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Developing a model of climate change behavior among adolescents

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Abstract
Research on adolescent climate change perceptions has uncovered key insights about how knowledge, concern, and hope might relate to behavior and the potential for educational interventions to influence these factors. However, few of these studies have employed treatment/control designs that might address causality and none have addressed how these factors might interact to influence behavior. We developed a model of behavior change where a climate education treatment impacted knowledge, knowledge impacted hope and concern, and hope and concern together impacted behavior. We empirically tested the utility of this model and the causal relationships within it using a pre/post, treatment/control evaluation of climate education among adolescents in North Carolina, USA ($n = 1041$). We found support for a causal relationship between the treatment and gains in knowledge, but not between treatment and behavior. However, we did find support for a path model in which climate change knowledge positively relates to increased climate change concern and hope, and increases in concern and hope predict changes in pro-environmental behavior. Low SES was related to smaller gains in knowledge, concern, and behavior. Our results contribute to a theoretical understanding of climate change behaviors among adolescents and suggest that climate education aiming to change behavior should focus on building hope and concern.

1 Introduction

Given the projected social, political, economic, and ecological impacts of climate change (IPCC 2018), efforts to mitigate gaps in public understanding of climate science and persistent apathy are critical. Polls suggest most people misunderstand the mechanisms of global warming (Ranney and Clark 2016). Researchers have attributed this lack of understanding to light (Plutzer et al. 2016) or misleading (Román and Busch 2015) coverage of climate

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change in schools, the complex nature of climate change (Sterman 2011), or misrepresentation of the issue by media outlets which employ ideological filters to the subject (Hamilton 2011). A large body of research suggests political ideology (Hornsey et al. 2016) and worldview (Kahan et al. 2011) are overwhelming drivers of climate change beliefs and policy support, with conservative political ideologies and hierarchical individualistic worldviews negatively related to accepting the reality of anthropogenic global warming and policies to combat it. The powerful influence of these ideologies and worldviews explains why polarization about the seriousness of climate change continues despite scientific consensus about its anthropogenic causes and potential impacts (Cook et al. 2013).

Fortunately, climate education strategies may be effective at overcoming the influence of worldview and political ideology, particularly among younger audiences. Despite the strong influence of ideology and worldview in shaping climate change beliefs and actions (Hornsey et al. 2016), several studies found climate change knowledge (i.e., understanding climate change science, causes, and impacts) positively relates to climate change concern, even among those who are ideologically or culturally predisposed to be skeptical of climate change (Stevenson et al. 2014; Shi et al. 2015; Ranney and Clark 2016). Further, whereas worldview may be the strongest predictor of climate change perceptions among adults (Hornsey et al. 2016), the influence of worldview disappears among adolescents as climate change knowledge increases (Stevenson et al. 2014). These findings suggest an opportunity to overcome polarization around climate change and promote behaviors to mitigate it through education with adolescents.

Climate change education research has responded to this opportunity to overcome polarization but would benefit from a synthetic causal model of behavior change. Several experimental studies indicate causal relationships between educational interventions and climate change knowledge (Sellmann and Bogner 2013; Karpudewan et al. 2014). However, knowledge gains alone typically do not impact behaviors (Kollmuss and Agyeman 2002). In one of the only experimental studies employing a control group to evaluate outcomes other than knowledge, Alexandar and Poyyamoli (2012) demonstrated participation in a service-learning project led to increased knowledge and skills needed to solve challenges around water resources and climate change. Non-experimental studies (e.g., observational, pre/post-testing) identify antecedents to behavior that may be impacted by education. For instance, participation in an edutainment program[1] related to climate change predicted gains in climate change knowledge, self-efficacy, behavioral intentions, and reported behavior among secondary school students (Flora et al. 2014). Similarly, climate change hope seems to be a positive predictor in encouraging environmental engagement (Ojala 2015) as well as climate change mitigation behaviors (Stevenson and Peterson 2015). Climate change concern is also predictive of behaviors (Stevenson and Peterson 2015; Hornsey et al. 2016). However, to our knowledge, no research has attempted to link these variables into one model of behavior change among adolescents or experimentally linked education to these outcomes.

