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Fear emotion reduces reported mitigation behavior in adolescents subject to climate change education

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Abstract
Emotion has been recognized as a significant factor affecting climate engagement behavior. However, empirical experiments testing emotions influencing behavioral changes, climate change education (CCE) in particular, are rare. In this study, we conducted a 2-week CCE program with the support of video clips to induce emotions such as fear and/or hope through the manipulated treatments and were then compared between emotion plus lecture group and lecture-only group for adolescents to explore how emotions affect self-reported mitigation behavior toward climate change. The study involved 1730 students from nine middle schools in three coastal cities (Xiamen, Shenzhen, and Ningbo) in China. The results demonstrated that emotional video clips were the successful stimulus for target emotions. There was a significant improvement in both knowledge-gaining and self-reported mitigation behavior in the lecture-only group, and climate change concern and involvement mediated the effect on mitigation behavior. Compared to the lecture-only group, the hope treatment group showed decreased knowledge gain but no significant effect on self-reported mitigation behavior. In contrast, emotion significantly reduced students' self-reported mitigation behavior in the fear treatment group, which was mostly pinpointed to the behavioral change of emission reduction activities. Thus, the study highlighted the importance of knowledge with appropriate emotions in adolescents to safeguard educational outcomes.

Keywords Climate change mitigation behavior · Climate change education · Emotion · Knowledge · Adolescent

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1 Introduction

Climate change is recognized as a major, anthropogenically induced environmental threat, with potentially severe and far-reaching consequences for human and natural systems (e.g., Oreskes 2004; IPCC 2007). Mitigation and adaptation measures are essential to address those climate impacts, which call for effective education strategies (IPCC 2007; Juhola and Westerhoff 2011). However, there is still not a broad agreement on which strategies are most effective for climate change education (CCE) (Monroe et al. 2017; Alan 2019).

1.1 Effects of knowledge on pro-environmental behavior

As a kind of environmental educational program, previous development of environmental education models is certainly relevant to CCE. For example, as previous studies indicated, knowledge has been a significant predictor of pro-environmental intention and behavior (Kaiser et al., 1999; Kollmuss and Agyeman 2002; Bamberg and Moser 2007). On the other hand, many theories of behavior change such as the belief-values-norm framework (Stern 2000), the theory of reasoned action (Fishbein and Ajzen 1975), and the theory of planned behavior (Ajzen and Fishbein 1980) have been recognized that the role of knowledge plays only as a minor and distal variable (Kollmuss and Agyeman 2002; Ajzen and Fishbein's 2005); other factors, e.g., motivation, awareness, values, attitudes, emotion, and locus of control, are also significant in predicting pro-environmental behavior or behavior change (Fliegenschnee and Schelakovsky 1998; Kollmuss and Agyeman 2002; Heimlich and Ardoin 2008).

The knowledge of climate change itself often differs in various dimensions, such as objective and subjective (self-reported) knowledge (Ellen 1994; Hornsey et al. 2016), the level and type of knowledge (Kollmuss and Agyeman 2002; Kaiser and Fuhrer 2003), and different subtype of knowledge, such as declarative, procedural, and effectiveness knowledge (Kaiser and Fuhrer 2003; Shi et al. 2016; Nguyen et al. 2019), which may also be associated with different CCE outcomes. For example, knowledge about the causes of climate change was found to be related to a heightened concern, while knowledge about the physical characteristics of climate change had either a negative or no significant effect on the concern (Shi et al. 2016). Furthermore, studies found multiple factors may work to strengthen knowledge associations with climate change mitigation action (Ortega-Egea et al. 2014). Therefore, the effect of knowledge itself on CCE requests a further investigation.

1.2 Effects of emotion on climate engagement behavior

Many researchers found that emotion was an important predictor of individual willingness to engage in climate change adaptation and mitigation behaviors (Van and Steg 2019; Xie et al., 2019; Brosch 2021; Geiger et al. 2021). Meanwhile, there is an increasing debate on the effects of targeting specific emotions to motivate or inhibit public engagement with climate change, especially the emotions of fear and hope (Ojala 2012; Lemanski and Villegas 2019). Studies demonstrated that fear showed positive effects on attitudes, intentions, and behaviors of climate engagements (van Zomeren et al. 2010; Skurka et al. 2018), and few circumstances under which they are not effective (Tannenbaum et al. 2015). Fear can raise risk perceptions and concerns about climate change (Skurka et al. 2018), thus may enhance engagement intentions (van Zomeren et al. 2010). However, some other climate change

communication literature pointed out that fear-based messages may drive people into a passive state of avoidance, denial, or helplessness, as the threat posed by climate change may be perceived as too large to be solved successfully, and thus hope-based messages should be preferred (Stern 2012; Hornsey and Fielding 2020; Vries 2020). The debate may also be due to the limited availability of empirical studies validating the pure effect of fear; however, in many cases, the above associations often result in correlations rather than cause-effect relationships (O'Neill and Nicholson-Cole 2009).

