G., Fisher, S.D., Poortinga, W., Whitmarsh, L., Steg, L., 2020. When worry about climate change leads to climate action: how values, worry and personal responsibility relate to various climate actions. *Glob. Environ. Chang.* 62, 102061–11. <https://doi.org/10.1016/j.gloenvcha.2020.102061>.
- Cohen, G.L., 2003. Party over policy: the dominating impact of group influence on political beliefs. *J. Pers. Soc. Psychol.* 85 (5), 808–822. <https://doi.org/10.1037/0022-3514.85.5.808>.
- Deng, J., Tang, J., Lu, C., Han, B., Liu, P., 2022. Commitment and intergenerational influence: A field study on the role of children in promoting recycling in the family. *Resour. Conserv. Recycl.* 185, 106403. <https://doi.org/10.1016/j.resconrec.2022.106403>.
- Flora, J.A., Saphir, M., Lappé, M., Roser-Renouf, C., Maibach, E.W., Leiserowitz, A.A., 2014. Evaluation of a national high school entertainment education program: the alliance for climate education. *Clim. Change* 127 (3–4), 419–434. <https://doi.org/10.1007/s10584-014-1274-1>.
- Geiger, N., Swim, J.K., 2016. Climate of silence: pluralistic ignorance as a barrier to climate change discussion. *J. Environ. Psychol.* 47, 79–90. <https://doi.org/10.1016/j.jenvp.2016.05.002>.
- Geiger, N., Swim, J.K., Fraser, J., 2017a. Creating a climate for change: interventions, efficacy and public discussion about climate change. *J. Environ. Psychol.* 51, 104–116. <https://doi.org/10.1016/j.jenvp.2017.03.010>.
- Geiger, N., Swim, J.K., Fraser, J., Flinner, K., 2017b. Catalyzing public engagement with climate change through informal science learning centers. *Sci. Commun.* 39 (2), 221–249. <https://doi.org/10.1177/1075547017697980>.
- Geiger, N., Gasper, K., Swim, J.K., Fraser, J., 2019. Untangling the components of hope: increasing pathways (not agency) explains the success of an intervention that increases educators' climate change discussions. *J. Environ. Psychol.* 66, 101366. <https://doi.org/10.1016/j.jenvp.2019.101366>.
- Goldberg, M.H., van der Linden, S., Maibach, E., Leiserowitz, A., 2019. Discussing global warming leads to greater acceptance of climate science. *Proc. Natl. Acad. Sci. PNAS* 116 (30), 14804–14805. <https://doi.org/10.1073/pnas.1906589116>.
- Goldberg, M.H., Carmichael, C.L., Lacroix, K., Gustafson, A., Rosenthal, S.A., Leiserowitz, A., 2022. Perceptions and correspondence of climate change beliefs and behavior among romantic couples. *J. Environ. Psychol.* 82, 101836. <https://doi.org/10.1016/j.jenvp.2022.101836>.
- Grønhoj, A., Thøgersen, J., 2009. Like father, like son? Intergenerational transmission of values, attitudes, and behaviours in the environmental domain. *J. Environ. Psychol.* 29 (4), 414–421. <https://doi.org/10.1016/j.jenvp.2009.05.002>.
- Grusec, J.E., Davidov, M., 2010. Integrating different perspectives on socialization theory and research: A domain-specific approach. *Child Dev.* 81 (3), 687–709. <https://doi.org/10.1111/j.1467-8624.2010.01426.x>.
- Han, P., Tong, Z., Sun, Y., Chen, X., 2022. Impact of climate change beliefs on youths' engagement in energy-conservation behavior: the mediating mechanism of environmental concerns. *Int. J. Environ. Res. Public Health* 19 (12), 7222. <https://doi.org/10.3390/ijerph19127222>.
- Hayes, A.F., 2013. *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-based Approach*, 2013. The Guilford Press, New York.
- Hung, L.S., Bayrak, M.M., 2019. Wives influence climate change mitigation behaviours in married-couple households: insights from Taiwan. *Environ. Res. Lett.* 14 (12), 124034. <https://doi.org/10.1088/1748-9326/ab5543>.
- Intergovernmental Panel on Climate Change, 2018. Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. <https://www.ipcc.ch/sr15/>.