We began to address this research need by experimentally evaluating how a climate change education intervention influenced climate change knowledge, concern, hope, and behavior among students in North Carolina, USA. A primary task was to develop a model of behavior change by building on environmental behavior models and empirical research specifically related to climate change educational interventions (see Section 2). We then experimentally

[1] Flora et al. (2014) define "edutainment" as an educational intervention that intertwines education material and popular entertainment content

evaluated the intervention using the model. We hypothesized the intervention would directly and positively impact climate change science knowledge (Stevenson et al. 2014; Flora et al. 2014). We expected increased climate change knowledge would lead to increased climate change concern and hope (Sundblad et al. 2007; Stevenson et al. 2014; Ojala 2016; Geiger et al. 2017), and that changes in concern and hope would be positively related to changes in climate change behavior (Smith and Leiserowitz 2014; Ojala 2015; Stevenson and Peterson 2015). In addition to testing these hypotheses, we also controlled for locale, gender, ethnicity, and socioeconomic status as these have been associated with differing climate change perceptions among children and adults and could create spurious effects if not accounted for (Ojala 2016; Stevenson et al. 2014).

2 Methods

2.1 Curriculum development

The educational intervention included four activities modeled after Project WILD, an internationally distributed environmental education curriculum focusing on wildlife biology, ecology, and conservation (see projectwild.org). Climate change education research suggests engaging activities may boost student learning (Flora et al. 2014), and Project WILD is characterized by highly engaging, hands-on activities (Project WILD 2014) and has been shown to boost cognitive skills (Stevenson et al. 2013). Other research suggests individuals are less influenced by worldviews when considering climate change impacts on biodiversity and wildlife than when considering impacts on people (Smith and Leiserowitz 2014; Stevenson et al. 2015). Although adolescents seem less influenced by worldview than adults, worldview does seem to influence perceptions at low levels of climate change understanding (Stevenson et al. 2014). Further, teachers, school administrators, parents, and lawmakers determine what is taught in classrooms, and these parties are heavily influenced by worldview (Wise 2010; Román and Busch 2015; Plutzer et al. 2016). Accordingly, a wildlife-based curriculum may provide an ideologically neutral vehicle for climate change education, thus facilitating implementation.

We relied on a diverse group of experts to provide iterative reviews during curriculum development. These included climate scientists, wildlife biologists, and educators. This process yielded activities that focused on (1) the difference between weather and climate, (2) how climate and weather relate to location of habitats and wildlife, (3) how wildlife managers can and are planning for climate change, and (4) how individual actions can mitigate climate change and improve climate resilience among wildlife (see Online Supplemental Information). These were designed to build knowledge (climate change science, causes, and impacts; activities 1–2), concern (e.g., communicating the impacts of climate change on wildlife; activity 2), hope (e.g., what others are doing, what you can do; activities 3–4), and behavior (activity 4) (Table S1; go.ncsu.edu/wwcc).

2.2 Theoretical model development

Because we are not aware of work developing behavioral models specific to climate change, we drew on environmental behavior models (McLeod et al. 2015) to contextualize constructs in the climate change education literature. Our model focuses on how our educational intervention builds climate change knowledge and in turn, hope and concern, which finally predict behavior change (Fig. 1). We chose these constructs because they are heavily used in existing literature on climate change education with adolescents (Corner et al. 2015) and relevant to prevailing behavior theories (e.g., Theory of Planned Behavior, Value Belief Norm theory: see below). The climate change knowledge component focused on knowledge of climate change science, causes, and impacts, as this tripartite of knowledge types is commonly used in K-12 education (Hestness et al. 2014). Researchers have critiqued a simplistic information deficit model (Nerlich et al. 2010), but situating knowledge within these behavior theories is necessary to provide insight into ways educational interventions can successfully impact behavior. In this context, we used the term "behavior" to indicate individual climate change mitigation behaviors such as turning off lights, as these are behaviors in which adolescents can independently carry out.