On the other hand, the emotion of hope appears to be constantly recommended for inclusion in environmental education (Ojala 2012; Stevenson et al. 2018). Hope may create goal congruence and enhance one's perceived control of a situation, leading to a more favorable attitude and increasing the intention to act (O'Neill and Nicholson-Cole 2009; Lee et al. 2017). However, critics of hope-based appeals have pointed out that optimistic messages about progress in reducing global carbon emissions increased hope, but reduced risk perceptions, and did not increase mitigation motivation (Hornsey and Fielding 2016). Additional research suggested the negative effect of hope may be due to different subtypes of hope, driven by different underlying appraisals, which even lead to an inverse result (Ojala 2015; Marlon et al., 2019). Nevertheless, emotion is important in CCE while whether their effects on promoting climate action and policy support are always positive is still open to debate (Brosch 2021).

Climate change affects humankind globally while the people most vulnerable to its impacts are children and youth in developing countries, where 85% of the world's children live (UNICEF 2014). Hence, effective CCE for teenagers is an urgent requirement. An increasing number of studies on CCE have been conducted on adults and college students and mainly from North American/Western European samples (but see Hu and Chen 2016; Lee et al. 2017, from Asia countries) and few studies dealing with children (e.g., Stevenson et al. 2014). Prior studies have shown that CCE may build concern and enhance knowledge among adolescents (Guy et al. 2014; Stevenson et al. 2014). Adolescents start to gain the ability to think systematically about all logical relationships within a problem (Steinberg 2005). They could consider possibilities, emotions, and facts that may impact decision-making either in positive or negative ways (Steinberg 2005). By contrast, unlike adults, adolescence is the formative phase for establishing cultural orientations; hence, the worldview that affects the perception of climate change may differ between adults and adolescents (Vollebergh et al. 2001).

1.3 Research hypotheses

The CCE aims to promote scientific facts to problem-solving skills, action competence, and advocacy (Mappin and Johnson 2005; Stevenson 2007; McNeal et al. 2017). In this study, we designed a curriculum focusing on factual knowledge of the climatic change, coupled with a video clip pro for the knowledge lectures intended to instill emotions of fear or hope as manipulated treatments, thus exploring how fear or hope affects curriculum-based CCE. Based on this background knowledge, we proposed the following hypotheses. H_1: Students who received lecture-only treatment will improve their knowledge of climate change, self-reported climate change mitigation behavior, and self-reported behavioral intention. H_2: Adding fear appeals to the educational message will increase teenagers' mitigation behaviors, and this increase will be mediated by an increase in climate change involvement. H_3: Adding hope appeals to the educational message will increase teenagers' mitigation behaviors, and this increase will be mediated by an increase in self-efficacy.

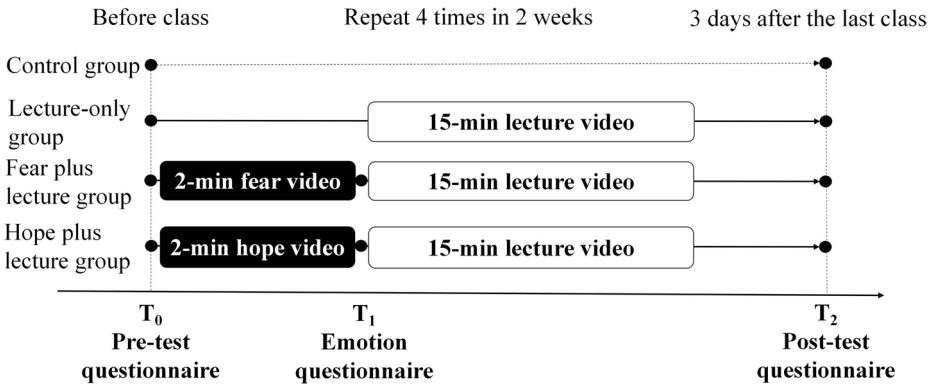

Fig. 1 Climate change educational program processes. The control group only completed the pre-questionnaires and post-questionnaires without any intervention. The lecture-only group watched the lecture videos but not the emotional clips. The lecture plus fear group watched one of the four fear clips before the lecture video, and the lecture plus hope group watched one of the four hope clips before the lecture video. The lecture frequency was two classes per week; thus, the course was finished in 2 weeks with four lectures. T_0 represents the time of pre-test before the program, T_1 represents the time of answering the questionnaire on emotions after the emotional video (emotional groups only), and T_2 represents the time of post-test, which was 3–5 days after the last class