- Ji, Z., Gong, Y., Li, Y., Sun, Y., 2023. Effects of monetary and nonmonetary incentives in individual low-carbon behavior rewarding system on recycling behaviors: the role of perceived environmental responsibility. *Sustain. Prod. Consum.* 38, 90–103. <https://doi.org/10.1016/j.spc.2023.03.026>.
- Jia, F., Yu, H., 2021. Action, communication, and engagement: how parents "ACE" children's pro-environmental behaviors. *J. Environ. Psychol.* 74, 101575. <https://doi.org/10.1016/j.jenvp.2021.101575>.
- Karpudewan, M., Mohd Ali Khan, N.S., 2017. Experiential-based climate change education: fostering students' knowledge and motivation towards the environment. *Int. Res. Geographic. Environ. Educ.* 26 (3), 207–222. <https://doi.org/10.1080/10382046.2017.1330037>.
- Lawson, D.F., Stevenson, K.T., Peterson, M.N., Carrier, S.J., Strnad, R., Seekamp, E., 2018. Intergenerational learning: are children key in spurring climate action? *Glob. Environ. Chang.* 53, 204–208. <https://doi.org/10.1016/j.gloenvcha.2018.10.002>.
- Lawson, D.F., Stevenson, K.T., Peterson, M.N., Carrier, S.J., Seekamp, E., Strnad, R., 2019a. Evaluating climate change behaviors and concern in the family context. *Environ. Educ. Res.* 25 (5), 678–690. <https://doi.org/10.1080/13504622.2018.1564248>.
- Lawson, D.F., Stevenson, K.T., Peterson, M.N., Carrier, S.J., L. Strnad, R., Seekamp, E., 2019b. Children can foster climate change concern among their parents. *Nat. Clim. Chang.* 9 (6), 458–462. <https://doi.org/10.1038/s41558-019-0463-3>.
- Markowitz, E.M., Guckian, M.L., 2018. Climate change communication: Challenges, insights, and opportunities. In: *Psychology and Climate Change*. Academic Press, pp. 35–63.
- Mead, E., Roser-Renouf, C., Rimal, R.N., Flora, J.A., Maibach, E.W., Leiserowitz, A., 2012. Information seeking about global climate change among adolescents: the role of risk perceptions, efficacy beliefs, and parental influences. *Atl. J. Commun.* 20 (1), 31–52. <https://doi.org/10.1080/15456870.2012.637027>.
- Mi, L., Sun, Y., Gan, X., Yang, Y., Jia, T., Wang, B., Xu, T., 2021. Predicting environmental citizenship behavior in the workplace: a new perspective of environmental affective event. *Sustain. Prod. Consum.* 27, 2037–2046. <https://doi.org/10.1016/j.spc.2021.05.006>.
- Monroe, M.C., Plate, R.R., Oxarart, A., Bowers, A., Chaves, W.A., 2017. Identifying effective climate change education strategies: a systematic review of the research. *Environ. Educ. Res.* 25 (6), 791–812. <https://doi.org/10.1080/13504622.2017.1360842>.
- Paço, A., Lavrador, T., 2017. Environmental knowledge and attitudes and behaviours towards energy consumption. *J. Environ. Manage.* 197, 384–392. <https://doi.org/10.1016/j.jenvman.2017.03.100>.
- Parry, S., McCarthy, S.R., Clark, J., 2022. Young people's engagement with climate change issues through digital media – a content analysis. *Child Adolesc. Mental Health* 27 (1), 30–38. <https://doi.org/10.1111/camh.12532>.
- Rousell, D., Cutter-Mackenzie-Knowles, A., 2020. A systematic review of climate change education: giving children and young people a 'voice' and a 'hand' in redressing climate change. *Children's Geograph.* 18 (2), 191–208. <https://doi.org/10.1080/14733285.2019.1614532>.
- Ryan, R.M., Deci, E.L., 2013. Toward a social psychology of assimilation: Self-determination theory in cognitive development and education. In: Sokol, B.W., Grouzet, F.M.E., Muller, U. (Eds.), *Self-regulation and Autonomy: Social and Developmental Dimensions of Human Conduct*. Cambridge University Press, New York, pp. 191–207.
- Ryan, R.M., Deci, E.L., 2016. Facilitating and hindering motivation, learning, and well-being in schools: research and observations from self-determination theory. In: Wentzel, K.R., Miele, D.B. (Eds.), *Handbook of Motivation at School*. Routledge, New York, pp. 96–119.