The direct impact of the educational intervention on climate change knowledge is the first step in our causal model, followed by changes in knowledge driving changes in hope and concern. Several studies featuring treatment/control designs have demonstrated that education can impact general environmental knowledge (Leeming et al. 1997; Rickinson 2001; Duerden and Witt 2010), and pre/post-evaluations and observational studies suggest that this dynamic may apply to the context of climate change (Öhman and Öhman 2013; Karpudewan et al. 2014; Flora et al. 2014). Accordingly, we expect a direct and positive causal relationship between the intervention and a change in climate change knowledge (Fig. 1). Because content knowledge has been included in environmental education models as an early step in a causal chain of variables leading to behavior change (e.g., knowledge about issues in the Hungerford and Volk (1990) model), we treat the knowledge as a precursor to hope and concern in our theoretical model (Fig. 1). Though some studies posit that climate change education, particularly with children, may breed despair (Stern 2012), observational studies link learning about climate change to climate change hope (Ojala 2015, 2016) and an experimental evaluation found knowledge-based interventions impacted both self-efficacy and response efficacy related to climate change (Geiger et al. 2017). Other studies have linked climate change knowledge to concern in both adult (Shi et al. 2015) and adolescent (Stevenson et al. 2014) contexts.

We situate climate change concern and hope as directly influenced by knowledge and driving behavior (Fig. 1). The term "concern" has several meanings in the literature ranging from an emotional response (Yang and Kahlor 2012) to something more like risk perception (Leiserowitz 2004). We draw on Stern and Dietz's (1994) definition of environmental concern to include affective orientation based on environmental values (e.g., how worried individuals are about climate change) and a cognitively based belief about the consequences of climate change. This definition is congruous with awareness of consequences the Value Belief Norm Theory as a direct antecedent of behavior, and numerous studies have identified climate

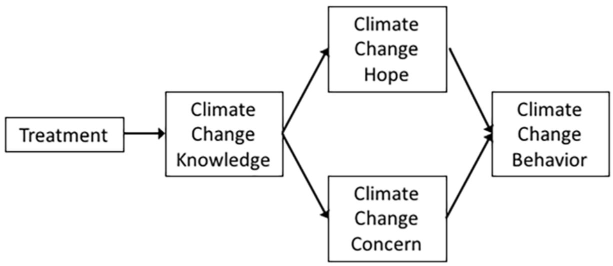

Fig. 1 Proposed theoretical model of how educational interventions influence climate change behaviors through knowledge, hope, and concern

change concern as a key predictor of climate change behaviors (Hornsey et al. 2016). Although there are several definitions of hope (Myers et al. 2012; Hornsey and Fielding 2016), ours draws on the Snyder et al. (1991) definition which includes both willpower and waypower. These two constructs are analogous to self-efficacy (belief in one's own abilities to effect change (Bandura 1977)) and response efficacy (belief that actions will lead to desired outcomes (Norgaard 2011)), both key predictors of behavior (McLeod et al. 2015). Further, climate change hope can reflect these efficacy beliefs on both individual (I can make a difference) and collective (working together, we can solve problems) dimensions (Ojala 2016; Stevenson and Peterson 2015; Li and Monroe 2018). Climate change is characterized by complexity, uncertainty, and a lack of immediate, tangible connections between actions (e.g., driving less) and impacts (e.g., collective emission reductions slowing global warming). Individuals may feel unable to address such a complex problem (low self-efficacy) or that individual or collective actions may be ineffective (low response efficacy). Accordingly, these individuals may respond to climate change messages with inactivity or denial (Stern 2012; Smith and Leiserowitz 2014). However, individuals displaying climate change hope respond with engagement and action (Stevenson and Peterson 2015; Ojala 2016; Geiger et al. 2017). The inclusion of hope and concern as drivers of behavior conforms with integrative environmental behavior models (Kollmuss and Agyeman 2002; McLeod et al. 2015), as well as observational research linking both concern and hope to climate change behavior (Stevenson and Peterson 2015; Ojala 2016).

2.3 Sampling

We sampled in three stages—schools, teachers, and students. This tiered sampling approach was necessary because sample frames of teachers and students were not public, but a directory of all schools was. We first randomly selected 85 middle schools from a list of all 770 North Carolina public middle schools. We then generated a sample frame of teachers at these schools by visiting each school website ($n = 377$). Next, we randomly selected 205 teachers to invite for participation. We selected this number of schools and teachers based on past experience in similar studies in which 25% of teachers responded to requests, and 50–60% of those participated in the studies (Stevenson et al. 2013, 2014). Similarly, in this study, of the 205 teachers contacted, 58 responded and 30 consented to participate. We randomly assigned these 30 teachers to a treatment or control group.