2 Methods

2.1 Study sites and procedures

Previous studies found that awareness of fatalities from natural hazards, vulnerability to sea-level rise, and living within floodplains can largely predict the risk perception of climate change (Brody et al. 2008; Spence et al. 2012; Demski et al. 2017). Coastal cities might physically be more vulnerable to climate change because they are situated in low-lying areas within the immediate proximity of the coast. Hence, we selected coastal cities from three coastal provinces as the study sites: Shenzhen (Guangdong Province), Xiamen (Fujian Province), and Ningbo (Zhejiang Province). The formal study was conducted from September 2019 to December 2019 in nine junior schools. In each city, two to four junior schools were selected using convenience sampling.

Data collection in this study adapted pre-intervention and post-intervention surveys and a control group design (Fig. 1). In each school, four classes of the same grade (grade 7, ages 11–15) participated in the study. One class was randomly chosen as the control group, which we did not intervene in; the other three classes received (1) a lecture, (2) a lecture plus hope group, and (3) a lecture plus fear group. For the lecture-only group, we provided four lectures in 2 weeks; each lecture consisted of a 15-min presentation video (total intervention time = (15 min × 4); see Supplementary Video 1). For the other two classes, we provided 2-min emotional videos before each presentation (total intervention time = (2 min + 15 min) × 4).

2.2 Lectures for CCE and emotional stimuli

The lecture videos used in this study came from Stanford Middle School courseware, climate change lesson plans for years 7–11 from "Oxfam Education," "China's Perspective on Climate Change" in a massive open online course (MOOC), and other

open-source educational videos from the YouTube. The lectures were presented four times, including four aspects (see Supplementary Table A1): concept of climate, facts of global climatic change, main causes of climate change, and climate mitigation action. Considering the fact that 7th-grade students might not have primary knowledge of climate change science, we simplified the concepts and used several animated videos to explain the scientific phenomenon (see Supplementary Video 1). Meanwhile, to decrease the emotional impact of lectures, we tried our best to apply a neutral image (e.g., line chart) and science language and finally recorded all four lectures as videos to avoid bias caused by the lecturers. Each lecture video lasted 15 min to ensure that all procedures were completed in one lesson (40 min).

The emotional clips used in the experiment originated from two documentaries on climate change: "A Warming Earth" (Chinese), 2008 and "An Inconvenient Sequel: Truth to Power" (English dialog with Chinese subtitles), 2019. The former film was awarded the title of Best Science Film at the 28th Golden Rooster Award in China, and the latter has been widely promoted and adopted as an educational material worldwide (David 2006; Expatica 2007). We edited four clips for each film by adjusting the needs of the contents, time length, and target emotion (see Supplementary Video 2). In "A Warming Earth," we selected "The Super Typhoon Saomai" and "Sea Level Rising" as fear clips and "Carbon Sequestration Technology" and "New Clean Energy" as hope clips. In "An Inconvenient Sequel: Truth to Power," we used "The Super Typhoon Haiyan" and "Extreme Weather" as fear clips and "Technical Leapfrog in Developing countries" and "The Paris Agreement" as hope clips. The fear group watched the four fear clips, and the hope group watched the hope clips. They watched these clips before the lecture videos throughout four classes. For example, the fear group watched "The Super Typhoon Saomai" first, then the lecture video "Concept of Climate" during the first lecture.

2.3 Pilot studies

To confirm that all emotional clips successfully induced the target emotion, we conducted two pilot tests before the formal study. A total of 29 adults from Menglun, Xishuangbanna, Yunnan Province including five environmental education specialists and 24 college students participated in it. First, we asked each participant to extract the video sequence randomly. We then played eight emotional clips one by one and requested participants to complete the emotional questionnaire immediately after viewing each video. In this test, all the target emotions were salient, which proved that fear and hope could be induced in adults through emotional clips (see Supplementary Video 2). Considering that one fear clip ("Mosquito-borne virus") was difficult for children to understand, we replaced it with another familiar topic: "The Super Typhoon Haiyan." We also considered evaluating the positive, negative, and neutral contents of these two emotions (see Supplementary Table A2).