- Ryan, R.M., Deci, E.L., 2017. *Self-determination Theory: Basic Psychological Needs in Motivation, Development, and Wellness*. Guilford Publications.
- Salazar, C., Jaime, M., Leiva, M., González, N., 2022. From theory to action: explaining the process of knowledge attitudes and practices regarding the use and disposal of plastic among school children. *J. Environ. Psychol.* 80, 101777. <https://doi.org/10.1016/j.jenvp.2022.101777>.
- Sameroff, A., 1975. Transactional models in early social relations. *Hum. Dev.* 18 (1–2), 65–79. <https://doi.org/10.1159/000271476>.
- Shi, J., Visschers, V.H., Siegrist, M., Arvai, J., 2016. Knowledge as a driver of public perceptions about climate change reassessed. *Nat. Clim. Chang.* 6 (8), 759–762.
- Spiteri, J., 2020. Too young to know? A multiple case study of child-to-parent intergenerational learning in relation to environmental sustainability. *J. Educ. Sustain. Dev.* 14 (1), 61–77. <https://doi.org/10.1177/0973408220934649>.
- Stevenson, K.T., Peterson, M.N., Bondell, H.D., 2016. The influence of personal beliefs, friends, and family in building climate change concern among adolescents. *Environ. Educ. Res.* 25 (6), 832–845. <https://doi.org/10.1080/13504622.2016.1177712>.
- Swim, J.K., Geiger, N., Fraser, J., Pletcher, N., 2017. Climate change education at nature-based museums. *Curator (New York, N.Y.)* 60 (1), 101–119. <https://doi.org/10.1111/cura.12187>.
- Swim, J.K., Geiger, N., Sweetland, J., Fraser, J., 2018. Social construction of scientifically grounded climate change discussions. In: *Psychology and Climate Change: Human Perceptions, Impacts, and Responses*, pp. 65–93. <https://doi.org/10.1016/B978-0-12-813130-5.00004-7>.
- Tian, J., Sun, M., Gong, Y., Chen, X., Sun, Y., 2022. Chinese residents' attitudes toward consumption-side climate policy: the role of climate change perception and environmental topic involvement. *Resour. Conserv. Recycl.* 182, 106294. <https://doi.org/10.1016/j.resconrec.2022.106294>.

- Tolppanen, S., Kang, J., Riuttanen, L., 2022. Changes in students' knowledge, values, worldview, and willingness to take mitigative climate action after attending a course on holistic climate change education. *J. Clean. Prod.* 373 <https://doi.org/10.1016/j.jclepro.2022.133865>.
- United Nations Environment Programme, 2020. *Emissions Gap Report 2020*. Nairobi.
- Valdez, R.X., Peterson, M.N., Stevenson, K.T., 2017. How communication with teachers, family and friends contributes to predicting climate change behaviour among adolescents. *Environ. Conserv.* 45 (2), 183–191. <https://doi.org/10.1017/S0376892917000443>.
- Van der Linden, S., 2017. Determinants and measurement of climate change risk perception, worry, and concern. In: *The Oxford Encyclopedia of Climate Change Communication*. Oxford University Press, Oxford, UK.
- Wang, J., Long, R., Chen, H., Li, Q., 2022. How do parents and children promote each other? The impact of intergenerational learning on willingness to save energy. *Energy Res. Soc. Sci.* 87, 102465 <https://doi.org/10.1016/j.erss.2021.102465>.
- Zhang, J., Tong, Z., Ji, Z., Gong, Y., Sun, Y., 2022. Effects of climate change knowledge on adolescents' attitudes and willingness to participate in carbon neutrality education. *Int. J. Environ. Res. Public Health* 19 (17), 10655. <https://doi.org/10.3390/ijerph191710655>.
- Zimmerman, B.J., Schunk, D.H., SpringerLink (Online service), 1989. In: Zimmerman, B. J., Schunk, D.H. (Eds.), *Self-regulated Learning and Academic Achievement: Theory, Research, and Practice*. Springer, New York. <https://doi.org/10.1007/978-1-4612-3618-4>.
- Žukauskienė, R., Truskauskaitė-Kunevičienė, I., Gabė, V., Kaniušonytė, G., 2021. “My words matter”: the role of adolescents in changing pro-environmental habits in the family. *Environ. Behav.* 53 (10), 1140–1162. <https://doi.org/10.1177/0013916520953150>.