We requested both treatment and control groups to administer pre- and post-surveys to their students in January and again in May of 2015. For the pre- and post-surveys, we sent all participating teachers surveys, answer sheets, and administration instructions by mail and requested teachers return the surveys within two weeks of receiving them. Six of the participating teachers withdrew from the study (four from the control group and two from the treatment group), citing lack of time. Although their motivations may have been related to this study (e.g., not wanting to teach about climate change), this potential did not impact how students were assigned to teachers, and therefore included in the study. Our final sample included 108 sixth graders, 93 seventh graders, and 206 eighth graders in the control group and 60 sixth graders, 166 seventh graders, and 408 eighth graders in the treatment group with the majority of students spanning ages 11–14 (25 students were 15 years or older). Most students in this sample were female (51.6%), and White (62.9%) with fewer African American (11.0%), Hispanic (9.01%), American Indian (1.25%), and Asian (2.4%) students. Some identified as multi-racial (10.35%) or other (3.74%). Most (64.6%) students attended a Title I school, a measure of socioeconomic status, that receive additional federal funding based on high percentages of low-income students (107th Congress 2002). For a summary of student demographics in the treatment and control groups, see Table 1.

2.4 Teacher training

Treatment teachers received in-person training in the *WWCC* module in December 2014. High-quality climate change education professional development programs center around science content, good scientific and pedagogical practices, and use of the outdoors (Shea et al. 2016), which we incorporated into the curriculum and associated training. The full-day training included a primer on climate science, causes, and observed and projected impacts in North Carolina by a representative of the state climate office. The remainder of the training followed a train-the-trainer format in which teachers played the role of students and at the conclusion of each activity, shared ideas for adapting the lesson to their context (Garet et al. 2009). After the workshop, we maintained an informal online presence through Moodle (Dougiamas and Taylor 2003) in which teachers were encouraged to share insights and feedback on the lessons and share ideas for implementation. These aspects of the training (teachers playing the role of students, discussing with others how to apply what they have learned, and follow-up engagement) follow best practices for effective teacher development (Garet et al. 2009).

2.5 Instrument development

Our instrument drew on several scales designed for adolescents. We drew on the adolescent climate change knowledge questions developed by Stevenson et al. (2014), the Stevenson and Peterson (2015) Adolescent Climate Change Hope Scale, and the concern scale used by Stevenson et al. (2014) that drew questions from one of the only large-scale surveys designed for this age group (Leiserowitz et al. 2011). We used the Stevenson and Peterson (2015) behavior scale which draws on several instruments measuring pro-environmental behavior of

Table 1 Demographics of sample by treatment and control groups ($n = 1043$). Each cell displays percentage of sample associated with demographic group for treatment and control groups, respectively

	Control group (11 teachers in 8 schools)	Treatment group (13 teachers in 7 schools)	Total
Grade			
6th	10.4	5.8	16.1
7th	8.9	16.0	24.9
8th	19.8	39.2	59.0
Gender			
Males	18.6	29.8	48.4
Females	20.5	31.1	51.6
Ethnicity			
White	22.6	39.6	62.2
Black	4.6	6.4	11.0
Asian	1.2	1.3	2.4
Native American	1.0	0.3	1.3
Hispanic	4.1	4.9	9.0
Multi-racial	4.3	6.0	10.4
Other	1.3	2.4	3.7

children and adolescents (McBeth et al. 2011; Ojala 2016) and measures self-reported participation in climate change mitigation behaviors. Although students may choose to participate in the various behaviors for multiple reasons, each behavior would logically reduce carbon emissions (e.g., turning off the lights when leaving a room). We used data available from the National Center for Education Statistics (US Department of Education 2012) to gather information on school locale and Title I status.