The second pilot test was conducted at a junior school in Kunming, Yunnan Province, with six first-grade classes ($N=285$). This pilot study aimed to (1) retest the validity of emotional clips, (2) examine the difficulty and duration of lecture videos, and (3) test the reliability and validity of questionnaires in the target population. All six classes ($N=285$) completed pre-questionnaires and post-questionnaires, and four of them ($N=180$) attended the education program. In this pilot study, the targeted emotions were significantly higher than other emotions among junior students; this also supported the validation of the emotional clips. The reliability of the two items in the pre-test questionnaire did not meet the

criteria (climate change concern, $\alpha = 0.57$; climate change involvement, $\alpha = 0.46$). However, after eliminating the two items by confirmatory factor analysis, the reliability of all variables was increased to an acceptable level ($\alpha > 0.60$).

2.4 Measures

The emotional responses were assessed after watching each video. Immediately after the students watched the videos that evoked emotions, they were asked to rate the strength of the 15 emotions they felt while watching the video on a scale of 1 (*not at all*) to 5 (*extremely*) (also see Nabi et al. 2018) (see Supplementary Table A2). Of these, three items each related to fear (*anxious, afraid, and worried*) (Cronbach's $\alpha = 0.90$); hope (*hopeful, encouraged, and optimistic*) (Cronbach's $\alpha = 0.88$); sadness (*sad, upset, and disappointed*) (Cronbach's $\alpha = 0.89$), neutral emotions (*careless, calm, and relaxed*) (Cronbach's $\alpha = 0.75$); and happiness (*happy, excited, and energetic*) (Cronbach's $\alpha = 0.91$). Given the bland and descriptive nature of the lecture-only group, the 15 emotion items would have been incongruous and potentially counterproductive by unintentionally priming emotional responses unrelated to lecture content. Thus, participants in the lecture-only group were asked about the general emotional intensity with four semantic differential items: This article seemed "*emotional/impressive/exciting*" (0 = *not at all* and 5 = *extremely*). To more closely match the time allotted to complete the threat message post-test, participants were asked several filler questions (e.g., "I learned a lot from this article," "The article seemed factual") that were not intended for analysis.

Perceptions The survey measured a range of perceptions associated with climate change, the related behavior, behavioral intention, and key demographic variables, as the effect of emotion on CCE may have interacted with self-efficacy (Witte 1992), the concern for climate change (Schupp et al. 2007), and climate change involvement (Witte 2009). We used published scales to test these variables and prepared four to six items for each variable in the initial version. After the second pilot study, we deleted items that had low reliability. The final questionnaire (Supplementary Table A3) includes seven variables using a 5-point scale ranging from "*strongly agree*" to "*strongly disagree*": four questions about climate change concern (Cronbach's $\alpha = 0.81$), taken from previous research on climate change risk perception (Stevenson et al. 2015); five questions concerning climate change involvement ($\alpha = 0.78$) based on environment involvement research (Schuhwerk and Lefkoff-Hagius 1995); five terms to test self-efficacy ($\alpha = 0.85$), five questions evaluating mitigation behavior ($\alpha = 0.84$), which came from climate change engagement research among young people (Mead et al. 2012; Ojala 2012); four questions testing mitigation behavioral intention ($\alpha = 0.85$), adapted from Hu and Chen (2016), who primarily researched Chinese students; and 15 questions on climate science knowledge. This was divided into two aspects: single-item in subjective knowledge and objective knowledge (true or false, single choice; $\alpha = 0.76$). These items were selected from previous research on climate change knowledge among teenagers (Tobler et al. 2012). We used factor analysis to find if climate change mitigation behavior can also be divided into two subgroups (KMO = 0.82): learning and communication ($\alpha = 0.87$) and emission reduction activities ($\alpha = 0.74$).

Demographics The socio-demographic variables of gender, age, ethnicity, and "Big Five Personality" (Rammstedt and John 2007) were included in the analysis (Supplementary Table A3). The "Big Five Personality" traits describe five discrete dimensions of personality: agreeableness, conscientiousness, extroversion, neuroticism, and openness. This study

found four sections through principal component analysis: agreeableness, conscientiousness, extraversion, and openness (Supplementary Table A4). The post-test survey had the same content, although the order of the items differed from the pre-test.

2.5 Data analyses

To verify the effectiveness of the emotional clips, univariate statistical models with one-way analysis of variance (ANOVA) were used.

The longitudinal analysis used 1539 adolescents with matched pre-test and post-test surveys, allowing changes for all climate-related outcomes to be calculated at the individual level. Univariate statistical models and pairwise comparisons with the Tukey honestly significant difference (HSD) test were used to evaluate the effectiveness of the emotion on perceptions and mitigation intention. Type III sum of squares was used to determine statistical significance ($p < 0.05$), and partial eta squared was used to evaluate the effect size.