We pre-tested the instruments using methods outlined in Stevenson and Peterson (2015). This included administering a draft instrument to 27 seventh grade students and 33 eighth grade students, eliciting written and verbal feedback from these students on items that were confusing, and conducting cognitive interviews with a subset of these students ($n = 5$) (Desimone and Le Floch 2004) to elicit suggestions for improvement in item wording and clarity and assessing construct validity (e.g., what does this question make you think of?). We tested the hope, concern, and behavior scales for reliability and validity using Cronbach's alpha and principal component analysis (PCA). Cronbach's alpha measurements indicated acceptable scores for climate change hope ($\alpha = 0.75$) and behavior ($\alpha = 0.78$). The alpha for climate concern ($\alpha = 0.67$) was similar to scores reported for similar risk perception scales (Betz and Weber 2002) and acceptable for an exploratory analysis (Hair et al. 2010). We used the rule of thumb of eigenvalues greater than 1 to determine the number of factors for PCA (Williams et al. 2012) and found that each scale was unidimensional, with the exception of the behavior scale, which included three factors but maintained high reliability as a single scale (Tables S3–S6).

2.6 Treatment delivery and data collection

Teachers enrolled in the study were responsible for delivering the four climate change lessons from the WWCC module to their respective classes. Teachers were asked to administer the pre-test as early as possible after training, teach the four lessons when they fit best in their curriculum (for the treatment group), and give the post-test as late as possible in the school year. All teachers (treatment and control groups) administered the pre-survey between December 2014 and January 2015 and the post-survey between April and June 2015. All treatment teachers reported using all four activities in their curriculum. To view the protocol provided to teachers for data collection, see the Online Supplemental Information.

2.7 Data analysis

We tested for direct treatment effects on each outcome variable in the model by running separate multiple linear regression models in which treatment group membership, Title I, and the associated pre-test score predicted a change in outcome (e.g., pre-test behavior, treatment, and Title predicting change in behavior, see Allison 1990; Dalecki and Willits 1991). We also ran a similar regression equation with change in knowledge directly predicting behavior. Initially, we also included student gender, race (White versus non-White), age, and locale (urban versus rural) as co-variates, but only Title I was a significant predictor. Inclusion of the pre-test scores accounted for the possibility of a ceiling effect, in which students who scored high initially had limited room for positive change (Theobald and Freeman 2014). Each of these regression equations included nested random effects to account for correlated responses among students (level one) within the same class (level two) and within the same school (level three).

We tested our theoretical model using path analysis through the generalized structural equation modeling (GSEM) package in Stata version 14.1. GSEM allows for more complex structural equation models, including multi-level modeling appropriate for our nested sampling plan (Gordon 2016). The model included nested random effects for school and teacher. Path analysis combines several multiple linear regression equations to test the likelihood that the observed data fits the proposed causal model (Streiner 2008). We used the standardized root mean square residual (SRMR) goodness of fit statistic, for which a value less than 0.08 is considered acceptable (a value of 0 is considered a perfect fit) (Hancock and Mueller 2006). This fit statistic is also appropriate for analysis using sampling weights (see below) (Bollen et al. 2013). We tested all hypotheses using the GSEM path estimates and associated p values. In addition to modeling the treatment impact on the four variables of interest (change in climate change knowledge, hope, concern, and behavior), we also included the pre-test scores for each of these variables to control for a ceiling effect on student responses (Stevenson et al. 2013; Theobald and Freeman 2014). Additionally, we included Title I status as a control variable in the model by creating paths to each endogenous variable (analogous to a dependent variable (Streiner 2008)). Because our sample underrepresented students attending Title I schools (64.6% in our sample versus 74.7% in NC; $t = -6.91$; $p < 0.001$ (US Department of Education 2012)), we weighted our sample.