We first used the model selection to understand how changes in mitigation behavior were related to the changes in perceptions within the emotion groups and lecture-only group ($N = 1155$, excluding the control group). We then adapted the mixed linear model in R (version 3.5.1), taking schools as a random factor (see Table 1). Furthermore, we adapted multiple-mediation analysis in Mplus to understand the changes in mitigation behavior in the three treatments. We compared the two emotion groups to the lecture-only group to verify the mediation effect in the emotion groups to mitigate behavioral change. We also compared the lecture-only group with the control group to examine the mediation effect in the lecture-only group to mitigate behavioral change ($N_{\text{fear}} = 796$, $N_{\text{hope}} = 753$, $N_{\text{lecture-only}} = 789$). All socio-demographic variables were included in the analyses as covariates. Bias-corrected bootstrap 95% confidence intervals (CIs) were based on 1000 bootstrap samples for indirect effects.

3 Results

3.1 Emotion manipulation check

ANOVA revealed that emotion-framing manipulation was successful in eliciting the intended emotional response (Supplementary Fig. A1). The threat video evoked a notably higher degree of fear ($M = 3.18$, $SD = 0.93$) than hope ($M = 2.10$, $SD = 0.87$), sadness ($M = 2.60$, $SD = 0.94$), neutral emotions ($M = 1.56$, $SD = 0.66$), and happiness ($M = 1.47$, $SD = 0.69$) ($F_{4,\ 2150} = 326.69$, $p < 0.001$, $\eta^2 = 0.378$). Similarly, the hope video triggered a higher degree of hope ($M = 3.32$, $SD = 0.99$) than fear ($M = 1.84$, $SD = 0.74$), sadness ($M = 1.57$, $SD = 0.66$), neutral emotions ($M = 1.90$, $SD = 0.71$), and happiness ($M = 2.77$, $SD = 1.10$) ($F_{4,\ 2175} = 317.94$, $p < 0.001$, $\eta^2 = 0.369$).

3.2 The effectiveness of emotion and lecture on climate science knowledge and self-reported mitigation behavior

Compared to the control group, the lecture-only group significantly improved climate change involvement ($F_{3,1545} = 3.99$, $p = 0.008$, $\eta^2 = 0.008$), self-efficacy ($F_{3,1545} = 4.94$, $p = 0.002$, $\eta^2 = 0.009$), climate science knowledge ($F_{3,1545} = 84.62$, $p < 0.001$, $\eta^2 = 0.141$),

and self-reported mitigation behavior ($F_{3,1545} = 9.14$, $p < 0.001$, $\eta^2 = 0.017$). There was no significant difference in climate change concern ($F_{3,1545} = 1.86$, $p = 0.14$, $\eta^2 = 0.004$) and behavioral intention ($F_{3,1545} = 1.90$, $p = 0.13$, $\eta^2 = 0.004$) (Fig. 2a-f). The fear group significantly decreased the self-reported mitigation of behavioral change compared to the lecture-only group (Fig. 2e). The hope group showed a significant decrease in knowledge gain compared to the lecture-only group (Fig. 2d).

Specifically, considering the two subgroups of mitigation behavior, i.e., learning and communication ($F_{3,1545} = 12.91$, $p < 0.001$, $\eta^2 = 0.024$) (Fig. 2g) and emission reduction activities ($F_{3,1545} = 3.33$, $p = 0.02$, $\eta^2 = 0.006$) (Fig. 2h), all three treatments displayed significantly higher communication behaviors than the control group (Fig. 2g). However, for the emission reduction activities subgroup, only the lecture-only group showed the greatest improvement among the other three groups. The hope group had no significant difference when compared to the lecture-only group, and the fear group was significantly lower than the lecture-only group (Fig. 2h).

3.3 Factors and variables explain self-reported mitigation of behavioral change

The mixed linear model showed that the fear group was negatively and significantly correlated with self-reported mitigation behavioral change (Table 1). Changes in involvement and

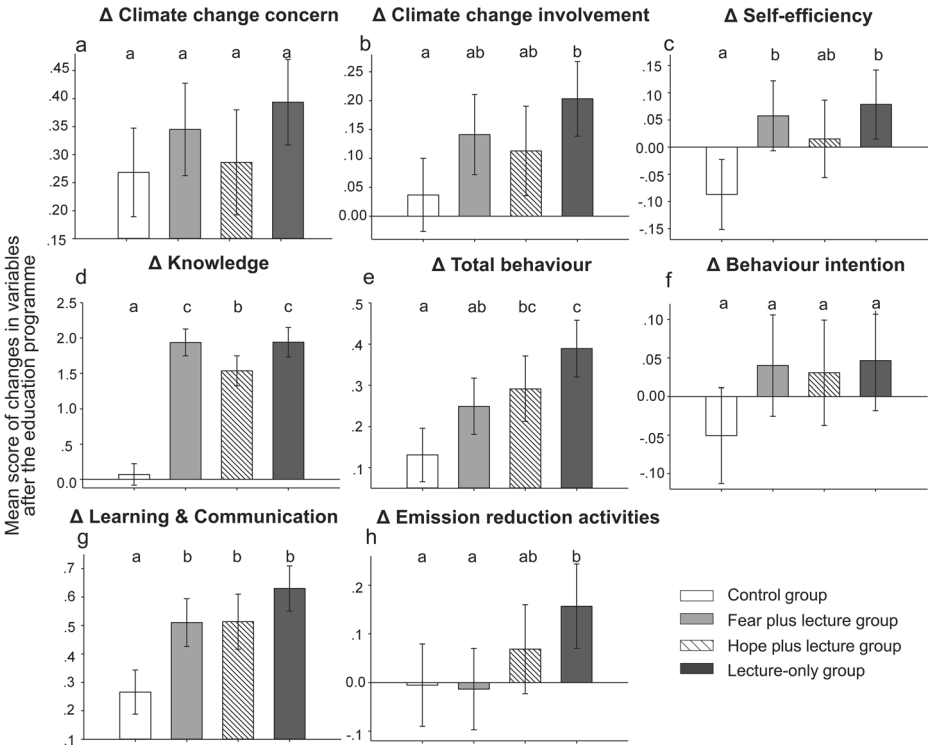

Fig. 2 The program's effectiveness on concern, involvement, self-efficacy, knowledge, self-reported mitigation behavior, and behavioral intention in four treatments. * "Δ" refers to the changes between post-test and pre-test surveys. Error bars refer to the 95% CI, statistical significance: $p < 0.05$

Table 1 A linear mixed model analysis of Big Five Personality, demographic variables, knowledge, emotion and lecture-only groups, and predictor variables for explaining the self-reported mitigation behavioral change. "Δ" refers to the changes between post-test and pre-test surveys, and numbers indicate unstandardized beta coefficients, $N = 1155$. School was controlled as a random factor in the model. The italicized values in the p-value column indicate statistic significance ($p < 0.05$). The collinearity test results for the variance inflation factor levels were acceptable

Predictors	*Estimates*	*CI*	*p*
Intercept	-0.60	-1.42 to 0.22	0.152
Agreeableness	0.08	0.04–0.11	*< 0.001*
Conscientiousness	-0.03	-0.06 to 0.01	0.154
Age	0.05	-0.01 to 0.12	0.100
Fear group	-0.11	-0.01 to − 0.12	*0.014*
Hope group	-0.04	-0.14 to 0.05	0.376
Pre-test CC knowledge	0.04	0.01–0.07	*0.004*
Δ CC knowledge	0.03	0.01–0.05	*0.006*
Δ CC concern	0.09	0.04–0.13	*0.001*
Δ CC involvement	0.21	0.14–0.27	*< 0.001*
Δ Self-efficacy	0.20	0.13–0.26	*< 0.001*
Marginal *R*2 /conditional *R*2	*0.182/0.185*		

self-efficacy were significant predictors of the self-reported mitigation of behavioral change. Agreeableness, pre-test knowledge, change in concern, and knowledge also showed a significant positive relationship with self-reported mitigation behavioral change. However, other personality traits and demographic variables failed to explain the changes in mitigation behavior (Table 1).

The multiple-mediation model showed that the lecture-only group indirectly affected mitigation behavior via concern, involvement, and self-efficacy (Fig. 3). When the indirect effects of these mediators were included in the model, the positive relationship between the lecture-only group and mitigation behavior increased (standardized direct effect, $c' = 0.136$, $p < 0.0001$; standardized total effect, $c = 0.193$, $p < 0.0001$); change in concern and involvement were significant mediators (95% CI [0.003, 0.033] and [0.013, 0.052], respectively). This model explained 13% of the variance in behavioral mitigation changes. The negative effect between the fear group and mitigation behavior cannot be explained by changes in concern, involvement, and self-efficacy. The hope group cannot affect the mitigation behavior through all three mediators.

4 Discussion

The function of emotion on CCE has been increasingly recognized while their effects often yielded mixed results (Brosch 2021). This study showed that the lecture-only group presented the most significant mitigation behavioral change among the three treatments. Induced fear in lecture treatment decreased changes in self-reported mitigation behavior, particularly on the change in emission reduction activities among adolescents. Hope plus lecture treatment did not show a significant impact on the mitigation of behavioral change compared to the lecture-only groups. Thus, our emotion-manipulating experiment shows that negative emotions may weaken mitigation behavior and knowledge may be the key factor that improves adolescents' pro-environmental behavior. This brings new insight that highlights a more prudential consideration needed for bringing emotion into CCE among adolescents.