3 Results

On the pre-test, students answered an average of 67.0% of the knowledge items correctly ($\bar{x} =$ 14.53 out of 21 possible points, SD = 3.04), were fairly hopeful ($\bar{x} = 35$ out of 56 possible points, SD = 8.81), had moderate levels of climate change concern ($\bar{x} = 9.93$ out of a possible 16 points, SD = 3.01), and reported moderate levels of climate change mitigation behaviors ($\bar{x} = 27.15$ out of a possible 50 points, SD = 6.62). These pre-test levels were similar across treatment and control groups, with the exception of differences associated with knowledge (control: $\bar{x} = 14.08$, SD = 0.15; treatment $\bar{x} = 14.8$, SD = 0.12, $t = -3.75$, $p < 0.001$; Table S2). Cronbach's alpha measures for the hope, concern, and behavior scales were similar to measures of the pre-test data ($\alpha = 0.80$, 0.66, and 0.76, respectively). Confirmatory PCA results supported a unidimensional hope and concern scale, and a three-dimensional behavior scale, all with factor loadings of 0.47 or greater. Each scale was moderately correlated to the others (knowledge-hope: $r = 0.23$, $p < 0.001$; knowledge-concern: $r = 0.29$, $p < 0.001$; knowledge-behavior: $r = 0.19$, $p < 0.001$; concern-hope: $r = 0.33$, $p < 0.001$; concern-behavior: $r = 0.33$, $p < 0.001$; hope-behavior $r = 0.39$, $p < 0.001$). For alpha and factor loading data for each item, see Tables S3–S6.

Our data supports a causal relationship between the treatment and gains in knowledge (Fig. 2). We did not find a direct relationship between treatment group membership and hope, concern, or behavior (Table 2). We found a weak direct relationship between change in knowledge and change in behavior (Table 2), suggesting that a causal link between knowledge and behavior as mediated by hope and concern may be present in association with relatively large knowledge changes. We did find support for each theorized direct relationship in the model (Fig. 2). Because GSEM does not allow for standard goodness-of-fit measures, we ran the model without the nested random effects to approximate fit (Christ et al. 2008). The data fit the proposed model and explained 67.0% of the variance (SRMR = 0.053; Fig. 2). Specifically, participation in the treatment group predicted increased climate change knowledge (Fig. 2).

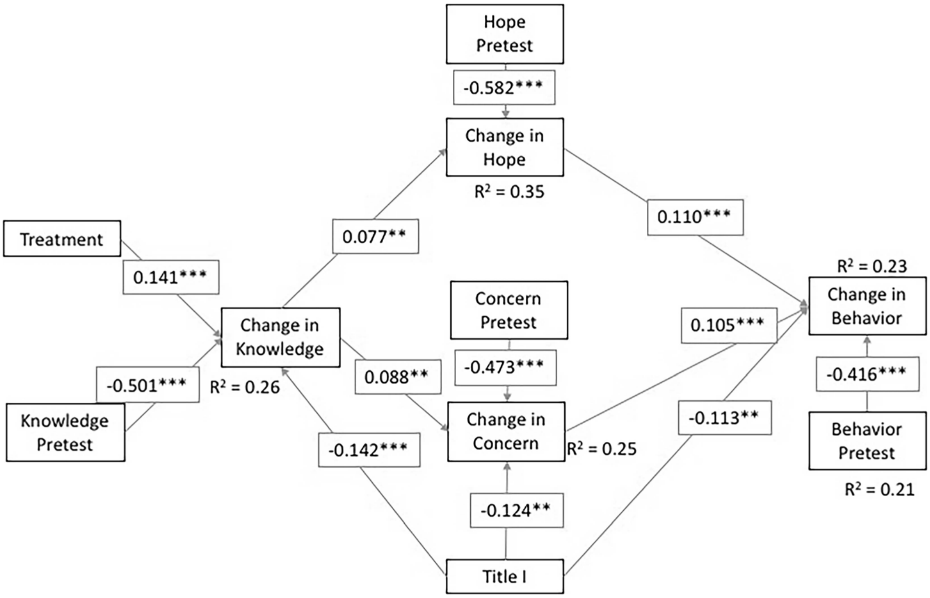

Fig. 2 Path model for impacts on climate change behavior among adolescents. The path coefficients displayed are standardized. We included random effects for school and classroom, which accounted for 1.3% of the model variance. Paths from Title I status to each endogenous variable were included in the analysis, but only the statistically significant paths are shown. Overall R^2 for the model was 0.664 and SRMR = 0.052. For Title I, 0 = non-Title I and 1 = non-Title I. +$p < 0.1$, *$p < .05$ **$p < 0.01$, *** $p < 0.001$

Increased knowledge predicted increased hope and concern, which together predicted increased levels of climate change mitigation behaviors (Fig. 2). Based on a comparison of the standardized beta coefficients, change in knowledge appeared more strongly associated with change in concern ($\beta = 0.088$) than change in hope ($\beta = 0.077$) (Fig. 2, Fig. S1). Change in hope ($\beta = 0.110$) appeared to be a slightly stronger predictor of change in behavior than change in concern ($\beta = 0.105$) (Fig. 2, Fig. S2). School-level Title I status predicted knowledge, concern, and behavior, with students attending Title I schools less likely to display increased knowledge, concern, and behavior with all other variables held constant (Fig. 2, Figs. S1, S2).