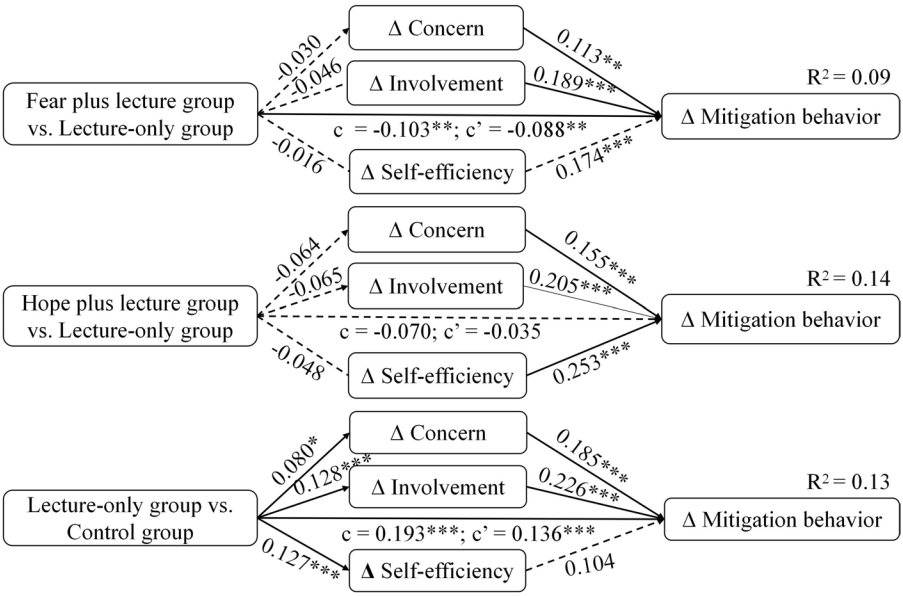

Fig. 3 Mediation analysis between treatments, climate change perception variables, and self-reported mitigation behavior. "Δ" refers to the changes between post-test and pre-test surveys. Coefficients are standardized, and the solid line shows that the regression analysis between the variables is significant. The dotted line shows that the regression analysis between variables is not significant; *c*' represents the standard direct effects; *c* represents the standard total effects; $N_{fear} = 796$, $N_{hope} = 753$, $N_{lecture\text{-}only} = 789$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This study provides a successful case for knowledge-based CCE in adolescents. In this study, knowledge, climate change concerns, involvement, and self-efficacy were all significantly related to mitigation behavior, which is consistent with previous studies (e.g., Gregory and Leo 2003; Tobler et al. 2012; Lazard and Atkinson 2015; Stevenson et al. 2015). The presence of knowledge difference between the lecture-only group and the control group suggested a significant progress in climate knowledge for the lecture group. According to the mediation analysis, the lecture-only group affected by mitigation behavior was partially mediated by climate change concerns and involvement. Thus, we suspect the declarative knowledge, such as the causes and the consequence of the climate crisis, may link to climate change concerns among adolescents. Recent studies also found that higher level of knowledge about the causes of climate change was an important driver of concern about climate change (Shi et al. 2015, 2016). In this study, our lecture on climate change knowledge includes four aspects: the physical characteristics of climate change, the cause of climate change, the consequence, and mitigation action. The climate change concerns and involvement and mitigation behavior change in the lecture-only group may largely be due to the knowledge improvement of the cause of climate change.

Contrary to our hypothesis, this study indicated that fear has a negative impact on the mitigation of behavioral changes compared to the lecture-only group. Fear neither increased students' concern about climate change nor improved their involvement in climate change, which suggests that the previous model for concern and involvement mediated positive effect on climate mitigation behavior did not exist in this study. Concerns

about climate change in the fear plus lecture group did not differ significantly when compared to the lecture-only group, even to the control group, suggesting that students from coastal cities may already hold relatively high levels of concern about climate change. An alternative explanation for this is that although physical vulnerability (living adjacent to the coastline) may influence risk perception, the limited understanding of climate change may weaken adolescents' judgments on the real risk of climate change (Brody et al. 2008). On the other hand, some studies also pointed out that fear-based messages may drive people into a passive state of avoidance, denial, or helplessness (Stern 2012; Hornsey and Fielding 2020; Vries 2020), such could generate even a negative impact on intension or behavior, which has been supported by this study. Likewise, many other available empirical data from the health communication literature indicated that communicating about threats without pointing out potential solutions can lead to the described maladaptive coping reactions (Witte and Allen 2000). Students may only feel fear without associating it with their risk perception, thereby the fear treatment failed to increase concern and involvement. Another possible explanation was due to cultural differences. Differing from most of the previous studies which were conducted majorly in Western countries (Henrich et al. 2010), this is the first manipulation experiment testing the emotional impact of CCE on Chinese adolescents. Several studies indicated significant differences in concern-action correlation existed between the West and the East (Nangyeon 2016; Eom et al. 2016, 2019). However, it is not clearly understood if the negative impact on mitigation behavior by fear is a distinct feature for children in Eastern countries, which requires further investigation.

There has been a call for increasing hope among youth in CCE (Stevenson et al. 2018), as this may enhance people's self-efficacy (O'Neill and Nicholson-Cole 2009; Stevenson and Peterson 2015; Lee et al. 2017; Geiger et al. 2021). This, in turn, leads to a more positive behavioral change. However, hope emotion treatment did not contribute significantly to most of the psychological variables when compared to the lecture-only group in this study. Notably, even the change in knowledge in the hope treatment group was lower than that in the lecture-only group. One possible reason is that hope only increased the adolescent's goal-oriented energy but not the ways to face barriers and achieve their goals. Geiger et al. (2019) found that increase in the perception that one can generate a diversity of routes to one's goal, even when encountering barriers, mediated the effect of the intervention on an increased discussion. It is also understood that hope may weaken people's motivation and make them less engaged (Hornsey and Fielding 2016). Similarly, a previous study also found that hope may not increase the collective motivation required for the collective action against climate change because it may serve as an emotion-focused coping function (Ojala 2016; van Zomeren et al. 2019). The complexity and scale of climate change may make it difficult for people to perceive this problem as controllable by action. In this study, an alternative explanation was that hope was induced as immediate emotion, and mitigation behavior was mainly tested in individuals. Individuals at a young age, in our case, had little chance to attend collective action for climate change. One possibility could be although hope did not increase self-reported mitigation behavior compared to the lecture-only group, this emotion may regulate adolescents' moods (Ford et al. 2018) and play a motivational role to support collective action in climate change in the future (Bury et al. 2020), which require further studies.

We note that our data is limited to be generalized to other areas and other age groups. As for different aged people, their differences in cognitive ability, knowledge, experience, and other internal and external factors will affect their decision-making process; thus, more research on different age groups is needed. To increase personal involvement, people in different places need relevant stimuli (Moser 2010). For instance, sea-level

rise can induce fear among teenagers residing in coastal areas, while its effectiveness on inland students is unclear. Further interventions and assessments are required for the interior areas of engagement. Because of the limited age group, this educational program was not pedagogically designed, failed to include essential climate communication theory such as socio-cultural cognition or worldview bias, or framing, and has not been tested in other culturally and geographically diverse areas. Moreover, further revisions of the questionnaire and research instruments and their deployment in other areas would also be advisable. Emotional stimuli in neutral materials should also be considered in future research. Although we carefully selected lecture materials using science graphs instead of disaster photos, these were still observed to arouse surprise and concern among teenagers. The solutions to avoid possible emotional interferences of knowledge videos require further exploration. Other more objective assessment methods such as skin conductance response (Ho and Lipp 2014) or eye tracking (Lisa et al. 2017) can be adapted to improve the accuracy of emotional data.

Current information on climate change consists of many emotional messages (Salama and Aboukoura 2018). Many educational materials also contain striking emotional information, often invoking fear or sadness. Our study suggests that to achieve effective educational outcomes from CCE, especially in the younger generation, fear should be seriously considered as this can be counterproductive, at least in Eastern culture. Knowledge-based CCE for adolescents is still an effective approach, particularly regarding the cause of climate change and skills to action. When hope is used in education, educators should focus on building a greater variety of methods of engaging in discussions and improving pathways of thinking, which may have the potential to promote more extensive discourse on the topic. Meanwhile, educators should work on ideas to boost students' involvement and concerns to improve climate change mitigation behavior in CCE. Particular storylines and visual materials based on local areas could increase teenagers' involvement and decrease the psychological distance of climate change (Mcdonald et al. 2015). In addition, other educational tools to strengthen personal relevance, such as engaging in thoughtful discussions and implementing a school or community projects, have proven to be effective CCE strategies (Hu and Chen 2016; Monroe et al. 2017).

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The corresponding author contributed to the study's design, manuscript revising, important intellectual content, and final approval of the version to be submitted.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Research involving human and animal rights This study involved human participants. All procedures performed in studies involving humans were performed according to the institution's ethical standards at which the studies were conducted, and ethical approval was obtained from the Expert Committee on Biomedical Ethics, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Science. The reference number for ethical approval is XTBG2019-002.

Conflict of interest The authors declare no competing interests.

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