4 Discussion

This experimental evaluation of an educational intervention with a control group strengthens evidence that climate change education causes increased climate change knowledge. This study also makes progress in developing a theoretical model of climate change behavior among adolescents that links knowledge, hope, concern, and behavior and highlights a need to better situate climate change education within this framework. A growing number of observational studies have linked education to many key student outcomes, such as a shared understanding of climate change science (Öhman and Öhman 2013), increased climate change hope (Ojala 2016), and higher levels of environmental engagement (Ojala 2016). Our results suggest that, at least with our intervention, the primary causal link between climate change education is with knowledge. We offer several explanations for the lack of causal links

Table 2 Directed effects associated with proposed path model of change in climate change behavior among adolescents

	Beta	Std beta	*P* value	Beta	Std beta	*P* value	Beta	Std beta	*P* value
	Change in knowledge			Change in hope			Change in concern		
Independent variable									
Treatment	0.97	0.16	< 0.001	0.79	0.04	0.36	0.20	0.03	0.39
Knowledge pre-test score	− 0.49	− 0.50	< 0.001						
Hope pre-test score				− 0.54	− 0.58	< 0.001			
Concern pre-test score							− 0.48	− 0.49	< 0.001
Title I[a]	− 0.88	− 0.14	< 0.001	− 0.80	− 0.04	0.39	− 0.65	− 0.11	0.01
Constant	7.60		< 0.001	28.51		< 0.001	5.48		< 0.001
Random effects									
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
School	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	4.66	< 0.001	< 0.001	39.80
Teacher	0.36	0.20	0.66	1.51	0.85	2.67	0.36	0.13	0.95
	Change in behavior			Change in behavior			Change in behavior		
Treatment	0.33	0.03	0.48				0.13	0.01	0.76
Difference in knowledge				0.09	0.05	0.08	0.06	0.03	0.26
Difference in hope							0.06	0.12	< 0.001
Difference in concern							0.21	0.11	< 0.001
Behavior pre-test score	− 0.38	− 0.44	< 0.001	− 0.38	− 0.44	< 0.001	− 0.36	− 0.41	< 0.001
Title I[a]	− 1.64	− 0.14	< 0.001	− 1.55	− 0.13	< 0.001	− 1.33	− 0.11	< 0.001
Constant	11.31			11.35		< 0.001	10.33		< 0.001
Random Effects									
	Estimate	Lower CI	Upper CI	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
School	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.19
Teacher	0.72	0.34	1.49	0.68	0.31	1.51	0.61	0.25	1.49

[a] Title I school (measure of low SES): 0 = no; 1 = yes

Each model includes the pre-test score for the associated dependent variable to control for a ceiling effect as well as Title I as a control variable. Each model is also nested by school and teacher, and associated random effects estimates are displayed below each model between treatment and concern, hope, and behavior. First, pre-test knowledge was higher in the treatment group than in the control, suggesting that treatment teachers may have started to build climate change understanding before pre-tests were complete, creating ceiling effects that precluded our ability to capture the full treatment effects. Second, although our intervention was specifically designed to foster concern, hope, and behavior and modeled after exemplary environmental education, it may have been unsuccessful. Future research exploring links between climate change education and behavior change should continue to experimentally identify programmatic attributes that directly link to concern, hope, and behavior. Specifically, research should identify how to balance communicating the reality of climate change and its impacts (linked to concern: Stevenson et al. 2014), with techniques to provide hope such as facilitating discussions focused on action strategies, which can build hope (Ojala 2016). Similarly, researchers should investigate how education might impact behavior by considering other common drivers, such as norms or perceived behavioral control (Kollmuss and Agyeman 2002). Finally, although activities were designed to address hope, concern, and behavior, science teaching often focuses on cognitive (i.e., knowledge and skills) rather than affective learning (Savelsbergh et al. 2015), which may help explain why the gains were limited to knowledge.

Although the causal treatment effects were limited to gains in knowledge, this study provides support for a theoretical model for climate change behavior among adolescents. Previous studies have uncovered knowledge, concern, and hope as key variables that may relate to behavior (Stevenson et al. 2014; Stevenson and Peterson 2015; Ojala 2016), which is consistent with environmental education research and theory suggesting environmental knowledge and attitudes interact to predict pro-environmental behaviors among young audiences (Hungerford and Volk 1990; Duerden and Witt 2010; Hollweg et al. 2011). Our model parallels these studies, which found that knowledge predicted concern (Stevenson et al. 2014), hope predicted behavior (Ojala 2016), and hope and concern together predicted behavior (Stevenson and Peterson 2015). As this research area grows, future studies should refine our model by testing key variables including worldviews (e.g., individualist versus communitarian), norms, and explicit measures of perceived behavioral control (Kollmuss and Agyeman 2002; Hollweg et al. 2011; McLeod et al. 2015). Although worldviews seem less-powerful predictors of climate change perceptions among adolescents than among adults, they polarize student climate change beliefs when students exhibit low levels of climate change knowledge (Stevenson et al. 2014), and many teachers and students have relatively low levels of climate change knowledge (Leiserowitz et al. 2011; Plutzer et al. 2016). Specifically, as worldview may moderate the relationship between knowledge and concern (Stevenson et al. 2014), research that includes worldview may find a stronger relationship between knowledge and concern than we did. Similarly, normative beliefs around climate change perceptions of friends and family as well as how often students discuss climate change may be additional factors to consider, as each of these has been linked to climate change concern (Stevenson et al. 2016) and behavior (Valdez et al. 2018).

The lack of significant relationships between gender, ethnicity, and aspects of climate change learning may highlight the importance of using models of climate change behavior that provide a more comprehensive assessment of social context. Floyd et al. (2009) noted that many studies of environmental behavior may erroneously assign importance to ethnicity, when underlying socio-cultural factors are actually shaping outcomes. Further, research from Sweden found that gender had no relationship with levels of climate change skepticism or engagement (Ojala 2015), and research finding females and non-White students had higher concern levels did not test the relationships in the context of a comprehensive behavior change model (Stevenson et al. 2014; Stevenson and Peterson 2015). Future research exploring how gender and ethnicity relate to climate change perceptions and learning would benefit from using comprehensive climate behavior models where spurious relationships are less likely to emerge. Similarly, future research could identify when key relationships develop, and how they persist or change through adulthood. The relationships we found associated with socio-economic status may point to a need to consider how poverty may impact climate literacy among adolescents. In the context of this study, Title I (low SES) schools underperform non-Title I schools in a range of academic areas, which likely helps explain lower levels of climate change knowledge (Sirin 2005). Further, low-performing schools often shift instructional focus to reading and math (Jones et al. 2003), which may make it even less likely for students at Title I schools to receive climate change instruction.

Uncovering the most effective strategies for encouraging climate change behaviors is critical to addressing challenges related to climate change, and this study provides insight into pathways to behavior among adolescents. Future research should continue to evaluate professional development and curricular interventions, testing the utility and building on the model we present here. In particular, education could build climate change hope through outlining strategies to mitigate climate change (Ojala 2016), as our results suggest gains in hope are an even stronger driver of behavior change than changes in concern. The recent interest in and support for climate education (Plutzer et al. 2016) is encouraging, but our results suggest that more research is need to understand how to ensure interventions may foster climate change mitigation behaviors among adolescents. Future research may explore the utility of this approach among adults, as some research does suggest that building knowledge may have an impact on climate change concern (Shi et al. 2015). Further, given the importance of collective action in mitigating climate change impacts (Fehr-Duda and Fehr 2016), educators and researchers may consider designing and testing interventions aimed at moving beyond individual mitigation behaviors. Finally, more research is needed to pinpoint characteristics of interventions that are most effective among diverse groups of students in order to promote climate literacy for all.

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